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STUDIES ON COMPUTER-ASSISTED INSTRUCTION (II)

A TRIAL PRODUCTION OF CAI SYSTEM

By

Ryuichi HAYASHI*

1. INTRODUCTION AND OVERVIEW

The main purpose of the study reported in this paper is to introduce a new type of computer-assisted instruction (CAI), in many respects more powerful than existing ones. The learning programs which have been used in existing CAI systems are classified roughly into two types. One is the type of linear program (Skinnerian learning program) and another is the type of branching program (Crowder's learning program). Since the former gives all students the identical questions and that in the identical sequence, there is no merit from the viewpoint of the individualized instruction that is the main goal in CAI. On the other hand, in the latter, since all the detailed branching directions have had to be determined in advance by a teacher depending on the anticipated student's responses on the occasion of making a learning program, it takes time and much trouble.

In this paper the type of jumping program taken account of the advantages in both learning programs is proposed. The summary of it is as follows:

1. The learning program is made into the type of linear program.
2. A mathematical model of jumping-decision criterion is constructed in order to let the learning program fulfill the functions of branching.
3. Jumping is allowed to the questions within a frame under the above model only when a student enters into each frame.
4. After jumping, a student must go forward or back question by question within the frame by whether he answered a question correctly or not.

In this type, although it is requested to satisfy the condition that a learning program must be made in order from the easy question to the difficult one, there is no need to determine all the detailed branching directions in advance. Thus this type facilitates the making of learning program in contrast with the type of branching program. Moreover, since the usual type of branching program has determined all branching directions in advance, it dose not always satisfy the essential purpose that branching should be allowed corresponding to student intelligence. The new type makes a student jump the questions by using a mathematical model expressing the relation between

*Laboratory of Mechanical Engineering, Faculty of Education, Shimane University, Matue, Japan.

student intelligence and question difficulty. However a student can jump the questions within a frame only at the entrance of each frame, but not every question. This is due to the reason why it is difficult in practice to construct such the mathematical model as can determine branching directions every student's response.

The learning program letting a student settle the concepts on the Ohm's law was made, and by using it the simultaneous paper test was carried out. In addition, a mathematical model of jumping-decision criterion was constructed under this test results and a CAI system was produced for trial. The mathematical model and the CAI system are described in detail henceforth.

2. A MATHEMATICAL MODEL OF JUMPING-DECISION CRITERION

2. 1. The making of learning program

The simultaneous paper test was attempted to 152 second-grade students (four class-rooms) in the Lower Secondary School affiliated to the Faculty of Education Shimane University (hereafter referred to as the preliminary experiment). It was carried out immediately after they had been over the learning on the Ohm's law through the textbook (Nov. 11, 1971). Therefore the mode of learning program was drill-and-practice.

In the making of learning program, the number of the steps (i. e., questions) within a frame became a serious problem because it was equal to the maximum number of the steps of jumping. Originally the type of linear program has the features that it consists of the small steps and a student will be unable to understand when he abbreviates the steps on the way. For this reason, it is not desirable that the number of the steps within a frame is overmuch. When too few, conversely, there is no merit in the type of jumping program that a intelligent student can go forward quickly by jumping on the way. Here, the number of the steps within a frame was three or four in consideration of the contents of the learning program ; the number of the frames was eight because test time allowed was 45 minutes ; the number of all the questions was 28 ; the response mode was limited to the numerical answers.

2. 2. Student intelligence

In order to construct a mathematical model of jumping-decision criterion, it was necessary, first, to evaluate student intelligence. The IQ score and the past test scores were adopted as the factors of student intelligence. Nevertheless the objective and quantitative methods of evaluation for student intelligence have not been still established due to so many influencing factors, the reason why the IQ score and the past test scores were adopted was that these could be measured briefly and reliably. As for the past test scores, the average value of nine test scores on science before the preliminary experiment was utilized. When the average value was calculated, each test score was transformed into Z-score so that the mean and the standard deviation were 50 and 10, respectively. The average value of nine Z-scores was utilized as a factor of student intelligence. This procedure is the same as that obtained the relative student intelligence among 152 students.

2. 3. Experimental procedures

The preliminary experiment was carried out after four classrooms had been divided into two groups by two classrooms. At that time, by testing the goodness of fit to the normal distributions for the IQ score and the average value of Z-scores, it was confirmed that each distribution was the normal one in both groups. In addition it was detected by t-test and F-test whether or not there were the differences in the means and the variances of two distributions (the IQ score and the average value of Z-scores) between both groups. As the result, on two distributions there were no significant differences in 5% level of significance between both groups. Hence it was able to be considered that each student in two groups was a random sample out of a population.

For one group, all the questions were given in order one by one without jumping and the hint to a question was given after the restricted hours of the question had been over (named L-group). Therefore a student proceeded to the following question under the assumption that he had understood the previous questions completely.

For another group, the questions were given conversely from the difficult one to the easy one within a frame (named J-group). Namely the sequence was such as 1−3, 1−2, 1−1, 2−3, 2−2, 2−1, ... A figure on the left side denotes a frame number and one on the right side a step number. The hint to a frame was given after all the questions within the frame had been attempted.

Table 1. The total rate of correct answer. (the rate of correct answer by 76 students)

Question number	L-group	J-group
1−1	0.67	0.68
1−2	0.57	0.55
1−3	0.57	0.37
2−1	0.83	0.80
2−2	0.55	0.57
2−3	0.57	0.58
3−1	0.42	0.32
3−2	0.34	0.20
3−3	0.29	0.18
4−1	0.67	0.76
4−2	0.47	0.55
4−3	0.50	0.51
4−4	0.42	0.45
5−1	0.72	0.68
5−2	0.71	0.75
5−3	0.70	0.74
5−4	0.57	0.65
6−1	0.62	0.75
6−2	0.53	0.61
6−3	0.41	0.36
6−4	0.34	0.41
7−1	0.71	0.79
7−2	0.75	0.74
7−3	0.34	0.30
7−4	0.30	0.34
8−1	0.74	0.88
8−2	0.38	0.29
8−3	0.28	0.20
8−4	0.16	0.07

2. 4. Preliminary experimental results

The rate of correct answer for each question by all the students in L-group and J-group is presented in Table 1 (hereafter referred to as the total rate of correct answer). Whether or not there was the significant difference in the total rates of correct answer between L-group and J-group was detected by t-test. The result was that there was no significant difference in 5% level of significance. Before the preliminary experiment it had been expected that the total rates of correct answer would be higher in

L-group than in J-group. This result might be caused by the poor making of learning program. That is, if the difference of question difficulty had been a little enlarged, the conditional differences between two groups might have arisen.

By using the paper test score of a student as the external criterion, the IQ score and the average value of Z-scores of the student as the criterion variables, the multiple correlation coefficients were obtained by means of the multiple correlation method. The result obtained was -0.2 for the IQ score and 3.3 for the average value of Z-scores. In consequence, only the average value of Z-scores was taken into consideration as the factor of student intelligence.

Secondly, the author investigated with how much probability a student possessing a certain intelligence can answer a question of a certain difficulty correctly. —This probability is called the probability of correct answer henceforth. Question difficulty and the probability of correct answer were defined as follows :

D ; Question difficulty D equals the total rate of correct answer.

Hence the smaller the value of D is, the more difficult the question is.

P ; The probability of correct answer P equals the relative fraction of the students who answer a question correctly among all the students with the identical intelligence.

This definition seems like roughness, but if the number of the students is numerous, it will approach to the real conditions.

The procedures, by which the mathematical model of P was determined, are described below :

The first assumption was that : Under whatever conditions the experiment is made, a student will have the same P on the questions of the same D.

Based on the above assumption, the questions which could be considered to be the same D were collected into groups out of both L-group and J-group. They were nine grades of D = 0.16～0.20, 0.28～0.32, 0.34～0.37, 0.41～0.45, 0.50～0.53, 0.55～0.57, 0.67～0.70, 0.74～0.76, 0.79～0.83 (see Table 1). Student intelligence also was divided into seven grades every six scores. Under the consideration that D's and student intelligences have a equal value in the identical grade, P was measured at each grade of student intelligence. The measured P's are plotted with the small circles for each grade of D in Fig. 1.

Next it was assumed, referring to Fig. 1, that P was in proportion to student intelligence. Under this assumption, a straight line

$$P = a \cdot I + b \qquad (1)$$

was determined by the least square method for each D. In equation (1), I is student intelligence, a and b are constants. The straight lines obtained are indicated with the solid lines in Fig. 1. The gradient a's and the point of contact b's of them are plotted with the small circles in Figs. 2 and 3, respectively.

Moreover, taking into consideration Figs. 2 and 3, it was assumed that both a and b changed linearly to D. Two straight lines obtained by the least square method were such as equations (2) and (3) :

$$a = 0.031 - 0.024\ D \qquad (2)$$

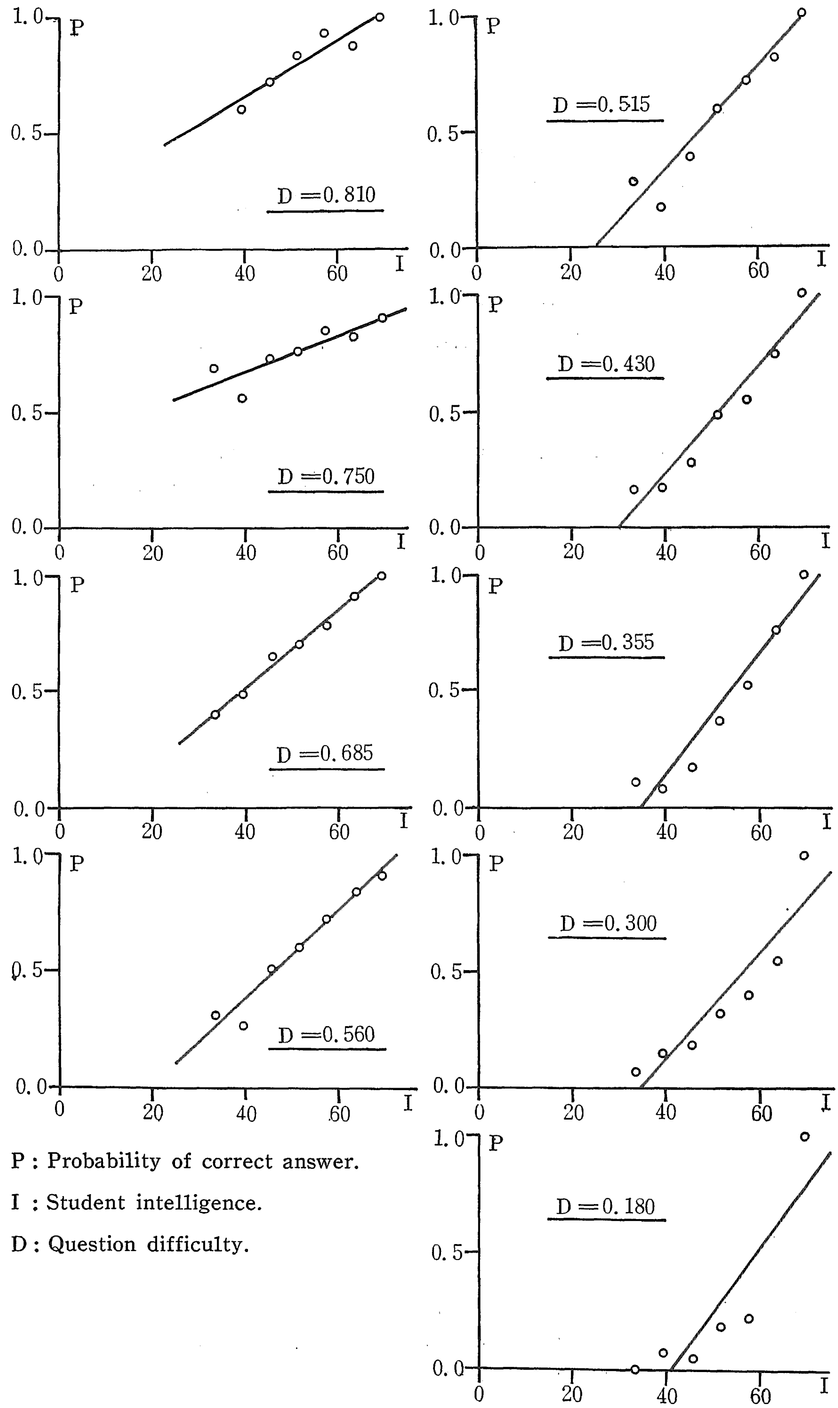

Fig. 1. Relation between the probability of correct answer and student intelligence.
Small circles : measured values.
Solid lines : straight lines by the least square method from the measured values.

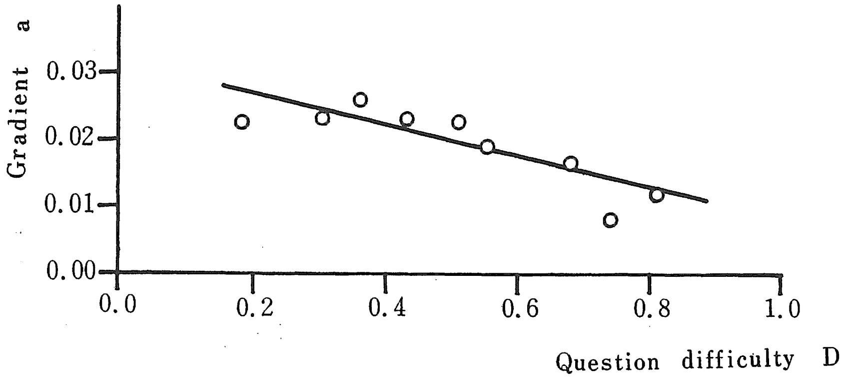

Fig. 2. Relation between gradient and question difficulty.
Small circles : values obtained from the straight lines in Fig. 1.
Solid line : straight line obtained by the least square method.

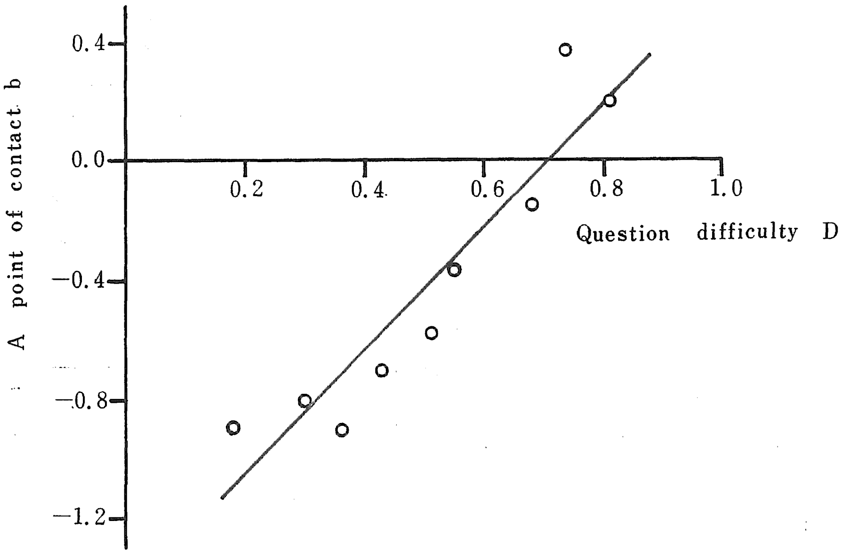

Fig. 3. Relation between a point of contact and question difficulty.
Small circles : values obtained from the straight lines in Fig. 1.
Solid line : straight line obtained by the least square method.

$$b = -1.47 + 2.07\ D \qquad (3)$$

These straight lines are indicated with the solid lines in Figs. 2 and 3.

When question difficulty D and student intelligence I are known, the probability of correct answer P is calculated from equations (2), (3), and (1). The obtained P was used as jumping-decision criterion.

3. A TRIAL PRODUCTION OF CAI SYSTEM

3. 1. Hardware configuration

The hardware configuration on the CAI system produced for trial was as follows:

Central processing unit : FACOM 270-20 (16,000 word-core) at the Shimane University Computer Center.
Input and output device : typewriter keyboard (FACOM WRITER).
Material presentation device : slide projector (KODAK CAROUSEL 800).
Audio presentation device : tape recorder (SONY TC-1150).

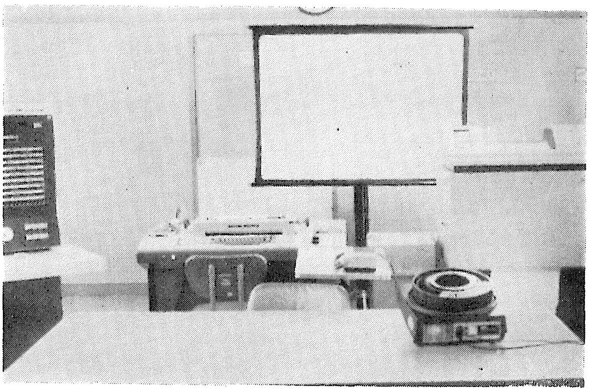

Fig. 4. Hardware configuration on CAI system.

Messages were typed out by the typewriter and a student in turn entered his responses on the keyboard. Because of using FACOM WRITER as the input and output device, this system could instruct only a student at a time. Materials were stored in the slide projector with the rotary magazine which could accommodate 80 slides, and they were made to go forward or back one by one with the manual remote controller. The hints to questions were recorded in the tape recorder controlled by hand. Fig. 4 shows the hardware configuration on this system.

3. 2. Flow of learning

Table 2 is a portion of an example printed out on the typewriter. The dialogue between the computer and a student is explained with Table 2:

First a student, who sits in front of the typewriter keyboard, informs the computer of the aim that he wants to take lessons by pushing a special key. As the result, the computer speaks to him "TYEP IN YOUR NUMBER" such as line 1 through the typewriter. Then he types in his student number through the keyboard, and the com-

Table 2. Illustration of the dialogue between a student and the computer.

line		
1	**TYPE IN YOUR NUMBER	
	15	
	**LET US STUDY	
	**QUESTION NUMBER	1−3
5	10	
	**VERY GOOD	
	**QUESTION NUMBER	2−3
	4	
	**VERY GOOD	
10	**QUESTION NUMBER	3−1
	0.3	
	**VERY GOOD	
	**QUESTION NUMBER	3−2
	4	
15	**MISTAKEN	
	**HINT DIAL 80	
	**QUESTION NUMBER	3−2 ONCE MORE
	5	
	**MISTAKEN	
20	**ASK TO TEACHER	
	** QUESTION NUMBER	3−3
	1.5	
	**VERY GOOD	
	**QUESTION NUMBER	4−4
25	12	

line		
	**MISTAKEN	
	**HINT DIAL 150	
	**QUESTION NUMBER	4−4 ONCE MORE
	4	
30	**VERY GOOD	
	**QUESTION NUMBER	5−3
	**TIME UP	
	**HINT DIAL 180	
	**QUESTION NUMBER	5−3 ONCE MORE
35	6	
	**MISTAKEN	
	**QUESTION NUMBER	5−2
	6	
	**VERY GOOD	
40	**QUESTION NUMBER	5−3
	3	
	**VERY GOOD	
	**QUESTION NUMBER	6−4
	15 **CANCEL ;	AGAIN
45	14	
	**VERY GOOD	
	⋮	
	**THE END	

puter looks for his intelligence. Thus a course of lessons begins. The marks " ** " on the left side represent the messages typed out through the computer.

In the next place, the cumputer calculates P about a question by the mathematical model of jumping-decision criterion described in Chapter 2 (i. e., equations (1), (2), and (3)) and judges whether he can jump the question or not. After determining the jumping direction, the computer types out the question number such as "QUESTION NUMBER 1−3", line 4. Since the student on this example is intelligent, he can jump the question numbers 1−1 and 1 −2. He throws on a screen the slide of the indicated question number with the manual remote controller, and attempts the question. The answer is typed in through the keyboard and subsequently a judgement key is pushed, line 5. So the computer judges whether his answer is correct or not and, if correct, types out "VERY GOOD", line 6. (All of D's, P's, and correct answers have been stored in the memory of computer beforehand.) Since the questions within the frame number 3 are difficult, he must begin with the question of the step number 1 without jumping, line 10.

As mentioned in Chapter 1, jumping is judged only when he enters into a new frame and then the questions within a frame, which remain behind the question given by jumping, are given one by one. Therefore the last step within a frame is bound to be given.

When the first answer of a question is incorrect, the computer types out "MISTAKEN", "HINT DIAL 80", "QUESTION NUMBER 3−2 ONCE MORE", such as lines 15∼17. The numerical value behind HINT DIAL is the dial number of the tape recorder. (The hint to a question has been recorded from the indicated dial number.) Then, he turns the tape up to the indicated dial number by hand, and attempts the same question again after listening to the hint. When the second time's answer also is incorrect and he has already passed through one question before, the computer types out "ASK TO TEACHER", lines 19∼20. On such an occasion, he requires the explanation about the question of a teacher and after explanation, can return to lessons by pushing a return key.

On the other hand, when he fails to answer the question given by jumping correctly twice, he must go back to the one previous question because of having not still passed through it, lines 31∼42.

The message "TIME UP" such as line 32 is typed out when there is nothing typed in for four minutes, and it is the same treatment as an incorrect answer.

The mistaken key operation, if it is before pushing a judgement key, can be corrected by a cancel key, line 44.

3. 3. Experimental results

The CAI system developed in Sections 3.1 and 3.2 was put in operation for eight students (January, 1972). A serious problem then arose : Above how much the probability of correct answer P is a student allowed to jump the question? Thereupon it was decided only with experience to make a student jump the question of which P was above 0.75. Eight students were chosen out of the students who had put the preliminary experiment and the material used was the same as in the preliminary one. Accordingly, they had experienced all the questions once.

Figs. 5 and 6 show two typical examples ($I = 84$ and 50, respectively) of the processes that the students followed. The feedback line in these figures represents the case that the student could not answer a question correctly and did over again.

Some of the pertinent data from the instruction of these students are presented in Table 3.

As it is clear from Figs. 5, 6, and Table 3, a intelligent student could jump and go forward quickly, while a poor one could go forward only question by question.

As shown in Table 3, the frequency of jumpings was 34 in all and of these 27 were the correct answers. Hence the rate of correct answer in jumping was about 0.8. Considering in connection with this value and the fact that a student was allowed to jump the questions on the occasion of P being above 0.75, it may safely be said that the mathematical model described in Chapter 2 was partially appropriate.

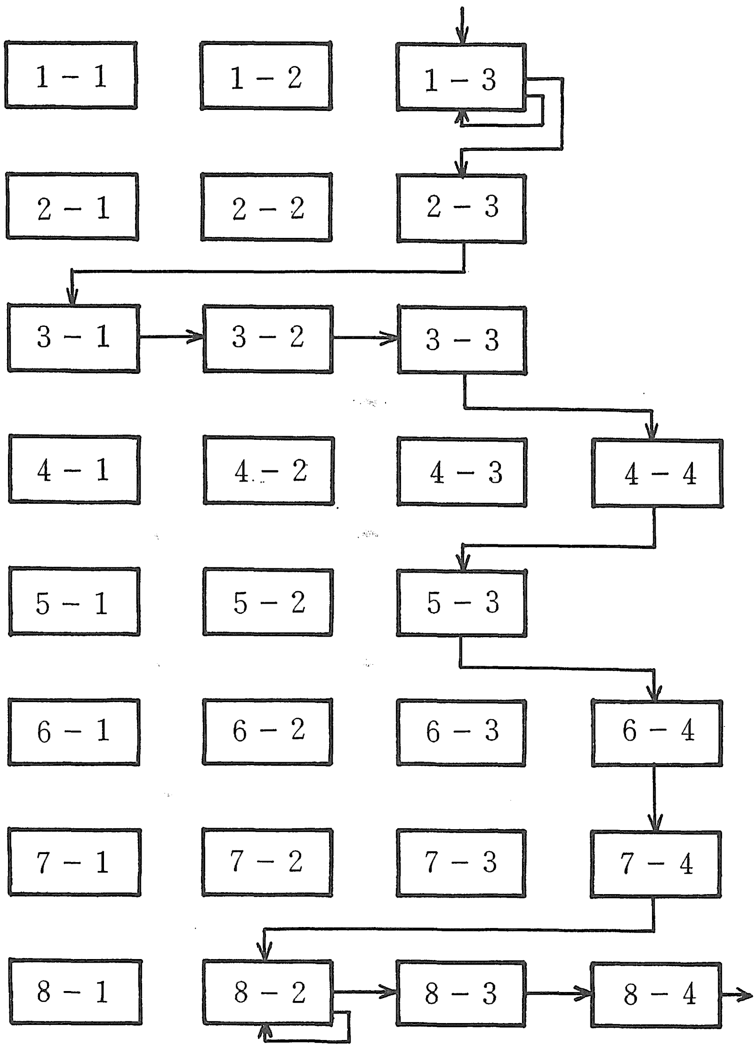

Fig. 5. Flow chart of the learning process that a student followed.
(student intelligence I = 84)
Feedback line : incorrect answer.

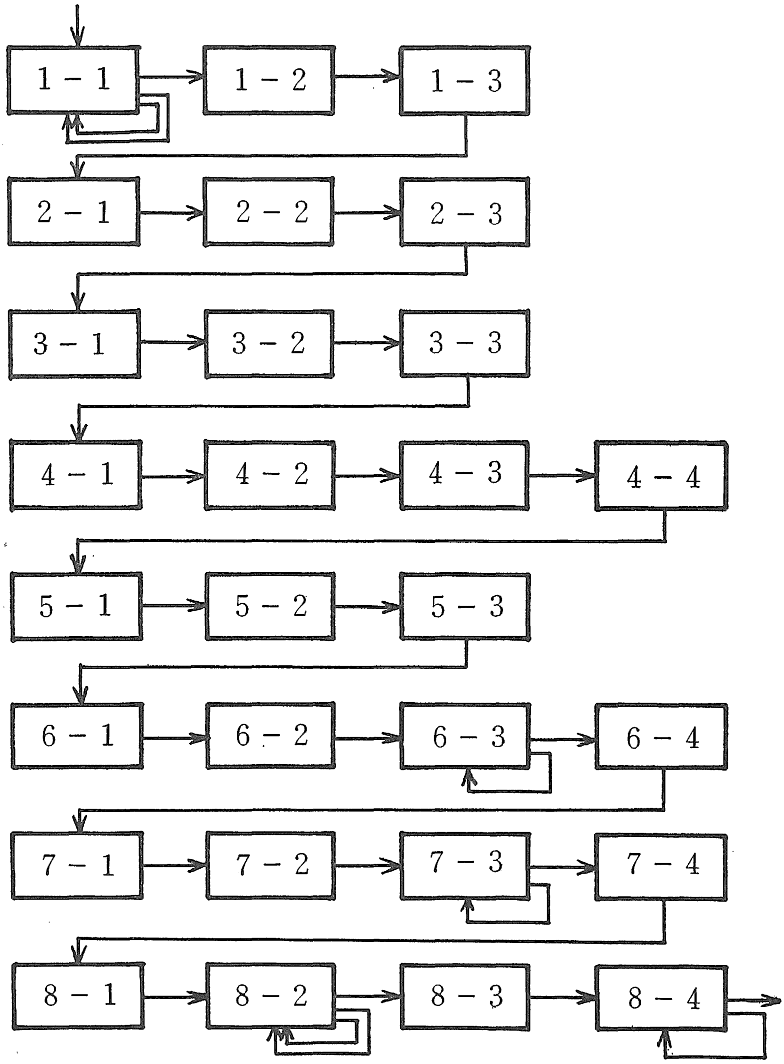

Fig. 6. Flow chart of the learning process that a student followed.
(student intelligence I = 50)
Feedback line : incorrect answer.

Table 3. Summary of experimental results.

Student intelligence	Time required (minutes)	Frequency of jumping	Frequency of correct answer in jumping
50	35	0	
57	30	1	1
63	40	4	3
63	31	4	4
71	19	6	4
74	21	6	6
76	21	6	4
84	15	7	5

4. DISCUSSION

When the mathematical model was constructed, education was understood as a probability phenomenon. That is, when a student was given a question, two states (correct answer or not) which he will present were considered as a probability event. Now that a phenomenon is grasped as a probability event, it is an indispensable condition that the phenomenon can be realized repeatedly under the same condition. On the experiments in education, however, there can't be the repetitive experiments of a true sense under the same condition due to so many influencing factors. Therefore, in order to grasp education as a probability phenomenon, we must collect a vast number of samples under the comparable conditions and handle them as the same ones. Two serious problems here arise :

How much the difference in the experimental conditions can we permit to handle as the same one ?

How many samples must be collected to obtain the true values in a population ?

A lengthy and careful investigation should be given to these problems. In Fig. 1, nevertheless the measured values about the probability of correct answer P were fairly away from the straight lines at both extremities of student intelligence I (particularly in case that question difficulty D is low), the straight line was assumed as the first approximation owing to the lack of samples.

Although the mathematical model was developed under the relative I and D within the population of the preliminary experiment, it must be corrected, of course, in the case of being applied to the different populations. For the purpose of the correction, it is necessary to establish such the methods of estimation for the absolute I as can express the difference in I's among the populations. For instance, if the identical questions are presented to the different populations, the method reported in the previous paper[1)] will be able to be utilized.

Besides, in accordance with the definition about D in Section 2.4, there is the disadvantage that a learning program must be examined to obtain D once at least.

Regarding this problem, the method to determine D quantitatively based on the veteran teachers' experiences is open to discuss.

In the type of branching program, a computer program must be made again every time a learning program changes. On the other hand, in this system, since the learning program is standardized, only the parameters (e. g., correct answers, the number of frames, the number of steps, I's, D's) may be changed and there is no need to make again a computer program every one. This is one of the main advantages in this system.

The impressions of the students who took the course of CAI were bisected into two opinions. One opinion was : "CAI is better than the conventional large class instruction because of being able to take lessons at my own pace". On the contrary, another one was the reverse by the reasons, such as :

(a) They strained on account of the unfamiliarity.

(b) The typewriter, the fan of computer, and so forth were noisy.

(c) A human teacher explains more kindly.

The disadvantages (a) and (b) were inevitable under the restricted devices, but they are not the essential problems because the technical settlement of them is possible, to some extent, even at present. (c) suggests as the direction of future study that we ought to direct attention to a more effective man-machine CAI system rather than an all-automated one.

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