STRUCTURAL PROGRAMMING IN EDUCATION

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1 PROGRAMMED INSTRUCTION FOR UNDERSTANDING

It is generally assumed that programmed instruction as administered by automated teaching machines can operate only as a conditioning action on the learner. The researches outlined in this paper indicate that there should be ways of utilizing programming techniques and electronically controlled teaching machines to enable the student to learn in a non-conditioned and reflective way, comparable in many respects to the learning processes in a face-to-face tutorial situation. The advent of such "higher level" automatically controlled teaching methods has wide implications for the future organization of the educational process.

In programmed learning, prepared material is given to the student who then studies the material at his own pace. The material is so organized as to help the student to learn efficiently and get help in seeing his mistakes. The writing of such programmes is a complex and time-consuming task. Depending to some extent on the particular programming method adopted, the factors which have to be taken into account in constructing a programme are:

(1) a defined learning task.

(2) a specific student population.

(3) an organization of material to be learned.

(4) an information presentation means.

(5) a form of challenge demanding a response in order to proceed further, (e.g. a question).

(6) a form of response registration, permitting the learner to continue.

(7) a feed back technique for diagnosing errors from response registration.

(8) types of help or remedial presentation depending on the type of error.

(9) some form of reinforcement or "follow up" encouragement.

Of particular importance in considering any form of programming is the inter-relation of (5) and (6) above. In the interval between that stimulus which provides challenge and the recorded response to the challenge, the mental exercise of the student is elicited. We shall term this the challenge-response interval (or C-R interval). The C-R interval is a concept which enables us to assess the quality and level of perception, cognition, and mental operation, which constitutes the act of learning.

Programmed writing, as generally available to date, consists in reducing the organization of the subject-matter to small logical steps which require a minimum stimulus-response interval with a maximum probability of success. In linear programming* (for example, the method due to Skinner based on the theory of Operant Conditioning) the steps trace a lengthy univalent pathway over the subject-matter. The response demand in the C-R interval of a linear programme usually requires the recollection of some appropriate word or phrase to which the learner has already been exposed earlier in the programme. Since success is regarded as a reinforcement to conditioned learning, the programme must be written so that the error rate is less than 5 per cent, for the intended student population.

• Richmond. W. K. *Teachers and Machines*, Collins, 1965. pp. 40-47

In branched programming, ** (for example, the method due to Crowder based on practical instructional patterns in the U.S. Air Force) the steps may be longer and a multivalent pathway is traced over the subject-matter depending on how the steps are mastered. The response demand in the C-R interval of a branching programme may be selection from yes/no alternatives or multiple choice actions (selection of any one from several items). The student can make errors but each wrong selection leads to remedial material which helps put him right. Constant feedback is regarded as more important than reinforcement.

•• Richmond. W. K. loc, cit. pp. 47-54.

Research work is proceeding on the possibilities of using more complex responses which make a greater demand in the C-R interval (for example, scanning, synthesis and judgment). *** Such approaches to programming generally require the presentation of subject-material in larger units in which the recognition of the relative relevance of different aspects of the unit is important. Research into the programming methods associated with the innovation of the Systemaster series of teaching machines falls into this category. A description of some structural approaches to programmed instruction (referred to as S.P.I.) which raises the whole level of learning in the C-R interval as developed by the Institute for Comparative Study follows.

••• For example see Leith, G. O. M. *A Handbook of Programmed Learning*, University of Birmingham

Different learning tasks require different learning situations. Where the learning task requires understanding rather than remembering, insight rather than repetition, the learning situation must involve structuring. By "structuring" we understand a multi-dimensional order that cannot be expressed in terms of a linear sequence. Thus, if a student of history is to understand an historical event, he must see it in several perspectives: economic, political, personal, and the act of learning must accordingly include a structural appreciation of the whole. Such structuring takes place through a mental act rather than through a mental action. A mental action enables the student to assimilate information or operations, but by itself will not lead to understanding. A mental act involves a synthetic step which must include recognition of significance and construction or relatedness. A mental action can be conditioned but a mental act involves a voluntary step forward by the student. Programmed instruction which aims at understanding should require of the learner such acts of recognition and construction not subject to immediate reinforcement. In terms of the function-level psychology outlined elsewhere (see paper 2 in this issue.) it is found that whereas mental actions are possible on the automatic and optimizing on the sensitive level, mental acts always require sensitive contact with the material presented and are fully effective only on the conscious level.

The learning task for the student in this approach is to become able to recognize a complex of interrelated meanings covering a subject field, and to discriminate their differing relevance to different aspects of the subject field.

This must take place in an extended C-R interval without immediate reinforcement. The learning task of being able to remember and recall the material is subordinate though not unimportant. The student populations for which such a primary task is suitable are assumed to be at the secondary and tertiary levels, although there is evidence to suggest it may also be relevant in certain areas of the primary stages of education. *

* 'Much of the problem in leading a child to effective cognitive activity is to free him from the immediate control of environment rewards and punishments. Learning that starts in response to the rewards of parental or teacher approval or to the avoidance of failure can too readily develop into a pattern in which the child is seeking cues as to how to conform to what is expected of him . . . they develop rote abilities and depend on being able to "give back" what is expected rather than make it into something that relates to the rest of their cognitive life. As Maimonides would say, "their learning is not their own".' J. S. Bruner, "The Act of Discovery", pp. 149-150, in *The Revolution in the Schools*, ed. Gross and Murphy. Harcourt, Brace, World Inc. 1964.

Eliciting authentic mental acts is at the heart of the face-to-face tutorial in its most powerful form. By setting the student a challenge and confronting him with the strengths and weaknesses of his responses, the tutor provides a situation in which the student, if capable, develops insight. In the tutorial situation the learning of Information and skills is subordinate to the primary task of learning to understand what is known. In designing the technique of S.P.I we have concentrated on the tutorial type of learning task.

S.P.I is not designed therefore to provide the Student with bad ground information learning; neither is it designed to give practice in techniques. It is designed to prepare the student to make the most effective contribution to the freely conducted face-to-face tutorial. The application of S.P.I, does not substitute self-instruction for teacher-student contact; it unloads the preparative aspects of tutoring from the teacher, enabling the time available for personal contact between the tutor and a group of students to be devoted to discussion and joint exploration of the field of study. S.P.I is a technique of programmed instruction compatible with efficient teacher-pupil relationship, thus providing a non-supervised learning situation intermediate between background learning and learning through personal interchange. Its value is not restricted to this central application, for it can be used both to accelerate background learning and to provide a relatively impartial test of understanding hitherto lacking.

2 THE STRUCTURAL METHOD

We shall consider first the method "A", which is the simplest form of S.P.I. Other, more complex methods "B" and "C" are being developed. Essentially, the method "A" is a system embodying the following components:

(1) A presentation (P frame) designed to call for appreciation of the content of the lesson as a structured whole rather than as a linear sequence of ideas.

(2) The setting of a mental challenge (Q frames) requiring thought about the presentation as a structured whole.

(3) A structured response method (M frame) used by the learner for expressing his response to the challenge.

(4) A tutorial decision logic permitting diagnosis and remedy of misconceptions and incomprehension (R frames).

A presentation frame with accompanying challenges, responses and remedies constitutes a unit referred to technically as a lesson. A series of lessons comprises a larger unit which can cover a coherent topic. We have found ten lessons to be a practical topic unit. The structure of a lesson is now considered in more detail.

The successful construction of S.P.I depends upon the way in which the presented material, questions (challenges), response items and remedial material arc framed. A single lesson must contain a consistent theme comprising at least three or four sub-themes or sub-aspects. The presentation frame is written so as to be of real assistance to the student if he reads it not simply trying to memorize the words but with an effort to grasp the meaning (i.e. paying attention to the semantic rather than the verbal). The question frame presents a challenge which requires a mental act rather than just a mental action. It is presumed the C-R interval may be several minutes. The response items (we are working with twenty per lesson at present) are statements derived from or related to the semantic content of the lesson. These items are formulated in such a way as not to give trivial verbal clues to responses required for a given question. The items are composed so that they do not obviously draw attention to the distinction between the sub-themes which are the concern of each separate challenge. The student records the combination of items that he considers adequately to express his understanding of the question by writing down corresponding numbers from the matrix or operating numbered keys in the case of the machine. Three or four challenges are made per lesson, which require specific responses to be selected from a field that comprises all the response items relevant to the main theme and all the sub-themes of the lesson. A complete pathway through a lesson is shown in Fig 1. A typical student would not find himself involved in all frames. This would depend on the kind of errors he made.

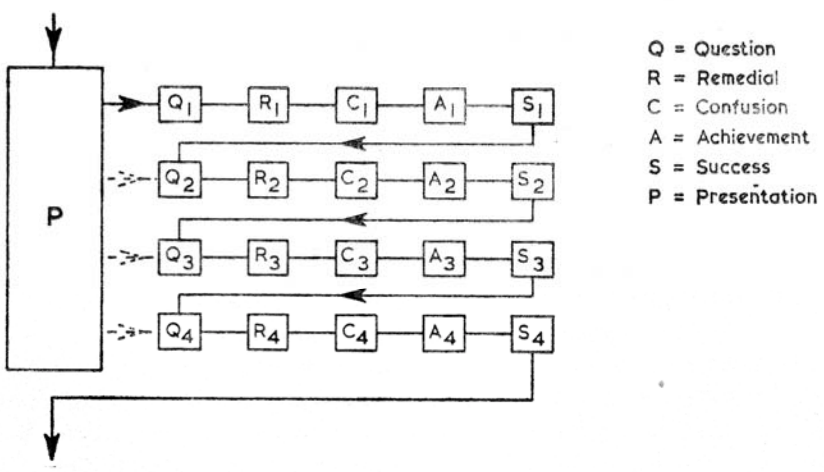

Fig. 1 The Typical Sequence of a Lesson

The diagnosis of the adequacy of the mental act is based on the following "tutorial" control logic: *

* I am indented to R. S. Arbon and C. Bright of the G.E.C. Hirst Research Centre for proposing suitable logical techniques for diagnostic analysis.

(1) If x then R where x = the inclusion of a response Item which indicates a misconception in relation to the challenge

R = remedial frame.

If not x then go on to (2).

(2) If not y then C where y = inclusion of response items which indicate comprehension of the essential point of the challenge.

C = clue frame.

If y then go on to (3).

(3) If not z then A where z = response items which indicated adequate grasp of the subsidiary points of the challenge.

A = achievement hints frame.

If z then go on to (4).

(4) When z then S. Where S = success frame which reinforces achievement.

The decision criterion (3) can be extended so that y and z are given numerical weightings according to importance. The weightings of all y and z terms selected are then summed and compared to a specified threshold (or "pass mark") t. The logic then reads:

(3) If sum < t then A.

If sum > t then S.

This technique offers scope to the programme writer to include teaching methods of induction and deduction, application of principles to specific examples, exemplification of specific principles, learning through discovery, and learning through interpretation. The tutorial control logic enables indirect help to be given to the student when errors are made. It also enables the programming of situations simulating the complexity of real life in which "learning from mistakes" is an inherent feature of the operation of human intelligence.

3 TECHNICAL IMPLEMENTATION OF THE METHOD

The two main forms of technical implementation of the method of structural programming are the book form and the teaching machine form. Neither of these approaches could be employed without extending the existing techniques. Both forms have their advantages and disadvantages, depending on such factors as the particular subject matter, the maturity of the students, whether assessment is being made, and the cost of utilization, Since the book form is essentially a much simplified version of the machine form, the machine form of programming is described here.

A form of presentation adopted is the optical projection of the requisite text. In addition a 20-term matrix of items relevant in meaning to the presentation text is provided for the student, for example, on a back illuminated card. This is termed "semantic identifier" since it identifies the meanings to be ascribed to the response buttons on the machine for a given lesson. This feature distinguishes the "Systemaster" Machine” * decisively from any existing teaching machines.

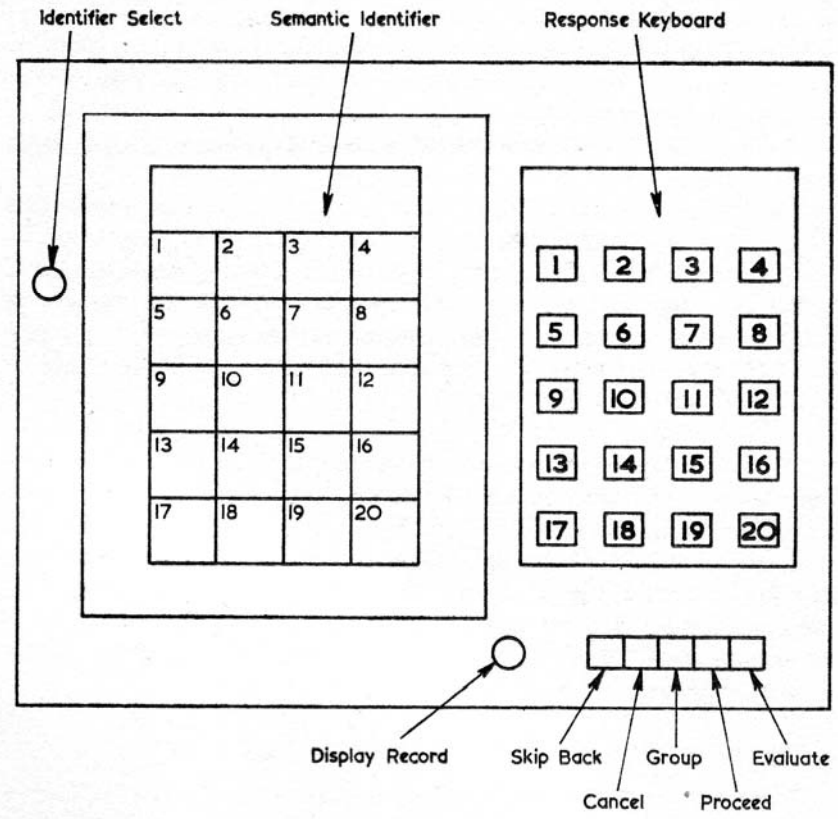

Fig. 2 Response Registration Keyboard

* This machine has been conceived and designed jointly by the Institute for Comparative Study and the Hirst Research Centre of the G.E.C. Ltd. of England. The Hirst Research Centre have also been instrumental in providing a logical system for structural programming. Patents for the "Systemaster" series of teaching machines have been applied for.

The response demand is in the form of a quest ion which requires the student after thinking out his answer to select some sub-set of n Items from the total set of 20 items. This leaves a complementary sub-set of (20-n) items considered irrelevant to the question. The Student is required therefore to compose a combinatorial response which indicates he has (a) recognized the total set of meanings in the 20 items and (b) is therefore able to distinguish that nexus of meanings which is relevant to the question posed.

The form of response registration is on a keyboard of 20 buttons (see Fig. 2) and the response is processed by the pressing of a further button labelled "proceed". This form of response registration enables (In-following diagnostic technique to be applied. The student's response is interrogated in the following manner, the detailed control data for each question being specified by the programme writer.

(a) Out of the relevant sub-set of 20-n, x (where x < 20-n) of items are designated as incompatible with grasp of the question. These are referred to as "forbidden" items. If the student selects any of these he is given a remedial presentation R which provides hints to help him on his next attempt at the question.

(b) Out of the relevant sub-set n some number y (where $y < n$) are designated as central to the point of the question and referred to as "essential" items. If the student omits to select any of these he is led to a presentation C which gives hints for the student's next attempt at the question.

(c) Each item in the sub-set n is given a weighting which describes its degree of relevance to the question. All numbers of the set 20-n except those which are x items are ascribed weightings. At this point the weightings of all items selected (including y items) are added and the value compared to a threshold specified by the writer. If the student fails to achieve this threshold (by under-selecting, over-selecting or erroneous selecting) he is led to a presentation A which gives hints to improve his achievement level at the next attempt. If the student equals or passes the threshold he is led to the next question on the original presentation and the process is repeated.

The logic of this diagnostic and remedial treatment may be summarised as follows:

(a) If x of 20-n selected then R.

If not then to (b).

(b) If y of n omitted then C.

If not then to (c).

(c) If sum of weightings of selected items < T then A.

If ., ., ... … .. > T then proceed

After each successfully answered question a further presentation S may be made which emphasizes the main points and elaborates any of these points sufficiently interesting to motivate the student.

The above procedure, described in abstract terms, may become clear through an example. This sample lesson is in an aspect in geomorphology. The sample (which commences on the following page) shows how the material would be handled if presented in a Systemaster Type A machine. The lesson presumes the student has some elementary knowledge of how weathering affects land forms and has made some observations in the field.

The power of this technique of programmed learning cannot be fully exemplified in an isolated sample lesson which is at the same time sufficiently simple to enable a reader unfamiliar with programmed instruction to get a tangible impression of how the structural method can treat a subject. More advanced examples of the technique will be available at a later date. (At this point the reader is recommended to study the lesson before reading further.)

Let us consider question one. The challenge made by this question is to scan the meaning of the twenty items of information, to consider in the light of the system of weathering action which combination is relevant to the question situation, and to indicate these items on the keyboard.

Let us assume that the student's first combination is (3/5/10/12/13). The diagnosis from the control data is as follows:

(a) As 5 then R.

It is presumed that the inclusion of "large masses of fast flowing water" indicates that the student has not reflected upon the question situation and has assumed the valley was a river valley. The remedial material R gives him hints accordingly.

Alternatively let us suppose the student selected the numbers (3/6/10/12/13). The diagnosis is:

(a) If not 5 then to (b).

(b) As not 9 then C.

It is assumed that in omitting to select "abrasion of solid upon solid" the student has missed the essential erosive process of the grinding and scratching action of a glacier. The additional C material gives him hints accordingly.

Alternatively let us suppose the student selected the numbers (4/6/9/10/11). The diagnosis is:

(a) If not 5 then to (b).

(b) If 6 and 9 then to (c).

(c) As sum of 0+.3+ 3+ 2-1 =7 is less than 8 then A.

It is assumed that in omitting "average high precipitation" and including "sudden heavy rain" the student is confused about the source of glacier ice. The additional A material gives him help accordingly.

Let us assume the student revises his answer to (4/6/9/10); he has the threshold of 8. In this case he is "let through" since the specification is that students are expected to get essential points without too much additional confusion. If the specification were that all students get everything clear, the threshold would be raised to 10. In this case the number of permitted attempts may be raised to 5 or 6.

4 FURTHER DEVELOPMENTS OF THE METHOD

More advanced forms of structural programming are utilized in methods "B" and "C". Detailed consideration of these is beyond the scope of this paper, but some key points are summarized below.

Method "B" will include all the operations of method "A" but in addition facilitates the asking of much more complex questions involving sequence, the analysing of these more complex responses, their logical diagnosis and the provision of feedback frames to assist learning. The response demand in method "B" requires not only that a relevant combination of response items is selected, it also requires that they be selected in some correct order corresponding, for instance, to the order of mental or physical operations required to solve a problem set by the question. Alternatively a sequence of groups of items may be required.

For example, in a biology lesson on mitosis or cell division, a P frame might contain an account (including visual material) of the reproductive activity which made clear the sequence of events that leads up to the formation of two daughter cells. Each main step in this sequence of events is termed by biologists prophase, metaphase, anaphase, telophase and interphase. Within each phase a number of changes take place to major constituents of the cell (e.g. the chromosomes) which enable the phase reached to be recognized. A response matrix corresponding to such a P frame might include the following items:

1. nucleolus visible
2. chromosomes appear as distinct double thread-like bodies held together by a single centromere
3. spindle develops between chromosomes
4. separation of daughter cells is complete
5. the mitotic cycle is completed
6. daughter centromeres move apart taking daughter chromosomes with them
7. centromeres orient on equator of spindle
8. nuclear membrane disintegrates
9. chromosomes condensing
10. new nuclear membrane forms
11. cell divides into two daughter cells
12. centrosome divides
13. centrosomes still undivided
14. chromosomes uncoiled and appearing as scattered chromatin
15. chromosomes elongate
16. cell begins to divide
17. nuclear membrane gone
18. chromosomes short
19. centromeres divide
20. sister centrosomes continue their separation toward opposite poles of the spindle.

These items each describe some sub-event in mitosis but are not arranged in any particular order. A series of Q frames related to the P and M frames might be as follows:

Question One: What is the sequence of events which describe the processes of change taking place in the chromosomes during mitosis?

Question Two: What is the sequence of events which describe the processes of change taking place in the centrosome during mitosis?

Question Three: What is the sequence of events which describe the processes of change taking place in the centromere during mitosis?

Question Four: You have now studied in detail some subsidiary processes in mitosis. Consider each of the main phases in turn and include any processes you consider relevant to that phase. Take each phase in the order of time sequence that it appears.

The "model" answers to such questions would be supplied by selection of the following items, where a sequence of brackets indicates order taken into account.

Question One: (14) (2) (9) (18) (15)

Question Two: (12) (3)

Question Three: (2) (7) (19) (6)

Question Four: (1/5/14) (2/3/8/9/12) (7/13/17/18) (6/16/19/20) (4/10/11/15)

Student responses to this kind of programme can also be diagnosed and remedied by suitable additional material in different types of remedial frames. These frames deal with (a) the accuracy of correct groups present in the answer (X frames); (b) the absence or presence of essential groups (Y frames); (c) the degree of correct order in the sequence of correct groups present (Z frames). The logical system required to control this procedure is much more complex than the "A" method and requires pretty complex electronics or the use of a digital computer to control it properly.

The method "C" is a much more advanced programmed method designed to simulate at high intensity open-ended challenges in problem-solving. The primary response demand is for the production of a short "essay" type statement requiring a great deal of careful thought in answer to a challenge such as a design problem, a conceptual problem in science, a management decision problem or a critical problem in history or literature. The method is best described in conjunction with the equipment it will require in order to implement it. A machine "C" will, in fact, be a complex configuration of interrelated equipment. The following units might be present:

UNIT 1: —A response keyboard equivalent to a typewriter keyboard with associated presentation means to permit a freely constructed response equivalent to a very short "essay".

UNIT 2:—A machine with capabilities equivalent to the "B" machine.

UNIT 3:—A presentation means for question and model answer display.

UNIT 4:—A random access information retrieval system.

UNIT 5:—A self-assessment keyboard.

The student is involved in his programmed environment as follows. On commencing the student is presented a complex problem on Unit 3 which he studies at length and devises a possible solution. On reaching a blockage he considers to be due to lack of information, he turns to Unit 4 and tries to elicit this information. Unit 4 is in fact programmed to contain a great deal of relevant background information for the problem being presented. On reaching a blockage which he considers to be due to lack of understanding of some concept involved he turns to Unit 2 and selects a suitable lesson sequence to assist him to develop this particular understanding. Unit 2 is programmed to contain lessons on all key concepts relevant to the problems presented. On reaching a formulated solution which he considers adequate he enters it into Unit 1. After doing this he can activate Unit 3 again and proceed to study a series of critical questions which assist him to criticize and adjust or even rethink his solution if he so wishes. When this stage is complete, the student commits himself to assessment of his solution. Unit 3 then displays one or more model solutions supplied by the programmer. The student compares his own with these and enters on Unit 5 his own assessment of his solution. This may include the assessment that his solution is better than any of the proffered model answers. The following sets of

information may be recorded (a) his solution; (b) his performance on Unit 2; (c) the data frames he used on Unit 4; and (d) his self-assessment on Unit 5. This information may also be statistically processed and made available for checking by tutors.

The above description of programming method "C" is indicative only since this type is very much in the innovative-research stage and may take several possible modified forms. It is only likely to be effective when tied up to a digital computer system.

Preliminary research studies in programme writing for S.P.I indicate its suitability for teaching scientific and technological subjects, and show promise for its suitability in history, philosophy and certain aspects of literature. Its use in language teaching remains unexplored. Preliminary studies also indicate its suitability for industrial and management training and in staff selection procedures.

The techniques of S.P.I could be adopted, with minor modifications in live teaching procedures with individuals or groups. In the latter case, each student would have a response unit which, for instance, enables statistical response information to be conveyed to a lecturer. The technique has also been adapted for use as a text book for self-teaching. More rigorous monitoring of the technique, with distinct advantages, is achieved when operated by means of a teaching machine. A suitable machine, containing a miniature control computer with integrated circuits, was designed in parallel with research on the programming. This has led to the "Systemaster" series of teaching machines now under development by the G.E.C. (see Paper 4 in this issue). Further, this machine can be adapted to form a new type of peripheral device to a computer using S.P.I, method as part of a computer aided instruction (C.A.I.) system. When used as part of a C.A.I, system, the technique will enable a number of parameters to be measured and will facilitate adaptive feedback control of some variables. This enables automatic assessment of performance, recording of learning strategy, flexibility over varying student populations, and a wide variety of statistical computations on performance characteristics of students. (See Fig. 3.)

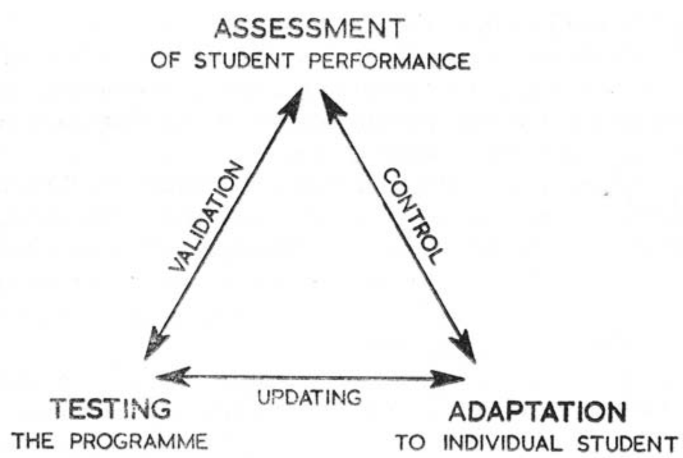

Fig. 3. Self-Optimising C.A.I. System

S.P.I is proving to be quicker and more economic to write than linear and branching programmed instruction. A course of ten lessons lasting one hour each requires between 100 and 150 hours by S.P.I, as compared to between 400 and 800 hours for other programming methods. The cost is estimated to be about one quarter of other methods. Savings in book and film production costs are also made.

The programmes should also lend themselves to accurate validation, especially if tried out in conjunction with a computer programmed to analyse responses for inadequate writing. The structure of the lessons and frames will permit easy revision and updating without costly re-writing of computer programmes.

A further advantage of S.P.I, is that it is possible to record and study the types of mistakes made by the student, and also the approach or strategy employed, the time taken and so on. Thus much more information on a student's capabilities is obtained than in, for instance, linear programmed instruction.

SAMPLE LESSON

LESSON X P FRAME

The Weathering of Land Forms

This lesson assumes you have already made observational and pictorial studies of different types of landscapes, and also that you have studied the simple physics of the way climatic agents, such as water, are able to change physical forms.

We can think of a system of weathering action which leads to a specific change in a given landscape. This change will depend on the mutual interplay of the overall pattern of the land and climate, the specific motive agents (such as wind, water, gravity, etc.), the particular erosive processes possible (such as abrasion, chemical breakdown, transportation) and the nature of the substrate of the land. In examining any particular case you should consider how this general system of action is specially operative in that case. Some important motive agents and erosive processes to bear in mind are now summarized.

Land forms originate primarily from the earth's crust. Rock is eroded to waste-mantle (shale, sand, etc.) by various actions.

The main agent for removal of the products of erosion is the gravitational effect. This is aided by water transport so that steepness of fall of land and heaviness of rainfall are important. Wind can also transport eroded material provided the particles are small enough and dry enough. When air or water flow they can transport material, but when the flow is slowed the material tends to be dropped and thus forms a sediment (as, for instance, at the mouth of a river). Such action can build up lowlands and even out landscapes. Vegetation aids the build-up of soil and protects against water and wind erosion. In dry areas or areas which are mainly dry and prone to sudden heavy downpours of rain, vegetation is sparse and erosion and transportation are more pronounced.

The sea is a special form of water action greatly changing coastal landscape. It can both remove large areas of coastline and also deposit sediment to reform coastline. In this case wave action is as important as gravitational action.

An underlying factor in the variety of land forms is the differences in the hardness of rocks and the varying mobility of waste-mantle and soil. Soft rocks under hard rocks may lead to overhanging forms (under-cutting). Soft sedimentary land may lead to rapidly changing river courses. Variations in coherence of waste-mantle may lead to different shaped valleys.

Reconsider these summaries in the light of the system of weathering action (overall pattern, motive agents, erosive processes and substrate type) which modifies land forms.

1. Strong dry wind	2. Sparse vegetation	3. Average high precipitation	4. Shattering of rock by frost or ice
5. Large masses of fast flowing water	6. Movement of ice masses	7. Average low precipitation	8. Water wave action
9. Abrasion of solid upon solid	10. Steep average slope of land	11. Sudden heavy rain	12. Deposition of particles
13. Rapid removal of material	14. Undercutting of soft rock	15. Abundant vegetation	16. Shattering of rock by extreme heat changes
17. Gentle average slope of ground	18. Abrasion of liquid upon solid	19. Slow flowing water	20. Loose particles moveable by flow

LESSON X **Q FRAME**

QUESTION ONE.

A mountain valley has a cross-section which is U-shaped. This valley has no bends of small radius and a wide flat floor along which flows a slightly meandering river. Any spurs evident high up the valley walls are truncated (cut off). Where spurs are truncated small tributary valleys are left with a steep drop from their ends to the main valley floor. (Accompanying illustration not included here).

Consider this land form carefully in the light of the system of weathering action, bearing in mind its similarity to any actual valleys you have observed. Which combination of factors appearing on the response matrix is important in the production of such a valley?

LESSON X **Q FRAME**

QUESTION TWO.

A single mound of sand appears immediately on one side of a large boulder on land. The inland region itself is very sandy and, in general, flat and level. The mound of sand is in the form of an elongated dome, (accompanying illustration not shown here).

Which combination of factors appearing on the response matrix is important in the production of such a land formation?

LESSON X **Q FRAME**

QUESTION THREE.

The profile of a cliff adjoining water shows a notch formation both just above and just below the water line. The notch is not more than a few feet deep. The cliff is formed in fairly continuous rock, the notched part being smooth and polished, the upper part being more angular and rough (accompanying illustration not included here).

Which combination of factors appearing on the response matrix is important in the production of such a formation?

LESSON X **Q FRAME**

QUESTION FOUR.

An area of farming country is scoured by deep gullies which expose loose top-soil and have cut into the subsoil. The ploughed land is thus destroyed by the encroaching gullies which are fed from runnels or rills. There are no woods and very little grassland in the area. (Accompanying illustration not included here).

Which combination of factors appearing on the response matrix is important in the production of such a formation?

QUESTION ONE COMMENTS

If you have selected 5, read below.

LESSON X QUESTION 1—R FRAME

You need to reconsider carefully some of the physical features of the valley described in relation to possible weathering actions.

Firstly, you should note that the U-shape implies a broad wearing action rather than a deep cutting action. There is no mention of river gorges. Secondly, the absence of bends of small radius implies an agent not susceptible to sudden directional changes. Thirdly, spurs formed at an earlier stage in the valley formation have been worn back by some new action effective over the whole surface area of the valley.

Reconsider your answer in the light of these additional remarks.

If you have omitted 6 or 9, read below.

LESSON X QUESTION 1—C FRAME

You have not recognized all the essential factors which combine to assist the formation of the valley.

You will appreciate that such a valley requires an eroding action of considerable power and able to act over a long period of time (thousands of years). The natural sculpture of such a valley also implies the removal of great quantities of waste-mantle including quite large boulders. The action of the factors which produce such a valley is also able to produce a wide flat floor to the valley.

Reconsider your answer with this additional information in mind.

If you have omitted 3 or 10, read below.

LESSON X QUESTION 1—A FRAME

You have selected the essential factors which lead to the formation of a U-shaped valley. The large masses of ice which we term glaciers move slowly down the emerging valley and grind away by abrasion the rocks. The glacier also transports the products of abrasion and deposits them in the form of moraines. Spurs which may have been formed by river action at an earlier climatic stage are ground back.

However, you have not yet got clear subsidiary factors which are important. Certain conditions are required to enable glaciers to form and also to enable them to move. Some conditions which appear in your table of factors may be totally irrelevant and others, though applicable to the general conditions of mountain valleys, may not be significant. Revise your answer in the light of these comments.

If you have included 3, 6, 9 and 10, read below.

LESSON X QUESTION 1—S FRAME

You have recognized the main system of factors which lead to the formation of a U-shaped valley.

By the movement of a glacier through a pre-existing river valley any mantle of rock-waste is removed, the interlocking spurs are trimmed off and ground into facets, and the valley floor is worn down. The valley is widened and deepened, and is eventually remodelled into its characteristic U-shaped trough. This trough has a broad floor and steep sides. Bends of small radius are absent since glaciers cannot make sharp turns like rivers can. The valley floor may be very flat where alluvial deposition after the glacier melts has rilled in unevenness.

The system of weathering action summarized is:

Overall pattern—mountains, with steep average slope, high precipitation.

Motive agents—ice.

Erosive processes—abrasion, transportation by ice.

Substrate—rock.

Now go on to question two.

N.B. Instructions in bold type do not occur in the teaching machine programme.

LESSON X **CONTROL DATA**

QUESTION ONE.

No. Permitted Attempts = 4

Total Possible Marks = 10

Threshold Mark = 8

1. −2	2. 0	3. +2	4. 0
5. F	6. N +3	7. −2	8. −1
9. N +3	10. +2	11. −1	12. 0
13. 0	14. −1	15. −2	16. 0
17. −1	18. −1	19. −1	20. −1

N.B. This information is stored in digital form in the teaching machine.

QUESTION TWO COMMENTS

If you have included 5,15 or 19, read below.

LESSON X **QUESTION 2—R FRAME**

You need to reconsider carefully some of the physical features of the rock and sand formation described.

The land surface is not coastal (it is described as inland) and it is generally flat. This suggests the water action is an unlikely agent since to produce a "shadow" effect the water would have to be flowing. This, in turn, would require some slope and probably channelling. Since the shadow is sand, the presence of abundant vegetation is unlikely since this would not permit the appearance of sand. Vegetation would also require plenty of moisture.

Reconsider your answer in the light of these additional remarks.

If you have omitted 1,7,12 or 20, read below.

LESSON X **QUESTION 2—C FRAME**

You have not recognized all the essential features which combine to assist the formation of this landform.

Sand is essentially a bulk of small loose particles which can thus be caught up in a flow process by gas or liquid and moved almost at the speed at which that fluid can itself move. Since water has been eliminated as a transportation means, and gravity is eliminated by the flatness of the land, the other obvious mechanism is air. The flow must also be slowed down in order to bring about the deposition on what is the lee side of the boulder. Rain is likely to be inhibitive to this process since it tends to congeal the sand particles.

Reconsider your answer in the light of these comments.

If you have omitted 2 or 16, read below.

LESSON X **QUESTION 2—A FRAME**

You have selected the essential factors which lead to the formation of a "sand shadow" behind a boulder. In dry, desert-like regions, hot dry wind blows the sand particles along. On meeting obstructions such as the boulder, the air flow is slowed on the lee side of the boulder and the sand falls out, forming a pile.

However, you have not yet clarified subsidiary factors which supplement or are associated with this process. It is clear that, although not necessarily devoid of it, dry sandy regions have little vegetation. The extreme heat changes in desert regions are also a secondary factor in breaking down of rock into sand.

Revise your answer in the light of these comments.

If you have selected 1,2,7,12,16 and 20, read below.

LESSON X **QUESTION 2--S FRAME**

You have successfully recognized the system of factors which lead to the formation of a sand shadow alongside a boulder in desert regions. Wind acts as an agent of transportation and hence erosion whenever loose surface materials are unprotected by a covering of vegetation. Sand grains are swept by the wind, travelling in leaps and bounds, until the wind drops or some obstacle is encountered. Behind an obstacle arrested air and eddy currents permit the gravitational effect to dominate and sand falls out, forming initially two tongues projecting in the form of a "swallow-tail". Eventually a single mound forms as the tongues thicken up and merge. If carried off down wind, a sand-shadow disperses, thus being distinguished from a drift.

The system of weathering action summarized is:

Overall pattern—flat very dry terrain, low precipitation.

Motive agents—wind.

Erosive Action—transportation and deposition by obstacle.

Substrate—sand and rock.

Now go on to question three.

LESSON X **CONTROL DATA**

QUESTION TWO.

No. Permitted Attempts = 4

Total Possible Marks = 15

Threshold Mark = 12

1. N +3	2. +2	3. −2	4. −2
5. F	6. −3	7. N +3	8. −2
9. 0	10. −1	11. −2	12. N +3
13. −1	14. −1	15. F	16. +1
17. 0	18. −2	19. F	20. N +3

QUESTION THREE COMMENTS

If you have included 4 or 1, read below

LESSON X **QUESTION 3—R FRAME**

You need to reconsider carefully some of the physical features of the cliff face described in relation to possible weathering actions. The notching of a cliff is a localized action on the cliff face and so is not likely to be the result of a general action such as a shattering process. Such processes tend to cause a cliff to break up relatively evenly and produce a silting up effect at the foot of a cliff by the formation of screes.

Reconsider your answer in the light of these additional remarks.

If you have omitted 8, 14 or 18, read below.

LESSON X **QUESTION 3—C FRAME**

You have not recognized all the essential features which combine to assist the formation of this landform.

The notch is obviously formed by some special action not operating in the middle and upper parts of the cliff. This special action must involve considerable wearing and undercutting which is most likely to be a water action producing a pounding and abrasive effect. The water at the foot of the cliff is likely to be sea water rather than lake water. Revise your answer in the light of these comments.

If you have omitted 5, 9 or 13, read below.

LESSON X **QUESTION 3—A FRAME**

You have selected the essential combination of factors which lead to the formation of an overhanging cliff adjoining water. Wave action on the cliff produces a more rapid erosion in the region around the water level through the wearing away of the rock mainly by abrasion of the liquid medium against the solid. The cliff face is then undercut.

However, you have not yet clarified certain subsidiary factors which are associated with this process. One of these is concerned with the removal of the eroded material, which clearly is transported away very efficiently by the water. Another feature is a further wearing action which is caused by the wave action hurling solid material against the cliff face leading to a solid action erosion.

Revise your answer in the light of these comments.

If you have selected 5,8,9,13,14 and 18, read below

LESSON X **QUESTION 3-S FRAME**

You have successfully recognized the system of factors which lead to the formation of an overhanging cliff on a sea front. The hydraulic action of the water thrown against the rock is able to break down rocks through producing shocks of enormous intensity. Undercutting of cliffs usually confined to near high-water mark. The rocks within the notch are worn smooth and round, also with the help of solid material carried in the waves. When the notch reaches a critical depth overhanging material walls away, thus cutting the cliff profile back into the coast line.

The system of weathering action summarized is:

Overall pattern—coastal region.

Motive agents—sea water wave action.

Erosive action—hammering and abrasion.

Substrate—rock.

Now go on to question four.

LESSON X **CONTROL DATA**

QUESTION THREE.

No. Permitted Attempts = 4

Total Possible Marks = 14

Threshold Mark = 1 0

1. −1	2. −1	3. 0	4. F
5. +2	6. −2	7. 0	8. N +3
9. +1	10. 0	11. −1	12. −1
13. +1	14. N +3	15. −1	16. F
17. −1	18. N +3	19. −2	20. −1

QUESTION FOUR COMMENTS

If you have included 10, 15 or 19, read below.

LESSON X **QUESTION 4—R FRAME**

You need to reconsider some of the features of the gullies described. It is clear that on agricultural land used for crop growing there are times when there are no crops actually on the ploughed land; the top-soil is quite exposed. Even when crops are growing the binding action of the crops on the soil is not equivalent to natural woodland or scrubland. It should also be evident that even if gullies do form with steep sides the average slope of agricultural land suitable for ploughing cannot be steep. The removal of soil in considerable amounts is not possible with only a slow flow of water.

Reconsider your answer in the light of these additional remarks.

If you have omitted 2,5,11 or 20, read below.

LESSON X **QUESTION 4-C FRAME**

You have not recognized all the essential features which combine to assist the formation of this feature.

The removal of material requires that it be in an unbound form. Consider which factors imply that the soil would be susceptible to being washed away. It is also important to remember that to get a water erosion strong enough to form gullies, water must accumulate at a rate which prevents removal of it by percolation. It must also supply enough impetus for transportation.

Revise your answer in the light of these comments.

If you have omitted 3, 13 or 17, read below.

LESSON X **QUESTION 4—A FRAME**

You have selected the essential factors which lead to the formation of an erosion gully in farmland. Since the topsoil is not strongly bound sudden heavy downpours of rain lead to topsoil being carried along until small channels form. These then quickly erode to form gullies.

However, you have not yet clarified subsidiary factors which supplement or are associated with this process. Generally, rainfall will tend to be fairly high in agricultural regions. It is true that in marginal semi-arid areas where farming goes on, this may not be the case, but we can discount this for the given example. This removal only takes place quickly when gullies have formed, since the average slope of the land may not give sufficient run-off.

Revise your answer in the light of these comments.

If you have selected 2, 3, 5, 11, 13, 17 and 20, tread below.

LESSON X **QUESTION 4 S - *FRAME***

You have successfully recognized the system of factors which lead to the formation of erosion gullies on farmland such as is found in California. The run-off of muddy water from sheet-erosion is concentrated into rills as soil is removed. These are dug deeper wider, growing into gullies. Once the gullies have been formed, they extend themselves towards the head and also throw out tributaries. The original gentle slopes are destroyed and a system of stream flow supersedes the sheet flow. The change from very slow to very fast erosive processes is accelerated by a climatic increase in the heaviness and frequency of rain-showers.

The system of weathering action summarized is:

Overall pattern—gently sloping farmland in climate with heavy showers.

Motive agents—large quantities of rain water.

Erosive processes—washing loose and transporting.

Substrate—sandy soil, sparse vegetation.

Now go on to Lesson X + 1.

LESSON X **CONTROL DATA**

QUESTION FOUR.

No. Permitted Attempts = 4

Total Possible Marks = 18

Threshold Mark = 14.

1. −1	2. N +3	3. +2	4. −2
5. N +3	6. −2	7. −1	8. −1
9. −1	10. F	11. N +3	12. 0
13. +2	14. −1	15. F	16. −2
17. +2	18. 0	19. F	20. N +3