PROGRAMMING FOR AUTOMATED INSTRUCTION

Francis Mechner

Public relations experts have expressed the opinion that the shock appeal which propelled the teaching machine into public view is in large measure due to the use of the word "machine." The possibility of a machine replacing a human being, and of all human beings the venerated teacher, fired the imaginations of scientists and journalists alike. The whirlwind of this excitement is still gathering momentum. But in the eye of the storm a small group of serious scientists has been quietly reaching the conclusion that the machine is one of the less important aspects of automated instruction, that it is at best the container, the casing of the real product. They have come to the realization that the revolutionary concept is not the machine but its content: the program. They are also coming to a second realization, that the power of the method is strongly dependent upon the quality of this program; that the conventional textbook is possibly just a case of extremely bad programming, and that the advantages of programmed instruction are more a matter of degree than of kind.

Accordingly, the art of programming lies at the heart of the method. It is at present a primitive art, which no man in the world has yet cultivated for more than a few years. No programming orthodoxy has yet become strongly entrenched, and new approaches are still emerging almost as rapidly as new programmers. But some tentative principles are beginning to be widely accepted. While these are not immutable, they are worthy of communication to the newcomers, if only as a starting point for further advances.

The programming philosophy advanced in this paper is presented in that spirit. It is based on some considerations loosely rooted in behavior theory, and on several years of programming experience. It is not a simple formula, but rather a set of principles applicable to a broad variety of problems. For this reason it is more a philosophy than a technique.

GENERAL PEDAGOGIC PRINCIPLES

1. Introducting New Concepts: In teaching something new, build on the student's present knowledge. Relate the new concept to things he already knows, even if the relationships are somewhat far-fetched. Analogies do not have to be perfect to be useful.

In teaching atomic structure, for instance, the electrons spinning around the nucleus may be likened to an object being twirled on a string. Similarly, living cells can be compared to bricks, the propagation of sound to waves in water, the exponential decay function to the draining of a bathtub or the height of successive bounces of a ball. The purpose of such metaphors is to give the student an initial repertoire of responses with respect to the new concept. The metaphor gives the instructor a starting point for the shaping process. One by one, the features of the metaphor can be replaced by features of the concept being taught: The hand twirling the string is the atomic nucleus; the object is twirling so fast that it can not be located; and there is no string. Once it has served its heuristic purpose, the metaphor can be dropped.

One may question whether it is good strategy to establish behavior that will later have to be eradicated. The answer is that this is an inevitable aspect of learning any skill, whether intellectual or physical. The learner never starts out with the ultimately-acceptable performance. The early approximations usually bear little resemblance to the finished product. They must nevertheless be reinforced if the learner's behavior is to be maintained at a level where it can be further shaped. This is true whether the skill being learned is walking, talking, playing a musical instrument, or doing mathematics.

2. Teaching New Terminology: Do not introduce a name, word, or expression until the need for it has been established. Begin by developing the concept. Introduce several specific instances of it, and then teach the student what the specific instances have in common. Before the general class is given a name, its properties or characterizing features must be described. Teaching the name can be a late stage in the teaching of a concept.

By the time the term is introduced, the student should almost be able to define the term. He should then learn several alternative but equivalent definitions. The alternative definitions must be explicitly taught. To "really understand" something means to be able to explain it in many ways.

When there are several names for a concept, that is, when several terms have the same definition (e.g., addition, summation, totalization) the student must learn them all. He must learn that they are all acceptable when one of them is called for, and that the same process is designated when any one of them is used.

3. Insuring Good Retention: When the student begins to forget something, he usually begins to confuse it with things that are similar. The more similar two concepts are, the more they interfere with each other.

There are two ways of insuring the rentention of related concepts: One is to focus on the difference between the concepts and to make sure that the student understands the difference. The other is to tie each one of the concepts to a different class. For example, in teaching a child about whales and sharks, one would (a) point out the differences between them (whales are larger than sharks, they spew up water, they eat smaller things, etc.) and (b) point out how whales resemble other mammals, and how sharks resemble other fish.

In teaching related concepts, the best strategy is to contrast and juxtapose them repeatedly. Alternating back and forth between them is frequently very useful. Finally, the student must learn to EXPLAIN the differences and similarities between the two concepts. He should be capable of answering a question of the form "compare whales and sharks". It is also important that he be able to say it in each of several equivalent ways. The student should never commit a particular sequence of words to memory as the answer to such a question. He should always learn several ways of saying it.

4. Teaching Long and Complex Sequences: In teaching any sequence, whether it is a word, a phrase, a sentence, a formula, an equation, or a diagram, begin by letting the student fill in missing segments. Make the missing segments increasingly larger, until

the student can produce the whole thing without support. For instance, say you want to teach the sequence SWXOMHB. The steps might be:

1. The first letter of the sequence SWXOMHB is ___.
2. Fill in the missing letter __WXOMHB.
3. The last letter of SWXOMHB is __.
4. Fill in the missing letters __WXOMH__.
5. The middle letter of SWXOMHB is ___.
6. Fill in the missing letters ___WX___MH___.
7. What word do the first, middle and last letters spell out ___________.
8. The letter before the O in SWXOMHB is __.
9. Fill in the missing letters __W__ __ MH__.
10. The letter after XO in SWXOMHB is __.
11. What are the three middle letters __ __ __?
12. Fill in the missing letters __W__ __ __H__.
13. How many letters are there in the whole sequence?
14. The second letter in SWXOMHB is ___.
15. W comes before __ and after __.
16. Fill in the missing letters __ __ __ __ __ __H__.
17. The next to last letter in SWXOMHB is __.
18. H comes after __ and before __.
19. Write the entire seven-letter sequence __ __ __ __ __ __ __.

HOW TO WRITE A PROGRAM

1. Outlining the Subject:

   A. Outline the subject in terms of 5 to 20 major headings. These might correspond roughly to the chapter headings of a textbook. Write these headings on red index cards, and order them according to some rational sequence.

B. Break down each of these headings into several subheadings. Write these on yellow index cards and again order them.

C. Do this again with green, and then once again with blue index cards. The words, phrases, and concepts written on the blue index cards should be the atoms of the subject, so to speak. They should be so elementary that a new one can be introduced approximately every five to ten frames of the program.

D. To introduce a new "blue" concept every ten frames does not imply that ten consecutive frames are spent on each concept, or even that a total of ten frames are allocated to that concept; a single frame may, and usually does involve more than one of the "blue" concepts. It merely means that the average rate at which blue concepts are introduced is approximately once every ten frames.

RED: The concept of number, manipulations of, numbers, arith postulational, etc. systems

YELLOW: set, theory number, systems number, theory etc.

GREEN: sets, isomorph, union, intersection, ordering, etc.

BLUE: collection, "set", elements, brackets, order, SAMPLE OUTLINE FOR SET THEORI (illustrative only)

1. collection
examples of sets
set
set = collection
5. members
elements
elements = members
letters stand for elements
separated by commas
10. brackets
picture of a set
order within brackets irrelevant
arrangement within enclosure irrelevant
empty set
15. examples of empty sets
null
null = empty
no element is repeated
combining two sets into one
20. examples of combining two sets into one
union
union symbol
union = combination
number of members in union
25. symbolizing a set
diagram of union
elements in union was in A or B or both
union = or
union = sum
30. common elements
overlap in diagram
junction
intersection
element in intersection of A and B
35. diagram of intersection
examples of intersection
etc.

2. <u>The Flow Chart:</u>

A. When a new blue concept is introduced do not spend too many consecutive frames on it. If you do, previously learned material will begin to slip away. Review items of previous material must be interspersed. It will rarely be possible to spend more than three to six consecutive frames on any single blue concept. The intensity with which a concept is treated should diminish gradually following its initial introduction, until it is finally reviewed no more than once every hundred frames or so.

B. To make this "thinning out" process systematic, a stencil, or template has been developed. It consists of a series of holes punched into an IBM card. The series thins out according to an exponential decay function. It is simply a digitized form of the function $\frac{dy}{dx} = KY$. For this function, the ratios of successive ordinates are equal. On the card, there are six digital exponential functions. For the first function, the ratio of successive ordinates is .96. For the others it is .92, .88, .84, .80, and .76 respectively. When a concept is difficult and requires intensive initial treatment, the programmer might choose the first function. If the concept is very trivial and easy, he might choose the last one. In any case, the programmer must make two decisions: When to introduce the new concept, and which of the six series to use.

The actual succession of concepts in the program is determined by the original outline.

Every dot in this flow chart represents a "response" by the student. For any given dot, the student is required to use or write the concept alongside which the dot appears. Sometimes there may be several dots vertically above each other. This would mean that several concepts should be integrated in that frame. Frequently, a convenient way of accomplishing such integration is to ask "essay" questions which tap all of the concepts involved. Note that it is not sufficient to have the student merely read the concept called for by the dot. He must actually <u>use</u> it.

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                        Successive Frames
                 1     5     10    15      20    25     30     35
collection ...         .     .         .                            .
     set              ...      .     .             .                   .
set = collection             ...     .     .       .          .
        numbers                    .....     .     .         .
         elements                         ... .        .         .
           elements = members                  ...     .         .
                               etc.
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While programming, always feel free to modify the blue concept sequence as you see fit. It will have been impossible to forsee all the problems while making up the original outline. A concept which may have seemed pretty elementary at that stage may prove to need some breaking down, and vice versa.

The choice of the exponential decay function for the thinning out sequence, though not quite arbitrary, is not based on any immutable law of behavior. It is merely the simplest formula available to describe a systematic thinning out. There is no need to adhere rigidly to the sequence dictated by the stencil. Review items may be moved around freely (i.e., several frames in either direction) in accordance with the requirements of the program. The purpose of the stencil is not so much to constrain the programmer to rigid adherence to an immutable sequence, as it is to remind him of what he must review when and to aid him in scheduling the review items systematically. Remember that "forgetting" on the part of the student should not be thought of as a leak through which knowledge drains away as a function of the mere passage of time. Rather, it is a process of "mixing up" old knowledge with new. The more similar the new things are to the old ones, the more forgetting will ensue. Accordingly, review is most necessary when something new that may generalize with the old is being taught. The stencil does not forsee this type of exigency. In such a case, the stencil may not suggest enough review items, and additional ones might have to be included.

3. General Principles of Frame Construction: The student should have to read every part of the frame to arrive at the answer. The fact that he answered correctly does not necessarily mean that he learned what you intended. A student can go through an entire program without error and also without learning anything about

the subject. After writing a frame, you should always ask yourself how much of the frame the student would have to read minimally in order to arrive at the correct answer. It should be assumed that the student first looks at the blank, if there is one. Then he reads away from the blank in ever widening circles until he can answer the question. The possible pitfalls are best illustrated by examples.

A. Cows are mammals. Cows are ________________.

Here the student copies the word mammals because of the formal parallelism between the two sentences. He does not learn "cows" are mammals," he only learns to copy the word mammals. The same function would have been served by the sentence "X Y mammals". Better ways of writing this frame would have been

a. Cows are mammals. What are cows?

b. Cows are mammals. To put it another way, Cows are one example of ____________.

B. Cows are often brown. Horses are also often ____________.

Here the student is cued by the word "often". Since often is preceded by "also" the second time it appears, the student automatically copies the previous successor of "often" without necessarily reading the rest of the sentence. Better would be:

a. Cows are often brown. So are horses. How does this make cows and horses similar?

b. Cows are often brown. Horses too are often brown. In other words, both _________ and __________ are often _______.

C. The planets orbit around the sun. The earth is a planet. The earth orbits around the ______________.

The student is cued by the words "orbit around the" and therefore does not have to read anything else in the frame. Some remedies might be:

a. The planets orbit around the sun. The earth is a planet. Therefore the earth _____ _____ _____ _____.

b. The planets orbit around the sun. The earth is a planet. What can we therefore say about the earth's movement in relation to the sun?

D. There are nine planets. The earth is one of the planets. The largest planet is Jupiter. Therefore _______________ is larger than the earth.

The student has no reason to read the first sentence which should have been omitted here, and reserved for another frame.

At this point the question may be raised whether there is any harm in including material which the student does not <u>need</u> in order to answer the question. After all he <u>might</u> read it anyway, even if he does not learn it very securely at that time. There are two answers to this. One is that the student may feel insecure and guilty if he does not master the entire content of the frame. For all he knows, you are counting on him to learn it and all, there may never be another occasion to review it. He was instructed not to go back over completed frames. You are therefore inadvertently putting aversive pressures on the student to learn any extra material which the frame might contain. The student has no way of ascertaining what portion of a frame's content is relevant to the material being learned. So he will learn to "play it safe" and memorize both the relevant as well as the irrelevant content of every frame. This would waste time and lower the student's morale. The student should be able to assume that if he can respond correctly, he has learned the relevant material, and will be able to progress securely. Unless this condition is met, programmed instruction will fall far short of its full potential power.

4. THE FORUM OF THE FRAME

The programmer is frequently tempted to put too many blanks into a single frame. Though this is not bad in itself, it can cause trouble. One kind of trouble it can cause is to create a hidden ambiguity, that is, a situation where there are several alternative correct answers. This ambiguity is often not apparent to the programmer, who has a certain set, (since he presumably knows the answer), but which will cause the student unnecessary conflict. An extreme example of this error would be a frame of the form, "The ____________ is the __________ of the ____________, the ____________, and the __________________". Clearly there are many possible ways to complete this sentence, though it may have seemed to the programmer writing the frame that there existed only one. In general, it is safest to avoid multiple blanks. When they are used, the frame should be carefully scrutinized for possible ambiguity.

A second trouble which multiple blanks can occasion is that they may pose a riddle to the student. There may only be a single correct way to complete the statement. Yet it may take a great deal of thought and effort to figure out what it is. Thought and effort expended in this way does not advance the student's knowledge of the subject. It only irritates him, and wastes his time. Though the programmer must always be careful not to give away the answer by inadvertent prompts, he should never hesitate to give away the question by any means whatever.

There is a limit to what a student can be taught by having him fill in blanks. It is a very useful device for the initial learning stages, and provides a convenient path along which small steps can be taken toward the final desired performance. But complete comprehension generally requires something more. Here are some of the types of questions the student should learn to answer if he is to be given a thorough understanding of the concept.

1. Explain the relation between A and B.
2. Compose a sentence using the expressions, A, B, and C.
3. Compare A and B naming two similarities and two differences.
4. Fill in the missing parts in the following table.
5. What is an A?
6. Define the term A.
7. In three short sentences, say what you have learned so far about A.
8. Fill in the missing parts of the diagram.
9. Someone says to you that A seems to be a case of B. Explain to him why he is mistaken.
10. Explain how you would go about finding out whether A is B.
11. Using information A, B, and C prove/derive/demonstrate D.
12. List n conditions under which A could occur/be true.
13. Give n examples of A.
14. Explain what an A is.

None of these is better than any other. The form of a particular frame should be dictated only by the requirements of the subject and the stage in the student's progress. A progression leading to ability to explain an abstract concept, for instance, might begin with a series of examples with the student filling in the key words. Then, again by means of fill-ins, the student might learn what the examples had in common. The student is then ready to fill in increasingly larger segments of the generalization until he can answer open-ended questions of the type shown above.

5. <u>Concurrent Development of Several Concepts</u>

One of the resources of programmed instruction is the possibility of teaching simultaneously several concepts which are prerequisites for a succeeding concept. This can be accomplished by switching back and forth between two concurrently-developing sequences. The two sequences may be entirely unrelated. Alternating between them, will of course, interrupt the continuity of each one. This apparent disadvantage is outweighed by a number of considerations, however. The main one is that the skill being taught in each sequence is brought under the control of a broader range of stimuli. If the student acquires any given skill only in the context of the topic in question, there always remains the problem of insuring that the skill will also be available to him when the context is changed. He may "forget" his skill when the situation is in some way altered. One way of counteracting this effect is to intertwine the learning of several different skills.

A second argument in favor of developing several sequences concurrently is the possibility of utilizing cross-ties that may develop as the two sequences unfold. An example of this is the mutual strengthening that arises in the teaching of chemistry when the topics of atomic structure and descriptive chemistry are developed simultaneously. The teaching of atomic structure is facilitated if the student already knows about hydrogen, oxygen, reactions, and the chemical similarities between the halogens. Similarly, the teaching of descriptive chemistry is greatly aided if such concepts as atom, molecule, electron, and valence can be invoked.

A third argument for concurrent development is the economy inherent in the simultaneous "maturation" of two concepts whose synthesis forms the basis of the next concept to be taught. To return to the chemistry example, both descriptive chemistry and atomic structure are prerequisites for understanding the periodic table. If the development of these two topics is concurrent, they both become available when they are needed. This strategy is superior to the less economical alternative of first teaching atomic structure, then descriptive chemistry, and reviewing atomic structure all through the descriptive chemistry sequence.

A simple example of the concurrent development principle is given below. Frames labeled A represent one sequence, and frames labeled B, another. The frames labeled AB are the synthesis of the two. Sequences A and B alternate approximately every two frames. This alternation rate is arbitrary, and could just as well have been every three or every four frames. Often, an alternation rate of every fifty or one hundred frames is appropriate. In any case, the specific switching points should correspond to natural discontinuities in the unfolding of the topic.

SUPPLEMENT I

PROGRAMMING FOR AUTOMATED INSTRUCTION

Francis Mechner

<u>What is a Frame?</u>

The above statement is an example of a frame, though a difficult one at this point in the program. Other examples of frames are:

Quadrupeds have ____________ legs.
(how many)

To be or not to be, that is the ____________.

In a short paragraph, summarize Hamlet's speech.

Explain how airfoil-shaped wings keep a plane aloft.

Mozart was born in the year ______.

Give three proofs of the Pythagorean theorem.

Complete the diagram of the circulatory system shown below, and fill in the missing labels.

Torrecelli used his mercury column apparatus to demonstrate ____________.

A plane is flying at an altitude of 2 miles. A parachutist jumps out. After 4 seconds, before his parachute has opened, he has fallen 256 feet. Over which planet was the plane flying? Explain your answer.

Make a table showing the first four periods of the periodic table.

Damage to the heart muscle due to occlusion of a coronary blood vessel is called ____________ ____________.

Name all the fungi that can cause onychomycosis.

If $A \cup B$ equals $A \cap B$, what can you say about A and B?

Write the decimal number 29 in the binary system.

Why are whales classified as mammals rather than fish?

In general, a frame is a question or an instruction. It is a statement which requires a response. There need not be a unique correct response. The important feature of a frame is that it enlists the student's participation. Consider the following statement:

> Occlusion or blockage of a coronary blood vessel, if prolonged, causes damage to the heart muscle, or myocardium. The medical term for myocardial damage produced by occlusion of a coronary blood vessel is myocardial infarction.

This is neither a frame nor a program; it is a lecture. The student could read on without having learned the contents of that passage. He has no way of knowing whether he has in fact learned what the author was counting on him to have learned. The same statement could be broken down into frames as follows:

1. Myocardial infarction is the medical term for damage to the heart muscle, or myocardium. Which part of the word "myocardium" means heart? Which part means muscle?
2. Damage to the myo__________ results from occlusion or blockage of a coronary blood vessel.
3. O__________ or blockage of a coronary blood vessel, if prolonged, causes damage to the __________.
4. Myocardial destruction due to __________ of a coronary blood vessel is called __________al infarction.
5. Myocardial __arction__ is the technical name for damage to the myocardium.
6. Occlusion of the coronary artery is one of the possible causes of __________ inf__________.

7. ____________ ____________ is the medical term for damage of the myocardium caused by occlusion of a ____________ ____________ ____________.

8. Define the term MYOCARDIAL INFARCTION.

The programmed version of the statement contains about three times as many words as the original statement. On the other hand, if the student has answered all eight frames, he has unequivocal evidence that he has mastered the relevant information and that he can proceed securely.

The experienced student, who knows how to learn from a textbook, improvises a program for himself as he reads along. He underlines the passages or expressions he feels are important, he makes up little questions which he asks himself as he proceeds, he goes back and reviews when he fears that previously learned material is beginning to slip away, and he periodically tests himself to make sure that his grasp of what he has learned is firm. Naturally, very few students succeed in acquiring this difficult skill during their academic careers, and those that do, frequently lack the discipline and self-control which is needed to exercise it. It is so much easier to just read along. Finally, the student is not very well qualified to program material which he is just learning. He cannot always know which questions to ask himself. He is not yet able to discriminate the important from the unimportant, or to place the emphases where they belong. The individual best qualified to do the programming is the textbook's author.

INADVERTENT CUES AND PROMPTS

A psychologist would say that the function of an instructional program is to bring the student's behavior under the control of the proper stimuli. This may sound like a rather narrow objective. Actually it covers all of learning. Questions, instructions, and all the examples of frames listed above, are stimuli. The responses to the questions and instructions constitute the behavior. If the student gives the right answers to the right questions, then his behavior has been brought under the control of the proper stimuli.

One of the greatest problems that confronts the programmer is to insure that the student's responses are coming under the control of the intended stimuli. A student may give the right answer for the wrong reason. The answer may be cued by cues and prompts that are extraneous to the subject. Such undesired cues and prompts can take innumerable forms. Before a programmer is really competent, he must be able to recognize such prompts and to avoid them in his writing. This requires not only experience, but also great verbal sensitivity, for there exists an almost endless variety of extraneous prompts.

In the discussion which follows, the expression "extraneous cues" will refer to cues which are not inherent in the subject being taught. Extraneous cues can, of course, be useful in constructing a new behavioral chain. The technique known as "fading" involves the elicitation of certain desired responses by the initial use of extraneous cues, and the gradual replacement of these cues by new ones which are more pertinent to the subject. So extraneous cues are not necessarily inadvertent; they may be used deliberately. The examples given below illustrate some of the most frequent types of extraneous cues. They are not an exhaustive catalogue. They are more like a collection of archetypical cases selected to sample the range of classes which are of practical importance.

Formal Cues

This is the simplest and most primitive kind of cue which does not even require knowledge of the language for its utilization. It is most frequently seen in frames that involve blanks, and it usually derives from the structure or the immediate verbal environment of the blank.

A. Fungi live on the dead cells of the skin, hair, and nails. Therefore the ____________, ____________, and ____________ are the infected areas in cases of superficial mycoses.

Even without knowing English, a student could recognize the formal correspondence between the three-word series implied by the blanks and the one that appears in the preceding sentence.

B. To pull harder means to pull with a force of greater size or magnitude. In general, the strength of a force is its ____________ or ____________.

Again, the only two words in the top line separated by the word or are size and magnitude. Therefore the word or between the two blanks is the cue which gives away the answer, and the programmer cannot count on the student to be affected by the remainder of the context.

Sequential Prompts

From a programmer's point of view, these are among the most insidious. They are difficult to detect because their effects extend across several frames, and because examination of any single frame does not reveal them.

The most obvious type of sequential prompt is a series of frames requiring the same response. The following sequence is an example:

1. A collection of dishes is called a set of dishes. Six cups might be called a ____________ of cups.
2. Several pieces of clothing might be called a ____________ of clothes.
3. A pack of cards can also be called a deck or a ____________ of cards.
4. Things do not even have to be of the same kind to be called a set. <u>Any</u> collection of things may be called a ____________.

The first two frames are good, but in the case of the third and fourth frames, the cue for the answer "set" is already no longer the frame itself. The actual cue is likely to be the answer just given in the previous frame. The student begins to behave in accordance with the attitude, "The answer seems to be 'set' every time". While this may lead the student to the right answer, it teaches him little about the meaning of the word "set"; it does not teach him to use the word in the appropriate interverbal context.

Suppose this particular defect were eliminated by rewriting the program as follows:

1. A collection of dishes is called a set of dishes. Six cups might be called a ____________ of cups.
2. Several pieces of clothing might be called a ____________ of clothes.
3. A pack of ____________ could also be called a deck or a set of cards.
4. Things do not even have to be of the same kind to be called a set. Any collection of things may be called a ____________.

Here the continuity is broken. In the third frame the answer is not "set" but something else, and the student does not learn to write the word "set" automatically in frame after frame.

But now there is still another criticism. There is still sequential prompting in the four frames. What three words in all cases precede the word "set" wherever it appears? The words are "be called a". This type of prompt is exceedingly difficult for the programmer to catch. To avoid it consistently, a programmer needs long experience and a sharp eye.

Syntactic Prompts

In the examples presented below, the prompt is neither of the formal nor of the sequential variety. It derives from the logical equivalence of certain types of statements.

Example 1.

> Myocardial infarction is caused by occlusion of a coronary blood vessel. How is myocardial infarction caused?

The student merely has to recognize the logical equivalence of "X is caused by ___" and "How is X caused?" Both statements require the same answer. To arrive at it, the student can regard X as an arbitrary symbol (he can ignore its formal or semantic connotations), and only needs to copy the relevant words, in the present case "occlusion of a coronary blood vessel". A better way to write the frame would be:

> Myocardial infarction is caused by occlusion of a coronary blood vessel. What might be the result of a blood clot blocking the coronary artery?

Here the student must consider whether a blood clot blocking the coronary artery is an instance of occlusion of a coronary blood vessel.

Example 2.

> A set is a collection of elements. What is a set?

This can be formulated as "X is Y. What is X?" The student, knowing from his experience with the English language that "X is ___" and "What is X?" are satisfied by the same answer, simply copies Y, without enriching his concept of either X or Y.

The only way the student now has of arriving at the answer is to count the continents. This not only makes for better retention of the number 5, but also makes the student more aware of what kind of thing he is enumerating.

Example 4.

A line is defined by its slope and y-intercept. How is a line defined?

One possible remedy is:

In order to be able to draw the graph of the line $y = mx + b$, you have to know m and b. m is the slope of the line and b is its y-intercept. So a line is defined by ____.

When the frame is written in this manner, the student must realize that the information that "defines the line" is the same as "what you have to know to be able to draw the graph of the line". Therefore, the frame forces him to think about what the word "defines" means. Then he has to extract the fact that the slope and the y-intercept, which are represented by m and b, constitute the defining information.

SUPPLEMENT II

PROGRAMMING FOR AUTOMATED INSTRUCTION

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MONITORING THE SHAPING PROCESS

In the following excerpts from programs, the answer which the student has to give changes gradually. Fill in the answer in each case, and observe the way in which it changes from one frame to the next.

I. 1. Manufacture means to make or build. Chair factories manufacture chairs. Copy the word here:

_ _ _ _ _ _ _ _ _ _ _

2. Part of the word is like part of the word factory. Both parts come from an old word meaning "to make or build".

m a n u _ _ _ _ u r e

3. Part of the word is like part of the word manual. Both parts come from an old word for "hand". Many things used to be made by hand.

_ _ _ _ f a c t u r e

4. The same letter goes in both spaces:

m _ n u f _ c t u r e

5. The same letter goes in both spaces:

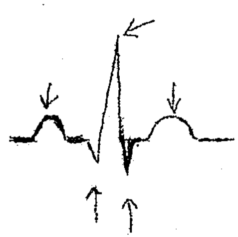
m a n _ f a c t _ r e

6. Chair factories _ _ _ _ _ _ _ _ _ _ _ chairs.

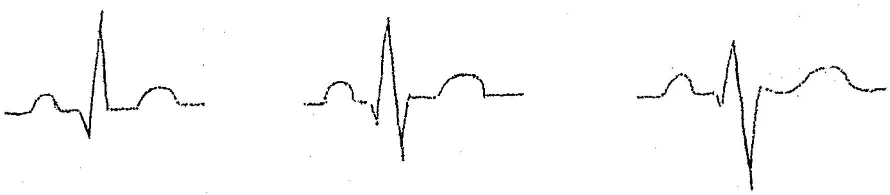
(After B. F. Skinner)

II. 1. The electrocardiogram is analyzed in terms of five deflections from the base line. These ____________ (how many) deflections are labeled with the letters P, Q, R, S, and T.

2. Label the five deflections of the normal tracing below, using the letters P, Q, R, S, T in that order, going from left to right.

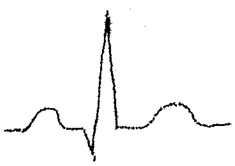


3. The S deflection is sometimes totally absent. In one of the tracings below the S deflection is absent. Show where it would be if it were present.



4. Label this normal tracing, indicating by arrows which deflection is designated by each letter. Also, show where the S wave would be if it were present.

5. The five deflections of the electrocardiogram are called waves. Label the five waves of this normal tracing.



6. In the tracing shown below,

the R wave is about ____________ times as large as the Q wave.
(how many?)

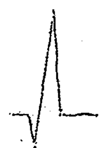
How large is the S wave?

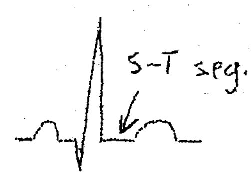
7. The Q, R, and S waves are missing in this diagram. Draw them in as they might appear in the normal electrocardiogram.

8. Compare the P and T waves in this diagram.

Which is longer, the P-Q segment or the S-T segment?

9. In this diagram, the P and T waves are missing. Draw them in as they would appear in the normal tracing.



10. What is the relation of the S-T segment to the base line? 

11. Draw the complete normal ECG tracing with all parts labeled, including the S-T segment.

III, 1. There are certain plant-like organisms that can cause disease. The one we are studying here is called a fungus. So we can say that one type of plant-like organism which can cause disease is called a ____________.

2. A fungus is a ____________-like organism that can cause disease.

3. Just as the plural of alumnus is alumni, so the plural of fungus is ____________.

4. The exposed parts of the skin, hair, and nails of the human body are made up of dead cells. Most disease-causing fungi live on dead cells. Therefore, most disease-causing fungi live on ____.

5. Disease-causing fungi live on dead cells. The reason why fungi are found on the skin, hair, and nails, is that they contain cells which are ________.

6. Disease-causing fungi live on the exposed and ________ cells of the skin, hair, and nails.

7. The horns of a bull are made of a substance called keratin. Your fingernail- and toenails, like the horns of the bull, contain the substance known as ________.

8. All of the dead cells of the exposed parts of the body are said to be keratinized. The dead cells of the hair, for example, contain the substance called ________.

9. In addition to the hair and nails, the dead cells of the exposed skin also contain keratin, and are therefore called k________ed cells.

10. What are the dead cells containing keratin called?

11. Compose a meaningful sentence which uses the following words:
    dead, cells, skin, hair, nails, keratin, keratinized.

The above are all examples of sequences where the student's answer gradually builds up in length and complexity.

It is not always easy for the programmer to keep track of the shaping process, which may extend over dozens and sometimes even hundreds of frames. As he writes the program, he can easily lose track of the stage he has reached. But even more difficult for the programmer is to keep track of the <u>rate</u> at which he develops concepts. Unless he monitors himself carefully, the speed with which he builds up different concepts may fluctuate widely.

The simplest way for the programmer to monitor the speed and direction of the shaping process while he is writing, is to keep a record of the answers for consecutive frames. He can keep this record on a separate sheet of paper, writing down each successive answer as soon as he has written the frame. The resulting record allows him to survey at a glance the evolution of the behavior being established. This method of surveying the learning process is based on the principle that the student is not expected to have learned anything he has not written. The only thing this record does not specify is the stimuli under whose control the indicated behavior is being brought. Though that aspect of the story is also important, its inclusion would make the record too unwieldy. The best compromise between a complete record and a useful one is the list of successive answers.

SUPPLEMENT III

PROGRAMMING FOR AUTOMATED INSTRUCTION

Francis Mechner, Ph.D.

HOW TO TEACH CONCEPTS

We say that a child has learned what a horse is when he says the word "horse" on the right occasions. These might include the presence of a horse, the sound of neighing, a picture of a horse, etc. But is this a sufficient condition for saying that this child knows what a horse is? Suppose he said the word "horse" not only on the occasions listed above, but also when other animals, such as cows, dogs, and birds appeared on the scene. Clearly, we would then say that this child does not know what a horse is, since he does not "discriminate" between horses and other animals. So we require not only that the term "horse" be applied to large four-legged hoofed animals that have manes and neigh, but also that it not be applied to animals that do not meet these specifications.

Psychology has a great deal to say about how concepts are taught most efficiently. Suppose a psychologist wanted to teach his child the concept of redness. The child can already say the word "red", but does not yet apply it appropriately. The psychologist might point in succession to pictures or objects around the room, and ask each time, "What color is this?" Every time the child gives the right answer, the psychologist provides some sort of confirmation or other suitable reinforcement. He does not point to the objects saying "This is red, this is green, etc." He lets the child make the responses himself.

The psychologist might first pick several red objects in a row, to let his student rack up a little confidence. Then he would occasionally point to a green object, accepting "not red" as a correct answer when one of these is shown. In choosing the red objects, he would be careful to include large ones as well as small ones, distant as well as near ones, dark as well as light, and coarse as well as shiny ones. This is to prevent any other attribute than redness from becoming associated with the response "red" through inadvertent fortuitous selection. The child learns to generalize among objects that have in common nothing other than redness.

Once the child shows signs of generalizing within the class of red objects and discriminating these from green ones, a new class, say yellow objects, may be brought in. These, like the green objects, would also be called "not red". The psychologist continues to alternate among the red, green, and yellow objects in a random or unsystematic way. As soon as this new discrimination is also learned, blue, black, purple, and orange objects are successively introduced into the training series. When the child no longer makes any mistakes--that is, no longer says "red" to things that are not red--he has acquired the concept of redness.

In short, we say that an individual has learned a concept when he applies the term (e.g. red, horse, chair, girl, hate, aldehyde, annelid, gyroscope, Lagrange integral) selectively to certain objects or situations. He must apply the term to the entities that fall within the category, and not to those that fall outside the category. A psychologist would say that he must learn to generalize within a class, and to discriminate between that class and other classes.

The psychologist teaching his child the concept of redness, was applying certain principles of concept formation that have been worked out by experimental psychologists in the learning laboratory. For one thing, he was letting the child make the responses. Whenever a desired response occurred, he rewarded it in a way he considered effective (confirmation, approval, praise, etc.). He established the generalization within the class of red objects by finding a wide range of objects from that class--objects that varied as much as possible in properties other than color. This was to make sure that the word "red" becomes associated with the color, rather than with any other property which these objects might share. Then he established a discrimination between red objects and objects having other colors by alternating the other objects with the red objects. He did not first show all the red objects, and then all the green, yellow, and blue objects. Rather, he alternated back and forth between all the various colors involved. Research has shown that the more frequent this alternation, the more rapidly the discrimination is learned.

In general, the student must first be shown a variety of specific instances or examples of the concept being taught. These should be alternated with the non-instances from which the concept is to be discriminated. The abstract or general statement cannot be properly understood without these preliminaries, and should therefore be deferred until the necessary generalizations and discriminations have been formed.

It is interesting that the principle of examples before the rule is not often applied by teachers. In his "Rules" article, Lloyd Homme points out that most people, when explaining something, first state the general rule and then illustrate it with examples:

> "...a tutor will typically enunciate a principle and follow this with a series of instances of the principle. The statistics tutor, for example, is likely to say: 'The mean is simply defined as Σx/N. For example, in the distribution below...'. The foreign language teacher might say: 'Such and such takes the objective case. For example,...'. The psychology professor says: 'The discriminative stimulus is a stimulus which sets the occasion for a reinforced response. For example, if we have a Skinner box...'."

Homme's observation is accurate, of course. It is also a provocative one in view of the fact that the alternative, which is to give the examples before the rule, is so much more effective, at least according to behavior theory. Why do so many people use the less effective method? Should this lead us to reexamine our theory?

Actually, the explanation is fairly straightforward. It is more useful to remember the general statement that mammals are warm-blooded animals that bear their young alive and nurse them, than it is to remember that each specific species such as cows, monkeys, horses, cats, dogs, rhinoceroses, sheep, etc. ad infinitum, is a mammal. Similarly, it is more useful to remember that the square of any number ending in five, such as X5 where X is everything to the left of the five, is equal to X times X+1 followed by 25, than it is to remember the squares of any specific numbers ending in five, such as 15 x 15 = 225, 25 x 25 = 625, 35 x 35 = 1225, etc. In general, one is better off remembering a body of information in a condensed and therefore abstract form, than in the form of innumerable specific instances. This is also why scientists prefer to store their knowledge in the form of general summary statements called theories, rather than in the form of huge masses of specific individual disconnected observations.

It is therefore easy to see why the general statement is so often the first one given by the teacher. It is simply the one which he remembers best and which is therefore the most accessible to him. The general rule, being the form in which an individual stores his knowledge, is also the form in which he can most easily produce it. Once he has stated the general rule, and while the "student" is asking "What do you mean?" or "Please explain", he has time to conjure up examples. This is socially much more dignified than the alternative, which is to pause and think of the examples before saying anything at all, and then to break the pregnant silence with some intellectually prosaic illustrations. To state the rule before giving examples is simply easier and more pleasant for the teacher.

The great teachers and writers of the past knew the principles of concept formation intuitively. Their writings provide us with some of the most powerful demonstrations of the effectiveness of giving the examples before the rule. La Fontaine teaches us a code of ethics through a series of allegorical fables. It is significant in this connection that Kant and Spinoza, who also had a great many ideas on the subject of ethics, are less widely read than La Fontaine. In his Little Black Girl in Search of God, Shaw conveys his message through a series of episodes. The little black girl is disillusioned in succession by Moses, Freud, Pavlov, and several other "false gods". Interestingly, these episodes are all non-instances of the concept being established. They build up the reader's concepts of what "God" is not, thereby preparing the reader for Shaw's concept of God as the residual category. If the psychologist teaching his child the concept of red had employed the same procedure, he would first have taught the child that green, blue, yellow, etc. are all "not red", and would have deferred the presentation of a red object until later. This type of negative discrimination training is effective when the learner's response is already at considerable strength but has not yet been properly focused.

Allegories, parables, satires, and metaphors are exceedingly interesting concept formation devices. La Fontaine's fables involve talking animals--specific animals who even have names. Had La Fontaine used specific people, all would be well and straightforward from the reader's point of view. The reader would never need to ask himself whether the principle applies to people in general. But since the characters are talking animals, the reader is induced to generalize. Obviously, these animals act very much like people. Any particular person? Nowhere does La Fontaine say it. The fact that La Fontaine leaves it up to the reader to pick a particular person, implies that he does not care which particular person is chosen, and therefore any person will do. So the parable is a subtle device for conveying the idea that the principle being exemplified has widespread applicability.

Folk sayings exemplify the same principle. "A stitch in time saves nine" is obviously not directed primarily at seamstresses. Its very specificity encourages induction. This is one possible reason why it is somewhat more telling than the equivalent, but more generalized saying, "An ounce of prevention is worth a pound of cure". Similarly, "The early bird catches the worm" and "Birds of a feather flock together" obviously have applications beyond ornithology. In a way, this device is used in all great literature. Oedipus is obviously not a real king, nor does Hamlet seem like a real prince. By choosing a slightly artificial, unreal, or un-naturalistic setting for a story, the author can convey the universality of his theme. In their theater, the ancient Greeks applied this principle rather effectively, if crudely: they used masks.

In Crime and Punishment, Dostoyevsky develops our concept of Raskolnikov's personality through a series of incidents, many of which involve interaction with Svidrigailov. Dostoyevsky uses Svidrigailov in a particularly ingenious manner. In some ways Svidrigailov resembles Raskolnikov, as a sort of "Doppelganger", and in other ways he is his opposite. So he furnishes a second personified example of the personality concept being established, and at the same time provides a contrasting non-instance from which it may be discriminated. Faust, in his opening speech, does not say that he is an erudite scholar who suffers from intellectual frustration, dissatisfaction, and self-hatred. Rather, he first enumerates the disciplines he has mastered (philosophy, medicine, jurisprudence, and theology) and culminates the list with the statement, "Here I stand, a wretched man, and am no wiser than before". Also, this is the first of a series of episodes by which Goethe gives the reader a sense of the futility of Faust's strivings. These episodes at the same time provide the contrasting non-instance of the next concept to be introduced, namely, Mephistophele's proposition. In general, the great masters of characterization do not describe their characters in abstract terms. They develop them by means of a series of well-chosen specific incidents which provide examples of the characters' behavior. The more effective these examples are, the less necessary is a final abstract summary, which is, in fact, frequently omitted altogether.

In poetry too, the poet frequently builds a concept or mood through a series of images which may be quite concrete. In "The Second Coming", for instance, Yeats develops a mood of general disintegration and chaos by means of such images as "The falcon cannot hear the falconer", "The center cannot hold", "The blood-dimmed tide is loosed upon the earth", etc. By the time he is through, the reader is fully persuaded that things are going rather badly, and is almost grateful when Yeats tells him "...the second coming is at hand". Baudelaire's thesis is that this is, in fact, the basis of all poetry--that abstract images are conveyed by appealing to the experience of the separate senses. In his preface to "The Flower of Evil", he says: "...poetry is like the arts of painting, cooking, and cosmetics in its ability to express sensations of sweetness or bitterness, beatitude or horror, by coupling a certain noun with a certain adjective, in analogy or contrast..."

The concept formation principle of examples before generalizations extends even to music. In the classical sonata form, the development section may be thought of as a series of specific examples of the first and second themes. The movement ends with a recapitulation which is a kind of summary statement of those themes, a summary which the listener can by that time appreciate as such by virtue of having heard the various "specific instances" it subsumes. Beethoven, the great master of form, was particularly adept at this type of summarization. Among the most powerful examples are the coda of the first movement of the Piano Concerto Number 3 in C Minor, where there are actually three successive summaries of increasing terseness, the final one being only five notes in length; the final staccato chord passage toward the end of the third movement of the Appassionata Sonata; the thirds passage near the end of the Archduke Trio; and the end of the first movement of the Ninth Symphony. In all these examples the summary theme contains the kernel or essence of all that came before.

In sum, the concept formation principle, which states that a general or abstract concept is learned by the establishment of generalizations among specific instances of the class and discriminations between instances and non-instances of the class, manifests itself in allegories, parables, folk-sayings, novels, plays, poetry and music. Its ramifications extend beyond teaching and education into the most diverse realms of human communication.

The principle has important applications in programmed instruction. Whenever a rule or principle needs to be illustrated with examples, the examples should come first. This is not to say that every general statement must be preceded by examples. Rather, if examples are given at all, they should come before the rule rather than after it.

In the following illustrations, various topics are programmed the right way, with the examples given before the rule, and the wrong way, with the examples following the rule:

RIGHT

1. A collection of dishes can also be called a set of dishes. Several crayons can be called a __________ of crayons.

2. Every member of the set of crayons is called an element of that set. Every member of the set of dishes, similarly, would be called ________________.

3. In general, the members of a set are called its ____________.

4. A collection of elements is a __________.

5. Make a sentence using the words <u>set</u> and <u>element</u>.

WRONG

1. A set is defined as a collection of elements. A collection of crayons, for example, would be a __________ of crayons.

2. The members of the set are called the elements of the set. Each crayon would be an ____________ of the set of crayons of which it is a member.

3. Each dish is an _____________ of the __________ of dishes.

4. The members of the set are called ____________.

5. A collection of elements is called ____________.

****

RIGHT

1. When wood is burned in the fireplace to heat the room, this wood is being used as fuel. The wood that burns during a forest fire would not be called ____________, because it is not being burned for heat.

2. The fuel which is commonly used to heat homes is oil. Oil is a fuel because it is burned for ____________.

3. Gasoline is used as automobile fuel. When it is burned, it provides the energy to move the car. In airplanes, gasoline is also used as a source of ____________.

4. Suppose a house is on fire. Why wouldn't the house be considered fuel?

5. Anything which is burned for heat or energy is called a ____________.

6. Explain how you would decide whether something that is burned should be called a fuel.

WRONG

1. A fuel is something that is burned for heat or energy. Something which is burned to get rid of it, like garbage, would not be a ____________.

2. Wood is sometimes burned in the fireplace to heat the room. When wood is burned in this manner, it is being used as a ____________.

3. Gasoline is used as automobile fuel. When it is burned, it provides the energy which moves the car. In airplanes, gasoline is also used as a source of ____________.

4. The fuel which is commonly used to heat homes is oil. Oil is a fuel because it is burned for ____________.

5. Anything which is burned for heat or energy is called a ____________.

6. Suppose a house is on fire. Why wouldn't the house be considered fuel?

7. Explain what a fuel is.

****

RIGHT

1. A gluco-corticoid is a corticoid involved in the metabolism of ____________. Similarly, a mineralo-corticoid is a corticoid involved in the metabolism of ____________.

2. The corticoids involved in the metabolism of glucose are called __________-corticoids, and those concerned with the metabolism of minerals are called ________-____________.

3. Complete the following table:

	Corticoid classification	Metabolic function of corticoids in that class
a.		
b.		

4. These two classes of corticoids are distinguished in terms of their ____________ function.

WRONG

1. Corticoids are classified in terms of their metabolic function. There are two classes of corticoids. How do corticoids of one class differ from corticoids of the other class?

2. For example, gluco-corticoids are involved in the metabolism of ____________ and mineralo-corticoids are involved in the metabolism of ____________.

3. A ____________-corticoid is a corticoid which participates in the metabolism of glucose. Similarly, a ____________-corticoid participates in the metabolism of minerals.

4. Complete the following table:

	Corticoid classification	Metabolic function of corticoids in that class
a.		
b.		

****

RIGHT

1. Each step of a program enlists the student's active participation by requiring him to ____________ a question, ______________ an instruction, or ______________ a blank.

2. His ____________ may be just a syllable or an entire paragraph.

3. Whether the student answers a question, follows an instruction, or fills in a blank, his response always requires ____________ participation.

4. In reading a book, listening to a lecture, or watching a film, the student can remain passive. In working through a program, on the other hand, he has to be __________.

5. In general, an important difference between a program and other means of instruction is that a program requires ____________________________.

WRONG

1. An important difference between a program and other means of instruction is that a program requires the student to participate actively. Listening to a lecture or watching a film, for example, does not require ________________.

2. At each step of the program the student must make an active response. He may be required to __________ a question, __________ an instruction, or ________________ a blank.

3. His __________ may be just a syllable or an entire paragraph.

4. In reading a book, listening to a lecture, or watching a film, the student can remain passive. In working through a program, on the other hand, he has to be __________.

5. Whether the student answers a question, follows an instruction, or fills in a blank, his response always requires __________ participation.

The principle of examples before the general rule should also be applied to the sequence of topics in a program, that is, to the syllabus. Before introducing the concept of evolution in a biology course, for example, the student must be taught the various specific "examples" of evolution, in other words, the data on which the theory is based. Before he is taught the concept of homeostasis, he must learn about different kinds of physiological equilibria. The beginning chemistry student is not ready for the concept of "element" until he has learned about several kinds of elements. Before a physics student can understand the concept of a field, he must be given experience with various different kinds of fields, and the data and observations that lead us to speak of a field. In mathematics, the student is not ready to understand what a proof is until he has seen a large number of different kinds of proofs, ranging from syllogisms to long derivations, and until he has learned to discriminate between the proof of a theorem and a demonstration of its correctness. He cannot understand what an operation is until he can add, subtract, multiply, etc. The mathematics student cannot appreciate the general concept of a group until he has had experience with several postulational systems that conform to the group postulates, as well as with some that do not. Finally, a person cannot adequately understand what a science is until he has been exposed to several sciences.

INTRODUCTION TO PROGRAMMING

by

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INTRODUCTION

Public relations experts have expressed the opinion that the teaching machine was propelled into public view in part by the shock appeal of the word "machine". The possibility of a machine replacing a human being, and of all human beings the venerated teacher, fired the imaginations of scientists and journalists alike. The whirlwind of this excitement is still gathering momentum. But in the eye of the storm a small group of serious scientists has quietly been reaching the conclusion that the machine is one of the less important aspects of automated instruction, and that Skinner's revolutionary concept is not the machine but its content -- the program. They are also coming to a second realization: that the power of the method is strongly dependent upon the quality of this program, that the conventional textbook is possibly just a case of extremely bad programming, and that the advantages of programmed instruction are more a matter of degree than of kind.

Accordingly, the art of programming lies at the heart of the method. It is at present a primitive art, which no one has yet cultivated for more than a few years. Currently, the main source of ideas for this art is the body of knowledge which behavioral scientists have generated during the past few decades. This source is gradually being replaced, however, by contemporary research which is rapidly gaining in importance, and will continue doing so in the foreseeable future. And yet, the application of behavioral science to programming technology is hardly a mechanical process. So far, we have witnessed only the bare beginnings of it. The domain of programmed instruction is as large as the domain of education. In fact, it is the domain of behavioral science. From this point of view, there is a wide gap between the current range of applications of programmed instruction and the eventual range. This gap will have to be bridged by research, ingenuity, and imagination.

WHAT IS A PROGRAM SUPPOSED TO ACCOMPLISH ?

A knowledge of plane geometry is the ability to solve certain problems and give the proofs of certain propositions. A knowledge of biology includes the ability to explain why it is that leaves look green, how a caterpillar is related to a butterfly, why eating salt makes you thirsty, how to breed fish, or why man bears such a striking resemblance to other mammals. A knowledge of French includes the ability to give a suitable reply to the question "Comment vous appelez-vous?". In all of these cases it is possible to specify what constitutes a knowledge of the subject. The knowledge can be measured by means of an examination or some other practical test situation.

Frequently the question is asked, "How can a program teach originality and creativity?", "How can it teach the rigors of study?", "How can it instill a thirst for knowledge?", "How can it teach the student to cope with real life?", "How can it teach him values?". The answer to all of these questions is the same: Programmed instruction can be used to teach anything that is clearly specified. The terminal behavior (the knowledge or ability which the student must end up with) must always be carefully defined. Originality, creativity, rigors of study, thirst for knowledge, coping with real life, and having good values, are not easily definable abilities. The programmer, not knowing what knowledge or behavior he must establish, does not know how to proceed.

Once the terminal behavior is specified, on the other hand, establishing it is comparatively mechanical. Almost any terminal behavior can be established through the application of behavioral technology. The present paper deals with some of the approaches that have been developed.

SHAPING THE STUDENT'S KNOWLEDGE

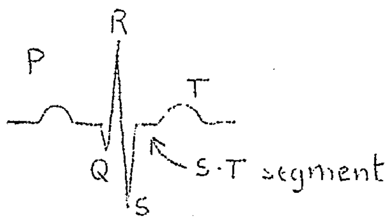
The guiding principle of learning theory is that behavior must occur before it can become established. The student does not learn anything he does not actually do. He does not understand something if he has not learned to explain it.

Stated in its most general terms, then, the programmer's task is to get the student to emit the desired behavior under the appropriate conditions.

Suppose the programmer wants to teach the student to make the correct response to the following stimulus:

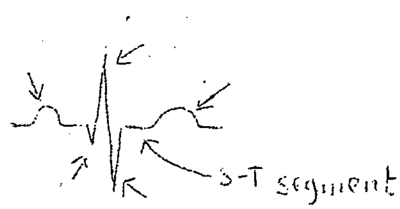
> Draw the complete normal electrocardiogram tracing. Label all its parts, including the S-T segment.

The desired response to this stimulus is:



This behavior could be shaped as follows:

1. The diagram at the right shows a normal electrocardiogram tracing. Using the letters P, Q, R, S, T in that order, label the five deflections from the baseline, going from left to right.



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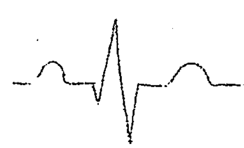
2. Label the five deflections in this normal electrocardiogram tracing using consecutive letters of the alphabet beginning with P. Use arrows to show which letter designates which deflection.



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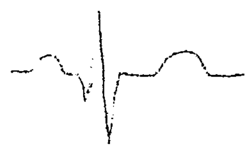
3. The five deflections of the electrocardiogram are called waves. Label the waves of this normal electrocardiogram tracing.

4. In the tracing shown at the right, the R wave is about ______ times as large as the Q wave and about ______ times as large as the S wave.

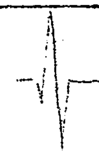
5. Draw in the Q, R, and S waves in the diagram below, as they might appear in the normal electrocardiogram.

6. What is the relation of the S-T segment to the baseline?

7. Compare the P and T waves in this electrocardiogram tracing. Which is longer, the P-Q segment or the S-T segment?



8. In the diagram below, the P and T waves are missing. Draw them in as they might appear in the normal electrocardiogram tracing.



9. Draw the complete normal electrocardiogram tracing. Label all its parts including the S-T segment.

Note that the last item of this short program calls for the terminal behavior which the programmer set out to establish.

Now suppose the programmer wanted to teach the student to answer the question: "Write a short paragraph explaining from which parts of the human body disease-causing fungi obtain their nourishment."

	1. Fungi do not belong to the animal kingdom; they belong to the ________ kingdom.
plant	2. F________ are plant-like organisms that can cause disease.

(F)ungi	3.	Just as the singular of alumni is alumnus, so the singular of fungi is ________.
fungus	4.	The exposed parts of the skin, hair, and nails of the human body are made up of dead cells. Most disease causing fungi live on dead cells. Therefore most disease-causing fungi live on ________ ________.
the exposed parts of the skin, hair, and nails of the human body	5.	Disease-causing fungi can live on the exposed parts of the ________, ________, and ________ because these parts of the body contain dead cells.
skin, hair, and nails	6.	Why can disease-causing fungi live on the exposed parts of the skin, hair and nails?
Skin, hair, and nails contain dead cells.	7.	The horns of a bull are made of a substance called keratin. Your fingernails and toenails are similar in composition to the horns of a bull. You might guess that they too contain ________.
keratin	8.	All of the dead cells of the exposed parts of the body contain keratin. Name the parts of the body where you think keratin can be found.
fingernails, toenails, skin, and hair	9.	What portions of the skin, hair and nails contain keratin?
the exposed portions which are made up of dead cells	10.	What is a fungus?
A fungus is a plant-like organism that can cause disease.	11.	Write a short paragraph explaining from what portions of the human body disease-causing fungi obtain their nourishment.
When fungi infect the body, they live on the dead cells of the exposed parts of the skin, hair, and nails. They feed on the keratin of these dead cells.		

Here again, the last two items of the program demand the terminal behavior.

In the next example the behavior being shaped is a mathematical skill. The student learns to square any number ending in five by a technique which enables him to do it mentally if the number is not too large (say, below 165).

	1. In the number 65, which digit precedes the 5? In the number 15?
6; 1	2. Which digits precede the 5 in the number 305? In the number 105?
30; 10	3. In the number 95, the digit preceding 5 is ______. As you count from 1 to 10, 9 is followed by ______.
9; 10	4. In the number 115, the digits preceding ______ are 11. As you count, the number 11 precedes the number ______.
5; 12	5. In the number 135, the digits 13 ______ ______________. These (complete the statement) digits form the number 13. Which number follows it as you count?
precede the number 5; 14	6. The digits 10 precede the number 5 in ______. The number __________ 10 is the number 11.
105; following	7. In each of the numbers below find the digits preceding 5. Then find the numbers which follow these digits as you count. 15, 35, 65, 685, 3895
1,2; 3,4; 6,7; 68,69; 389, 390	8. Now do it for 25; for 5.
2,3; 0,1	9. In the number 115, the digits ______ precede the 5. 11 is followed by ______. Multiply 11 by 12.

11; 12; 132	10. 9 follows ______ which precedes the digit 5 in the number ______. Multiply 9 by the number it follows as you count.
8; 85; 72	11. Again multiply the digit preceding the 5 in the number 55 by the number which follows it as you count.
30	12. Now do this kind of multiplication for the number 15; for 35; 45; 95.
2; 12; 20; 90	13. Square 25 the long way: 25 x 25 = ______. The 2 in 25 is followed by 3 as you count. Again, do the multiplication 2 x ______ = ______. The first digit of 625 was also ______.
625; 2 x 3 = 6; 6	14. For each of the numbers below multiply the digits preceding the 5 by the number which follows it: 5 ______ x ______ = ______ 15 ______ x ______ = ______ 35 ______ x ______ = ______ 65 ______ x ______ = ______ 125 ______ x ______ = ______
5 0 x 1 = 0 15 1 x 2 = 2 35 3 x 4 = 12 65 6 x 7 = 42 125 12 x 13 = 156	15. Now square each of the numbers in the left hand column: 5 0 x 1 = 0 15 1 x 2 = 2 35 3 x 4 = 12 65 6 x 7 = 42 125 12 x 13 = 156
25; 225; 1225; 4225; 15,635	16. The squared numbers all end in ______.
25	17. What relationship do you notice between the two sets of circled numbers? 5 0 x 1 = 0 025 15 1 x 2 = 2 225 35 3 x 4 = 12 1225 65 6 x 7 = 42 4225 125 12 x 13 = 156 15,625

The second set consists of each of the numbers in the first set followed by 25.	18. Can you guess what the squares of the missing numbers might be? 5 0 x 1 = 0 025 15 1 x 2 = 2 225 25 ______ 35 3 x 4 = 12 1225 45 ______ 55 ______ 65 6 x 7 = 42 4225 85 ______ 105 ______ 125 12x13 = 156 15,625
25 2 x 3 = 6 625 45 4 x 5 = 20 2025 55 5 x 6 = 30 3025 85 8 x 9 = 72 7225 105 10x11 = 110 11,025	19. Square 95 mentally. Square 75 mentally.
95 9 x 10 = 90 9025 75 7 x 8 = 56 5625	20. 25 x 26 = 650. Which number squared is equal to 65025?
255	

Here, the last two frames call for the terminal behavior. This terminal behavior differs from the type illustrated in the previous examples in that it is not a specific response or sequence of responses, but a skill -- the ability to make the right responses in a large, though restricted range of situations.

It might also be noted that this last example -- the mathematical one -- is designed for a somewhat more elementary level than the previous two examples. The medical examples are suitable for college graduates; the mathematical example would work for the average fourteen year-old.

THE IMPORTANCE OF SMALL STEPS AND ACTIVE RESPONSE

Read the following statement:

Occlusion of a coronary blood vessel, if prolonged, causes damage to the heart muscle, or myocardium. The medical term for myocardial damage produced by occlusion of a coronary blood vessel is myocardial infarction.

Now without looking back, try to define the term MYOCARDIAL INFARCTION. You would probably find this difficult. Undoubtedly, you read the above statement without really learning its contents. This was not unreasonable, since you did not know what aspect of the statement would be important. In that type of situation, most people tend to scan lightly until they reach a point where some specific response is demanded of them. They they go back and focus their attention on the relevant parts. If you had known that you would be called upon to define the term "myocardial infarction" before you started reading the statement, you would have been able to proceed much more efficiently.

A program increases the efficiency of learning by focusing the student's attention on the significant points as he learns. If the student has answered a frame correctly, he knows that he has mastered the relevant information and can proceed securely. Here is what the above statement might look like in a programmed form:

	Myocardial infarction is the medical term for damage to the heart muscle, or myocardium. Which part of the word myocardium means heart? Which part means muscle?
cardium: heart myo: muscle	"Myocardium" is the medical term for __________ __________.
heart muscle	Damage to the myo__________ results from occlusion or blockage of a coronary blood vessel.
myo cardium	Oc__________ or blockage of a coronary blood vessel, if prolonged, causes damage to the __________.

oc clusion; myocardium or heart muscle	Myocardial destruction due to _________ (which means blockage) of a coronary blood vessel is called _________al infarction.
occlusion; myocardi al	Myocardial _____arction is the technical term for damage to the _________ _________.
inf arction; heart muscle	Occlusion of the coronary artery is one of the possible causes of _________ inf_________.
myocardial inf arction	_________ _________ is the medical term for damage to the myocardium caused by _________ of a _________ _________.
Myocardial infarction; occlusion; coronary artery	Define the term MYOCARDIAL INFARCTION.
Damage to the myocardium caused by occlusion of a coronary artery.	

The programmed version of the statement contains about four times as many words as the original statement. On the other hand, if the student has answered all nine frames correctly, he has unequivocal evidence that he has learned the relevant material, and that he will not have to go back to patch up the gaps in his knowledge.

The experienced student, who knows how to learn from a textbook, improvises a program for himself as he reads along. He underlines the passages or expressions he feels are important, he makes up little questions which he asks himself as he proceeds, he goes back and reviews when he fears that previously learned material is beginning to slip away, and he periodically tests himself to make sure that his grasp of what he has learned is firm. These practices are sometimes called "good study habits". Naturally, very few students succeed in acquiring this difficult skill during their academic careers, and those that do frequently lack the discipline and self-control which is needed to exercise it. It is so much easier to just read along. Finally, the student is not very well qualified to program material which he is just learning. He cannot always know which questions to ask himself. He is not yet able to discriminate the important from the unimportant, or to place the emphases where they belong. He spends time on many things that are unnecessary or irrelevant. The individual best qualified to do the programming is the textbook's author.

THE FRAME

What is a Frame of a Program?

The above statement is an example of a frame. Other examples of frames are:

Quadrupeds have ________ legs.
(how many)

To be or not to be, that is the ________.

In a short paragraph, summarize Hamlet's speech.

Explain how airfoil-shaped wings keep a plane aloft.

Mozart was born in the year ________.

Give three proofs of the Pythagorean theorem.

Complete the diagram of the circulatory system shown below, and fill in the missing labels.

Torrecelli used his mercury column apparatus to demonstrate ________.

A plane is flying at an altitude of 2 miles. A parachutist jumps out. After 4 seconds, before his parachute has opened, he has fallen 256 feet. Over which planet was the plane flying. Explain your answer.

Make a table showing the first four periods of the periodic table.

Damage to the heart muscle due to occlusion of a coronary blood vessel is called ________ ________.

Name all the fungi that can cause onychomycosis.

If $A \cap B$ equals $A \cup B$, what can you say about A and B?

Write the decimal number 29 in the binary system.

Why are whales classified as mammals rather than fish?

In general, a frame is a question, a statement with a blank in it, or an instruction to do something.

A frame always requires a response from the student. Usually, the student is informed of the correct answer immediately after he has made his response. Naturally, there need not be a unique correct response. The confirmation may take the form of a paraphrase, or an outline of how the answer should have been developed. The important feature of a frame is that it enlists the student's active participation.

Which Response to Require

At every frame, the programmer must decide which response to require of the student. It may be a question of which word to leave blank, which question to ask, which instruction to give, or in general, what the student must do.

If the programmer remembers that the student only learns that which he says, and not that which he merely reads, his problem becomes comparatively easy. It is then only a matter of deciding through what steps to shape the desired behavior, that is, of finding the shortest and most strategic route.

It is very easy for the programmer to forget that the student must actually display the the performance he is acquiring. One experienced programmer, in teaching the comparative electrolytic properties of salt and sugar solutions, wrote the following frame:

> A salt solution is capable of conducting ________ while a sugar solution is not.

where he meant to write:

> A ________ solution is capable of conducting electricity while a
> salt/sugar
>
> ________ solution is not.
> salt/sugar

or

> Which is capable of conducting electricity, a salt or a sugar solution? ________

The programmer must be careful never to lose sight of the terminal behavior toward which he is working.

The Form of the Frame

The overriding objective of a program is always to shape the student's knowledge in the desired direction. The form of any particular frame is always subordinate to this objective.

The sample programs in the preceding pages illustrate a few of the possible forms that frames can take. "Fill in the blank" items are frequently useful in the early stages of the formation of a concept, and often provide convenient stepping stones toward the final desired knowledge or performance. But thorough comprehension generally requires something more.

A progression leading to the student's ability to explain an abstract concept, for instance, might begin with his filling in the key words in a series of examples. Then, again by means of fill-ins, the student might learn what the examples had in common. He is then ready to fill in increasingly larger segments of the generalization until he can answer open-ended questions of the type(s) shown below:

1. Explain the relation between A and B.
2. Compose a sentence using the expressions A, B, and C.
3. Compare A and B, naming two similarities and two differences.
4. Fill in the missing parts in the following table.
5. What is an A?
6. Define the term A.
7. In three short sentences, say what you have learned so far about A.
8. Fill in the missing parts of the diagram.
9. Someone says to you that A seems to be a case of B. Explain to him why he is mistaken.

10. Explain how you would go about finding out whether A is B.

11. Using information A, B, and C prove/derive/demonstrate D.

12. List n conditions under which A could occur/be true.

13. Give n examples of A.

14. Explain what an A is.

None of these forms is better than any other. The form of a particular frame should be dictated only by the requirements of the subject and the stage of the student's progress.

If the student has never done anything other than fill in blanks, he will be able to exhibit his knowledge only when confronted with a fill-in item. He will be at a loss if someone happens to ask him an open-ended question about the subject such as, "What is a cardinal number?" or "Why is force a useful concept in physics?" or, for that matter, if he asks himself a question such as "Let's see, what have I learned so far about sets?" or "How do I know that the sum of the angles of a triangle is 180 degrees?" When the student is unable to reply to such self-questioning, he feels that he "has not learned anything". It has been observed that students, after completing a program consisting exclusively of fill-in items, do, in fact, report that they did not learn anything. This observation is rather puzzling when one considers that these students obviously learned a great deal, since they were able to fill in answers at the end of the program which they could not fill in before. The observation is less puzzling, however, when one considers the manner in which the student tests himself to find out whether he has in fact learned anything. He does not give himself a fill-in item to do. He tests himself the way he would test anyone else -- by asking himself open-ended questions.

MULTIPLE CHOICE ITEMS

Learning theory tells us that multiple choice items are pedagogically unsound. When reading a multiple choice item, the student at best constructs what he considers the correct answer, and then looks for that answer among the alternatives given. If all goes well he finds it there, and receives his confirmation. But more often, all does not go well. The student, in looking through the alternatives reads several false, though plausible-sounding statements. For the item to have any value, the three or four errors that are suggested to the student must be plausible statements. To some extent he will learn them. Alternatives that would never have occurred to him begin to sound pretty good. Skinner tells the story of the child confronting the question "What is Pasteurized milk?". This was something the child knew pretty well. But among the incorrect alternatives was "Milk from cows that have been fed on the pasture". This plausible - sounding answer had never occurred to the child. The child may finally have chosen the correct answer. But months later, the child would already be considerably less certain as to which of these two plausible sounding answers, both of which he "read some time ago" was correct. By reading and studying incorrect alternatives, the student inevitably learns them to some extent.

Unsound as it is, the multiple choice item addresses itself to a problem with which the programmer must be concerned. It is the problem of teaching the student to avoid errors. How will the student learn to avoid errors if he never gets a chance to make any? Behavior theory tells us: Not by making them. You should not teach a student to avoid errors by setting traps for him and then punishing him for falling into them. Rather, the student should first be taught the correct behavior until this behavior is secure. Then the student should learn to identify and even analyze the various possibilities of error. He might be instructed to explain why a false statement is false, and perhaps how it might be changed to make it true. He might be asked to trace the error in a problem which has an error in it. He might even be asked to construct a certain type of error. The important difference between this type of contact with false statements and the type of contact involved in doing multiple choice questions is that the student knows from the beginning that the statement is false. He links it in his behavioral repertoire with the response "This is a false statement" or something equivalent. In this way, the student can learn to avoid an error without making it. He need never stop answering the questions correctly. In a multiple choice item, on the other hand, the student will read and study the incorrect alternative as a possible correct answer before he decides that it is not. Of course, he may actually end up choosing the incorrect alternative. In that event he is reprimanded. We know from learning theory that negative reinforcement is not a very effective way of abolishing unwanted behavior. Positive reinforcement for the correct behavior has much more lasting effects. Finally, the student may merely read and study the incorrect alternative, and not choose it at all. In that case, it will have been learned to some small extent, and will never have become tagged as "false" either by punishment or through positive reinforcement. The programmer spends a great deal of time and effort thinking up good traps. The student, even if he does not fall into any of them, comes away with his knowledge blurred by latent errors and misconceptions which linger in his repertoire waiting to emerge on future occasions.

There is still another argument against multiple choice items. A multiple choice item only teaches the student to <u>recognize</u> the right answer. It does not necessarily teach him to <u>give</u> the right answer. The ability to recognize a correct statement is very different from the ability to construct it. In ordinary life, it is usually the latter ability that is called for. The individual may have to formulate the statement to himself in order to cope with a certain situation, or he may have to explain it to someone. He may have to state a principle in answer to a question, or as the justification for doing something. It is very difficult to think of practical situations in which a person is asked "Which of these statements is the true one?" Even insofar as multiple choice items do succeed in teaching, what they teach is rather impractical.

THE INCLUSION OF EXTRANEOUS SUBJECT MATTER WITHIN THE FRAME

In an earlier discussion the point was made that the student can learn most efficiently when he knows what knowledge he is expected to glean from the material he is studying. The passage on myocardial infarction was used to illustrate how a program focuses the student's attention upon that which is important for further progress. In reading a passage of ordinary prose, the student who has not yet developed a broad perspective over the material is likely to get hung up on irrelevant or incidental details. This slows him down, reduces his efficiency, saps his energy, and often lowers his morale. It is not surprising that very few individuals are able to read through text books.

A good program permits the student to adopt the attitude that if he can respond correctly he has learned the relevant material and will no longer have to worrry whether he has "gotten the point". In this respect, the program may be thought of as a behavioral tree marker, which charts the student's trail through the forest of ideas.

Consider the following example:

1. There are nine planets in the solar system. The earth is a planet. Jupiter is the largest planet. Therefore __________ is larger than the earth.

Now the program can proceed in one of two ways:

2a. How many planets are there in the solar system?

2b. The planets of the solar system are Mercury, Venus, Earth, Mars, Saturn, Neptune, Uranus, Jupiter and Pluto. How many planets are there in the solar system?

The difference is crucial. First let us consider 2a, the left hand version. The programmer expects the student to have learned the contents of the previous frame. When the student sees that frame he will say to himself either, "Ah, it's a good thing I read the previous frame carefully; there are nine.", or "Oh, oh, I guess I didn't read the last frame carefully enough." In either case the effect is the same: the student will read frames more "carefully" in the future, so carefully that he will learn not only everything the programmer wants him to learn, but also a great deal of material which is irrelevant. One or two incidents of this type are sufficient to make the student feel insecure and guilty if he does not master the entire content -- relevant and irrelevant -- of every frame henceforth. For all he knows, the programmer is counting on him to learn it all and will not give him another chance to review it. By requiring the student to do more than just answer the question, the programmer inadvertently puts pressure on the student to learn the entire content -- relevant and irrelevant -- of every frame. The student, who has no way of ascertaining what aspect of the frame is important, plays it safe and learns it all. This gives the program some of the disadvantages of the traditional text.

Consider alternative 2b on the other hand:

> The planets of the solar system are Venus, Mercury, Earth, Mars, Saturn, Neptune, Jupiter, Uranus, and Pluto. How many planets are there in the solar system? ________

In this case the student does not experience the contingency of being rewarded for having learned, or punished for not having learned the irrelevant statement in the previous frame. Granted, he gets the answer "nine" by counting the planets. But he does make the response "nine" to a reasonably non-trivial stimulus, and when asked "How many planets are there in the solar system" a few frames later, the chances are he will answer without difficulty.

The above discussion makes one significant point: Do not teach important facts or concepts by stating them in one frame and then asking the student to make the relevant response in a subsequent frame. This practice, while it may work, will also damage the student's efficiency in going through the program.

It goes without saying that every frame must, of necessity, contain a certain amount of material which is irrelevant to the required answer. For example, the number of words in the frame, and the average number of e's per word, are irrelevant attributes which every frame possesses, regardless of how masterfully it is designed. The student could very easily be taught to focus his attention upon these aspects of the frames. If the programmer asked the student on two or three occasions, "How many words were there in the previous frame?" the student would quickly learn to count the number of words in each frame. The example is extreme to the point of being absurd, but it illustrates the point: If the programmer does not want the student to attend to irrelevant details, he should never ask the student to attend to anything which is irrelevant to the question, since the student cannot yet discriminate detail from non-detail. While there is little harm in including irrelevant material in a frame, there is great harm in requiring the student to learn it.

In the above example, it was pointed out that the right hand version of frame #2 is satisfactory. This frame could have been preceded in one of two ways:

1. There are nine planets in the solar system. The earth is a planet. Jupiter is the largest planet. Therefore __________ is larger than the the earth.	1. The earth is a planet. Jupiter is the largest planet. Therefore __________ is larger than the earth.

2. The planets of the solar system are Mercury, Venus, Earth, Mars, Saturn, Jupiter, Neptune, Uranus, and Pluto. How many planets are ther in the solar system?

Here, both alternatives are equally good. The statement "There are nine planets in the solar system" as it appears in the left hand version of frame #1, is innocuous. The student may or may not remember it in the following frame. Whether he does or not is unimportant, since frame #2 is selfsufficient. The only advantage the student will reap from remembering the statement is that it will enable him to answer frame #2 somewhat faster. Whether this is sufficient reason for including the statement in the frame is a matter of the programmer's style.

INADVERTENT CUES AND PROMPTS

A psychologist would say that the function of an instructional program is to bring the the student's behavior under the control of the proper stimuli. This may sound like a rather narrow objective. Actually it covers all of learning. Questions, instructions, and all the examples of frames listed above are stimuli. The responses to the questions and instructions constitute the behavior. If the student gives the right answers to the right questions, then his behavior is under the control of the proper stimuli.

One of the greatest problems that confronts the programmer is to insure that the student's responses come under the control of the intended cues. (The terms "cue" and "stimulus" are synonymous.) A student may give the right answer for the wrong reason. The answer may be cued by cues and prompts that are extraneous to the subject matter. Such undesired cues and prompts can take innumerable forms. Before a programmer is really competent, he must recognize such prompts and avoid them in his writing. This requires not only experience, but also verbal sensitivity.

In the discussion which follows, the expression "extraneous cues" will refer to cues which are not inherent in the subject matter being taught. Extraneous cues can, of course, be useful in constructing a new behavioral chain. The technique known as "fading", for example, involves the elicitation of certain desired responses by the initial use of extraneous cues, and the gradual replacement of these cues by new ones which are more pertinent to the subject. Extraneous cues are not necessarily inadvertent; they may be used deliberately.

It is important for the programmer to take the attitude that the student is working against him at all times. This attitude is conducive to good programming. It assumes that the student's only concern is to get the right answer each time. The student should not be expected to worry about whether he gave the right answer for the intended reason. In fact, it is desirable for the student to take the attitude that if he answers correctly, he is on firm ground. In this way, he will attain the objective with the maximum speed and efficiency. This point is discussed more fully in the next chapter.

After writing a frame, the programmer should always check it by asking himself how much of it the student would have to read minimally to arrive at the correct answer. For example, if there is a blank in the frame, the programmer should assume that the student will first look at the blank, and then read away from the blank in ever-widening circles until he can answer the question. It should never be assumed that the student will attack a frame by reading it from the first word to the last. The student will use only the cues he needs. The programmer should never expect him to respond to any others.

The examples given below illustrate some of the most frequent types of extraneous cues. They are not an exhaustive catalogue. They are more like a collection of archetypical cases selected to sample the range of classes which are of practical importance.

Formal Prompts

This is the simplest and most primitive kind of cue which does not even require for its utilization knowledge of the language. It is most frequently seen in frames that involve blanks, and it usually derives from the structure of the immediate verbal environment of the blank.

A. Fungi live on the dead cells of the skin, hair, and nails. Therefore the __________, __________, and __________ are the infected areas in the cases of superficial mycoses.

Even without knowing English, a student could recognize the formal correspondence between the three-word series implied by the blanks and the one that appears in the preceeding sentence.

B. To pull harder means to pull with a force of greater size or magnitude
In general, the strength of a force is its _________ or _________.

Again, the only two words in the top line separated by the word <u>or</u> are <u>size</u> and <u>magnitude</u>. Therefore the word <u>or</u> between the two blanks is the cue which gives away the answer, and the programmer cannot count on the student to be affected by the remainder of the context.

C. The planets orbit around the sun. The earth is a planet. Therefore the earth orbits around the _________.

The student is cued by the words "orbit around the" and therefore does not need to read anything else in the frame. Some remedies might be:

The planets orbit around the sun. The earth is a planet. Therefore the earth ____________________________.

The planets orbit around the sun. The earth is a planet. What can we therefore say about the earth's movement in relation to the sun?

<u>Sequential Prompts</u>

From a programmer's point of view, these are among the most insidious. They are difficult to detect because their effects extend across several frames, and because examination of any single frame does not reveal them.

A. The most obvious type of sequential prompt is a series of frames requiring the same response. The following sequence is an example:

1. A collection of dishes is called a set of dishes. Six cups might be called a _________ of cups.
2. Several pieces of clothing might be called a _________ of clothes.
3. A pack of cards can also be called a deck or a _________ of cards.
4. Things do not even have to be of the same kind to be called a set. <u>Any</u> collection of things may be called a _________.

The first two frames are good, but in the case of the third and fourth frames, the cue for the answer "set" is already no longer the frame itself. The actual cue is likely to be the answer just given in the previous frame. The student begins to behave in accordance with the attitude, "The answer seems to be 'set' every time." While this may lead the student to the right answer, it teaches him little about the meaning of the word "set"; it does not teach him to use the word in the appropriate intraverbal context.

Suppose this particular defect were eliminated by rewriting the program as follows:

1. A collection of dishes is called a set of dishes. A collection of six cups might be called a ________ of cups.

2. Several pieces of clothing might be called a ________ of clothes.

3. A pack of ________ could also be called a deck or a set of cards.

4. Things do not even have to be of the same kind to be called a set. <u>Any</u> collection of things may be called a ________.

Here the continuity is broken. In the third frame the answer is not "set" but something else, and the student does not learn to write the word "set" automatically in frame after frame.

B. But this still does not eliminate all the sequential prompts in these four frames. What three words precede the word "set" wherever it appears? The words are "be called". This type of prompt is exceedingly difficult for the programmer to catch. To avoid it consistently, a programmer needs long experience and a sharp eye.

C. A particularly dramatic example of this type of sequential prompt appeared in a program on optics. In the section of the program where the student learned to discriminate between reflection and refraction, there was a long series of frames in which the answer to be filled in was either "reflection" or "refraction". Typical frames were:

You see yourself in the mirror because light is __________ from its surface.

When you stand in shallow water, your foot appears foreshortened because the light rays are __________ in passing through the water-air boundary.

Taken by themselves, these frames are good. But in the block of frames in which this discrimination was taught, every blank which required "reflection" as the answer way followed by the word "from" or "by", while every blank which required "refraction" as the answer was followed either immediately or several words later by the word "through". A student could go through that section without making any errors, and without learning anything more than putting in the word "reflection" when the blank is followed by "from" or "by", and the word "refraction" in all other cases, especially if the word "through" appears in the same sentence. Clearly, this was not the only discrimination the programmer intended to teach.

D.

		Vercingetorix, king of the Gauls, was conquered by Julius Caes____.
	Caes ar	Vercingetorix, king of the Gauls was __________ by Julius Caesar.
	conquered	Vercingetorix, king of the Gauls was __________ by Julius __________.
	conquered; Caesar	Vercingetorix, king of the __________ was __________ by __________ __________.
	Gauls; conquered; Julius Caesar	

etc.

The student learns to recite the sentence mechanically. He will quickly learn it by heart. But if he should have the misfortune to be asked "What was the outcome of Caesar's campaign against the Gauls?", he would probably answer that he does not know.

The student should be taught the historic fact by learning to say it in each of several ways.

	Vercingetorix, king of the Gauls, was conquered by Julius Caesar. This marked the capitulation of _________ to the Romans. (which nation)
Gaul	What was Vercingetorix in relation to the Gauls?
king	_________ _________ led the Roman army against Vercingetorix.
Julius Caesar	Julius Caesar finally defeated _________, king of the Gauls.
Vercingetorix	The Gauls were conquered by _________ _________.
Julius Caesar	What was the outcome of Caesar's campaign against the Gauls?
Vercingetorix, king of the Gauls was defeated.	
	etc.

Syntactic Prompts

In the example presented below, the prompt is neither of the formal nor of the sequential variety. It derives from the logical equivalence of certain types of statements.

Example 1. Myocardial infarction is caused by occlusion of a coronary blood vessel. How is myocardial infarction caused?

The student has merely to recognize the logical equivalence of "X is caused by ______" and "How is X caused?" Both statements require the same answer. To arrive at it, the student can regard X as an arbitrary symbol (he can ignore its formal or semantic connotations), and only needs to copy the relevant words, in the present case "occlusion of a coronary blood vessel". A better way to write the frame would be:

> Myocardial infarction is caused by occlusion of a coronary blood vessel. What might be the result of a blood clot blocking the coronary artery?

Here the student must consider whether a blood clot blocking the coronary artery is an instance of occlusion of a coronary blood vessel.

Example 2. A set is a collection of elements. What is a set?

This frame can be formulated as "X is Y. What is X?" The student, knowing from his experience with the English language that "X is ______" and "What is X?" are satisfied by the same answer, simply copies Y, without enriching his concept of either X or Y.

The following ways of writing that frame would be preferable:

a. A set is a collection of elements. In a set of dishes, an individual dish would be a(n) __________ of that set of dishes.

b. A set is a collection of elements. So a collection of dice could also be called a(n) __________ of dice, and a die would be a(n) __________ of that collection.

c. A set is a collection of elements. So all the elements of a collection, taken together, make up a __________.

d. Red, green, blue, and yellow crayons make up a set of crayons. Cups, saucers, and plates make up a set of dishes. A set of tools might consist of a hammer, screwdriver, and drill. A brush and paints could be called a __________.

These forms are all preferable because they focus the student's attention upon the relation between the set and its elements. Example (d) is especially good because the specific examples precede the statement of the general case, and because the relationship between the set and its elements is stated in several ways: "elements make up the set", "set consists of elements", and "elements could be called the set".

Example 3. There are five continents. How many continents are there?

The student knows that "There are ________ X's" and "How many X's are there?" have the same answer, which can simply be copied without regard to the actual quantity involved. A better form would be:

> The earth's continents are Africa, Asia, America, Europe, and Australia. How many continents are there?

The only way the student now has of arriving at the answer is to count the continents. This not only makes for better retention of the number 5, but also makes the student more aware of what kind of thing he is enumerating.

Example 4. A line is defined by its slope and y-intercept. How is a line defined?

One possible remedy is:

> In order to be able to draw the graph of the line $y = mx + b$, you have to know m and b . m is the slope of the line and b is its y-intercept. So a line is defined by ________________________.

When the frame is written in this manner, the student must realize that the information that "defines the line" is the same as "what you have to know to be able to draw the graph of the line". Therefore, the frame forces him to think about what the word "defines" means. Then he has to extract the fact that the slope and the y-intercept, which are represented by $\underline{m}$ and $\underline{b}$, constitute the defining information.

Example 5. The hydrogen atom has $\underset{\text{(how many)}}{\underline{\hspace{3em}}}$ electron.

Most students are rigid-enough grammarians to choose "one" as their answer. It might be tempting to eliminate this syntactic prompt by changing the frame to:

> The hydrogen atom has ________ electron(s).
> (how many)

By putting in the parenthesized 's', the programmer says to the student, in effect, "I will not tell you whether it is 'one' or a number greater than one". The student asks himself "Why did the programmer go through so much trouble to leave 'one' as a possible alternative? If the answer were some number greater than one, he would not have bothered, and would simply have left 'electrons' plural. So the answer is probably 'one' ". In such a case, a simple way out for the programmer is write the frame in the form of a question:

> How many electrons does the hydrogen atom have?

Example 6.

> Mushrooms are sometimes poisonous. Berries are also sometimes ________.

The word "sometimes" is a formal prompt. On top of that, it is preceded by the word "also" the second time it appears. This adds a syntactic prompt to what is already a formal prompt. The student automatically copies the previous successor of "sometimes" without necessarily reading the rest of the sentence. Better would be:

> Mushrooms are sometimes poisonous. Berries are also sometimes poisonous. How does this make mushrooms and berries similar?

> or

> Mushrooms are sometimes poisonous. Berries are also sometimes poisonous. In other words, both ________ and ________ are sometimes ________.

Example 7.

> The range of the visible spectrum extends from 4500 uu to 7500 mu. What is the range of the visible spectrum?

Once the student has realized that "the range extends from" means the same thing as "the range is", his problem is solved. The programmer's intention, on the other hand, was to get the student to respond to the actual values, and to the fact that they delimit the visible portion of the light spectrum. A good solution would be:

> The range of the visible spectrum extends from 4500 mu to 7500 mu. What is the range of the invisible spectrum?

Logically, the question is the same, since the invisible range is the complement of the visible range. But psychologically, it is quite different. In the second version the student's attention is focused on the intended stimuli.

AMBIGUOUS FRAMES

Earlier, it was pointed out that the frame:

> The planets orbit around the sun. The earth is a planet. Therefore the earth orbits around the
>
> ________.

could be corrected by changing it to

> The planets orbit around the sun. The earth is a planet. Therefore the earth ______________.

This method involves increasing the number of words left blank and thereby eliminating the words that provided the prompt. Now suppose we tried to apply this method to the other example used earlier:

> Fungi live on the dead cells of the skin, hair and nails. Therefore the ________, ________, and ________ are the infected areas in cases of superficial mycoses.

and changed this to

> Fungi live on the dead cells of the skin, hair, and nails. Therefore the ____________________ are the infected areas in cases of superficial mycoses.

Though the formal prompt has been eliminated, a new difficulty has been created in its place. The frame is now somewhat ambiguous. Among the possible answers are "dead cells", "dead body areas", "outer portions of the body", and even "keratinized cells". Therefore a different type of solution must be found.

The ambiguity created by multiple blanks is often not apparent to the programmer, who has a certain "set" (since he presumably knows the answer), but which will cause the student unnecessary conflict. Extreme examples of this error would be frames like:

a. The _________ is the _________ of the _________, the _________, and the _________.

b. The _________ are _________ if and only if _________ and _________, and sometimes if _________.

Clearly, there are many possible ways of completing these frames, though it may have seemed to the programmer at the time of writing that there exists only one. In general, it is safest to avoid multiple blanks. When they are used, the frame should be carefully scrutinized for possible ambiguity.

A second trouble which multiple blanks can occasion is that they may pose a riddle to the student. There may only be a single correct way to complete the statement. Yet it may take a great deal of thought and effort to figure out what it is. Thought and effort expended in this way does not advance the student's knowledge of the subject. It only irritates him, and wastes his time. Though the programmer must always be careful not to give away the answer by inadvertent prompts, he should never hesitate to give away the question by any means whatever.

The conclusion, then, is that prompts cannot always be cured by leaving blank the words that did the prompting, because of the ambiguities that may ensue.

Suppose an inexperienced programmer tries to eliminate the prompt in this way and discovers that his frame is now ambiguous. He started with the frame:

> Digested food is absorbed into the bloodstream. The small intestine is the portion of our digestive system where most of our food is _________.

The intent of the frame is to teach the expression "food is absorbed". The words "food is" constitute a formal prompt, however. So the programmer tries:

> Digested food is absorbed into the bloodstream. The small intestine is the portion of our digestive system where most of our _________ _________ _________.

But now he realizes that "food is digested", "digestion takes place", "bellyaches are localized", and "bile is secreted" are all possible answers. So, to eliminate these alternatives, he resorts to the following expedient:

> Digested food is absorbed into the bloodstream. The small intestine is the portion of our digestive system where most of our f________ i__ a________.

This device is rarely effective. First of all, there is now a new prompt. ("Which three words that I just read begin with f, i, and a respectively?") Even if the prompt is not an easy one to utilize, the student is challenged by a time consuming riddle. A more direct solution to the programmer's problem would be:

> Digested food is absorbed into the bloodstream. Another way of saying "most of our food passes into the bloodstream through the small intestine" is "most of our food ____________________ through the small intestine".