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NOTES ON PROGRAMED INSTRUCTION AND ITS APPLICATION IN A NATURAL SCIENCE COURSE FOR FRESHMEN STUDENTS^{1, 2}

LINCOLN PETTIT

Department of Natural Science, Michigan State University, East Lansing, Michigan

ABSTRACT

Limited programed instruction, used in conjunction with non-programable materials, has proved very effective, despite the detailed approach and bulky book. Most students approved of it and most instructors felt it raised levels of class discussions.

INTRODUCTION

The combined factors of increasing numbers of students, shortages of trained teaching personnel, and the growing volume of information available (with rapidly changing interpretations of old and new information) have directed attention to a new instructional technique which qualifies for the title of "academic breakthrough." The new technique is called *programed instruction*. It is the purpose of this paper to describe and offer comments about the use of programed instruction in portions of the course in natural science at Michigan State University under the leadership of Dr. C. A. Lawson and Dr. Emanuel Hackel. At the present time over 7000 students are required to take three terms of natural science in the University College for graduation. Programing has been used for nearly 4 years, excluding experimental classes for 3 previous years. Its future depends upon decisions to be made during the coming year, in a major course revision planned by the whole staff. The programed portions are used in the laboratory and cover about one-fifth of the total time (6 of 30 weeks).

Several kinds of programed instruction exist. Two of these, related closely to the linear style (of Skinner) and the branching style (of Crowder), are described here as techniques used successfully thus far in teaching natural science. Linear and branching styles of programed techniques are printed variations of the Socratic question-and-answer method.

Linear programing proceeds step-by-step in a single pathway with a series of alternating questions and answers (see Example 1). The branching method presents a series of questions and offers multiple-choice responses for each question from which the student selects an answer. If the student selects an incorrect answer, he is guided to a sentence which informs him both that he is wrong and why he may have made the wrong choice. Thus he returns to the remaining available choices to select another answer (see Examples 2 and 3).

A more complete description of the two methods is to be found in Cram's paperbound book, itself programed (1961). A monograph by Stolurov (1961) contains several hundred references to papers on programing, often referred to as "teaching by machine," although only a very small percentage of current programed instruction in the United States is done by machine. The term "self-teaching" is often used in place of the term programed teaching. The Lumsdaine

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and Glaser text (1960) presents considerable information on the subject. Some other additional references have been appended to this article.

EXAMPLE 1. Linear Method

Part II. Linear Equations, Direct Relationship and Direct Proportion

Note that answer to question raised is provided in the left-hand box on the *next* page.

(Vol. III, Natural Science Manual)

p. 55

Lay worksheets I and II side by side so that the equations, tables and graphs on the two sheets may be compared easily. On worksheet I, examination of pairs of values of x and y satisfying equations 1, 2 and 3 in tables A_1 , A_2 and A_3 shows that for all these, as x increases in value, the value of y _____.

p. 57 increases

On worksheet II examination of pairs of values of x and y satisfying equations 4, 5 and 6 in tables A_4 , A_5 and A_6 shows that for all these, as x increases in value, the value of y _____.

p. 59 increases

Def: When two variables are so related that *as one increases in value the other increases also*, the two variables are said to be directly related to one another.

On the basis of your answers to frames 1 and 2 and this definition, the variables x and y in each of the six equations on worksheets I and II are _____ related.

p. 61 directly

Recall that all the equations 1 through 6 on worksheets I and II belong to the group of equations that may be represented by the general formula $y = \text{_____} + \text{_____}$.

PREPARATION OF PROGRAMED MATERIAL

Writing a program calls for a higher degree of sophistication than "regular" textbook writing because each subject must be completely analyzed for its interdependencies. Each new idea must be introduced in a logical order, usually with the assumption that the reader has had no previous experience with it. The author examines the inclusive headings with a view to their relative place in the sequence. Subordinate parts must be arranged so that nothing is taken for granted.

Beginning at the most elemental level consistent with the kind of reader expected to use the material, the author moves at a methodical pace from one minor point to another, gradually building upon observations, operations, and repetitions until the highest level of knowledge desired is attained. Initial steps or "frames" are easy; terminal frames are more difficult. Eventually the student is led to do independent thinking.

In using a programed text, the student is given some basic information and is then asked a question. In the *linear* method, a space is provided for the student to write the response. The correct answers are provided, but are usually covered or "masked" on the side. He simply slides the masking sheet down the page, or turns the page, and compares his answer with the correct one. Ordinarily no effort is made to deceive or trap the student. Frequently the response is simply a restatement of a few words in the question, or at most an elementary deduction. The student is immediately reinforced by seeing whether his answer is right or wrong.

For example, a student is first introduced to simple explanations about the use of the equals-sign and the plus-sign, and then is led through more and more advanced arithmetic into algebra, and finally into a test of goodness-of-fit for graphed data, all in the space of forty pages. The steps are so designed that most students are capable of following and, in nearly all cases, fully understanding every step. Example 1 is from a study designed by Dr. Floyd V. Monaghan to teach students about the gas laws, in keeping with our program of theory-development.

A more complex series of lessons dealing with the study of genetics, employing

the *branching* technique, has been devised by Dr. C. A. Lawson and Dr. M. A. Burmester over a 3-year period. These have appeared in three books published by the D. C. Heath Company (1962, 1963, 1966). Another section, by Dr. Clarence Schloemer, is an in-depth study of sickle-cell anemia, and includes paper chromatography in a study of proteins. So far, the most successful programs have dealt with factual, predictable knowledge, though enthusiasts claim that "anything can be programed."

EXAMPLE 2. Branching Method

	This selection is taken from a point more than half-way along in the study of genetics.
Vol. I, Natural Science Manual p. 12-8	We have presented two methods of obtaining ratios and probability equations of offspring from a cross. If one has the ratio, one can convert it directly into a probability equation, and if one has the probability equation, one can convert it to a ratio. However, from this one must not infer that the two have exactly the same meaning. The ratio gives us the relative frequency of the different kinds of genotypes to be expected in a large number of offspring. The probability equation gives us the probability of the occurrence of any one genotype. If two individuals heterozygous for normal skin pigmentation had a large number of children, what would be the numerical relationship of albinos and normal individuals among the offspring? To answer this question we would employ the idea of <ol style="list-style-type: none"> 1. ratios. 2. probability equations.
p. 12-10	<ol style="list-style-type: none"> 1. Correct. We would use the idea of ratios. Continue. 2. Wrong. When you say that there are three normal to each albino, you are stating a relationship of frequencies of the various phenotypes and not the chances of occurrence of a particular event. Return.
p. 12-12	If two individuals heterozygous for normal pigmentation wished to know what the chances were that their first child would be an albino, they would use the idea of <ol style="list-style-type: none"> 1. ratios. 2. probability equations.
p. 12-14	<ol style="list-style-type: none"> 1. Wrong. When we inquire into the chances of occurrence of an event, we employ the ideas of probability. Return. 2. Correct. They would use the idea of probability equations. Continue on page 2C.
p. 12-2	Using the probability equation $\frac{1}{4} AA + \frac{1}{2} Aa + \frac{1}{4} aa = 1$, what would be the chance of this couple producing an albino as their first child? Recall that normal pigmentation is dominant. <ol style="list-style-type: none"> 1. 0 2. 25% 3. 50%

DIFFICULTY OF COMPOSITION

Programing techniques have been adapted to a wide variety of instructional problems. Because they are essentially self-study methods, the various techniques satisfy many requirements for correspondence courses, and are also used for prerequisite study. The United States armed forces use them extensively. Many modifications in style and content have appeared and, as may be expected, there is a wide range of excellence. Writers quickly discover that composition is difficult.

Linear programing is less difficult than the branching technique. In the

former, the principles of association and of conditioning are used. For example, a descriptive topic, such as the circulatory system—the chambers and valves of the heart, the blood vessels, and the pathways of blood in circulation—although not examined in our course, has been developed step-by-step by the linear method. Over and over, the student responds to questions about the parts and pathways of the system. If the student follows the program, honor-bound to learn without attempting shortcuts, he will almost certainly know the course of the blood in a relatively short time. Programed instruction, because of its thoroughness and repetitive nature, is known to leave a sizable, permanent residue of knowledge when used through a long span of time. A great advantage is the impossibility of last-minute cramming, with its well known evils.

Programed *branching* material (especially that of a complex nature) is more difficult to compose. Only an experienced teacher and writer can develop a good program of this kind. However, the type of material treated can be more sophisticated. Authors must be so familiar with the subject that they anticipate the common mistakes of interpretation and judgment made by average students. A

EXAMPLE 3. Branching Method

- This section appears near the end of a study of evolution.
- Vol. II, Natural Science Manual
p. 15-27
- Continuing with the marble analogy, one way in which the frequency of blue to white marbles in the "gene pool" might be maintained, despite the removal of blue marbles, would be for white marbles to change to blue marbles at a rate sufficient to keep pace with the rate at which the blue marbles are being removed. In terms of genes rather than marbles, the ratio of Sk genes to sk genes in the American Negro population could be maintained at the present level if the rate of change (mutation) of sk genes to Sk genes per generation equalled the rate of removal of Sk individuals by actual death and genetic death from the population. Do you agree with this statement?
- p. 15-28
1. Yes 2. No
-
2. Incorrect. If the rate of mutation of sk genes to Sk genes equalled the rate of loss of Sk genes through death, actual or genetic, from the population, an equilibrium would have been established for these genes in the population. Try again.
 1. Correct. The Sk genes are being removed from the gene pool of the American Negro population by both actual and genetic death. To avoid the actual decrease in the frequency of the Sk genes in the population during the course of succeeding generations, it would be necessary for sk genes to mutate to become Sk genes at a rate equal to the rate of loss of these genes. The sk gene does mutate to become the Sk gene. *The rate of mutation, however, is much below that necessary to keep the Sk gene maintained in the American Negro population at its present level.* Since this is the case we have reason to predict that
 1. The frequency of the Sk gene in the American Negro population will gradually increase relative to the sk gene.
 2. The frequency of the Sk gene will decrease generation after generation in the American Negro population until the rate of loss is balanced by the rate of gain through mutation.
 3. I cannot follow this line of reasoning.
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1. No. Since the rate of mutation is not sufficient to maintain the present ratio of the Sk gene to the sk gene in the American Negro population, and since Sk genes are being removed from the gene pool by the actual and genetic death of Sk individuals at a rate exceeding the replacement rate, it is not valid to deduce that the frequency of the Sk gene will gradually increase relative to the frequency of the sk gene. Try again.
 3. The line of reasoning is as follows: Individuals afflicted with sickle cell anemia in the American Negro population are not transmitting their Sk genes to offspring due to actual and genetic death. Thus, Sk genes are being lost from the "gene pool" of this population. The rate of mutation of sk genes to Sk genes is not sufficiently high to offset the rate of loss of Sk genes. Therefore, the present ratio of Sk genes to sk genes in

EXAMPLE 3.—*Continued.*

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- the population will not be maintained at its present level. With this assistance, try again.
2. Correct. The rate of mutation of the Sk gene from the sk gene is not sufficiently high to replace those Sk genes lost by genetic death. We assume that the frequency of the Sk gene will continue to decrease, generation after generation, in the American Negro population, until the rate of mutation of sk genes to Sk genes equals the rate of loss of Sk genes from the gene pool.
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- p. 15-29 This decrease of the Sk gene relative to the sk gene in the American Negro population, due to the lack of a sufficiently high mutation rate to replace the Sk genes lost to the gene pool, supports the view that the genotypes leading to sickle cell anemia, sickle cell trait, and the normal condition among American Negroes at present are
1. not in a state of genetic equilibrium.
 2. in a state of genetic equilibrium.
-
2. No. Since the ratio of Sk genes to sk genes in the American Negro population is changing generation after generation, though at a decreasing rate, it is not valid to state that the genotypes derived from these genes are in equilibrium. Try again.
1. Correct. Since the ratio of Sk genes to sk genes in the American Negro population continues to change, generation after generation, due to the lack of a sufficiently high mutation rate and to other reasons, it must follow that the genotypes and phenotypes derived from these genes are not in a state of equilibrium in this population.
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more refined handling of topics is required, but rewards of heightened interest and keener acumen and perception on the part of students accompany use of material prepared by this technique. Indeed, the subtleties of logic and the methods of science may emerge as by-products—if they are not the major purpose of the studies, as they are with those of us who teach. The student must read with far greater attention, and must be alert to small degrees of difference in the multiple-choice responses offered him.

Both methods, linear and branching, can be constructed in ways which oblige a student to develop intricate thought processes, but the branching kind seems to offer the best possibilities for making programed instruction interesting and thought provoking. Weaknesses in the branching style exist, however. For example, the “frames” are usually “scrambled;” that is, the reader must go, for example, from page 6 to 17 and back to page 3, etc., and turning pages becomes tiresome. In addition, many texts tend to be wordy.

STUDENT REACTION

Among the numerous analyses of the merits of programed instruction one may find data strongly supporting such instruction, as well as data less encouraging to its proponents. Readers interested in a detailed description of these findings are referred to *The Journal of Programed Instruction* (1965).

Experimental classes often react over-enthusiastically, in part because they are inspired by the pioneering spirit, or affected by the “Hawthorne” effect, of novelty. For example, we have found that at least in one exercise, the students reacted very favorably when the material was presented in mimeographed form, but subsequent classes using the same material in printed form, incorporated in our laboratory manuals, expressed less enthusiasm. Nevertheless, most students like programed material more than conventional methods, at least in moderate amounts. They clearly do as well, and in some cases much better on examinations. Students

who follow old patterns of procrastination are far worse off under programed instruction at examination time. Rapid reviewing is almost impossible, although note-taking for definitions and for other essential knowledge becomes habitual with the best students. Students using programed material report that they are inclined to discuss their homework with other students to a greater extent, a desirable result.

A few students express dissatisfaction because the slow, methodical steps bore them. They seek outside, straightforward readings as a substitute, though, by doing so, they frequently gain a false sense of security because of the lack of practice in the logical processes of thought. If the examination emphasizes reasoning rather than recall, students who received the ordinary textbook treatment often lack the necessary experience.

Shortcuts are virtually impossible in studying programed lessons. However, variations in reading speed exaggerate inherent differences in completing lessons among students. Consequently, average students and slow students must devote more time to this type of material than they would to an ordinary assignment. Because programing is not used widely enough on any given campus at the present time, it is difficult to judge how many fully programed courses average and slow students might be able to cope with. At the other extreme, rapid readers express dissatisfaction with the "finely granular" steps and small "comprehension leaps" characteristic of thorough programing.

It is clear that not everything should be programed. Some material can be handled more effectively and economically by reading ordinary textual descriptions. In addition programed textbooks are expensive. For example, the classification lists of animals and plants are unsuitable.

As knowledge grows regarding this technique, it becomes clear that it is a every profitable method for achieving certain objectives. However, extending it indiscriminately is unwise, if not futile, from the student's view.

INSTRUCTOR REACTION

At first instructors feel they are unnecessary in a laboratory course where apparatus and the programed material provide all that the student needs. In a short time, however, students begin to ask questions, so that the instructor soon moves about as in the past, clearing up knotty problems and at times enlarging upon the subject where interest is shown. Larger laboratory sections can be handled without much extra burden. In addition, the obligatory thoroughness of a well written programed exercise raises the level of discussions. Persons attracted to teaching because they enjoy imparting information lose some of the reward that follows explanations. Program-enthusiasts, on the other hand, say that the method frees the instructor for more careful lecturing. Although this writer cannot quantify instructor reaction, it is safe to say that the same wide range of opinions found in discussions about teaching techniques in general also applies to this one method. The ultimate success and continuance of a novel technique such as this one is beset by perils linked with a multitude of factors. In order for programed teaching to be fully effective, of course, staff acceptance is essential.

DISADVANTAGES OF PROGRAMED TEACHING

Some negative aspects of programing have been mentioned earlier; those intrinsic in the technique merit description.

For one thing, there is an increase of 50-100% in the total printed pages in the programed situation. Where outside reading is assigned (we require a set of reprints from the *Scientific American*), the total expense of accessories in the course rises to an objectionable level.

An absence of emphasis attends this kind of instruction. It is partly overcome in lecture periods, but it breeds monotony during study. This lack of emphasis can be overcome in print by underscoring and by the use of chapter summaries.

Homework and laboratory work acquire a smooth quality of sameness difficult to describe. This quality strains the attention-span of students all along the continuum of ability. The extensive use of programing is sometimes boring to some students; one remedy seems to be an alternation of styles during a term's work.

There is the temptation, too, to "peek ahead" for answers, to accelerate the study chore. Keen disappointment comes from many students who initially race through an assignment and attempt to avoid the expected mental exertion by peeking ahead, and who then fail a test. They claim "completion" of the work, and may quickly erect hostile barriers to further use of programing. Prevention of this reaction has taken the form of three 50- to 60-page "study guides," one each term. Each guide contains study questions, glossary, sample test questions for each chapter, and a complete final examination from a past year, revealing some of the many types of "thought questions" which can be devised. Since most questions display a demand for application of knowledge and a new approach to studying, just as programed exercises do, students using the study guides learn to know what is expected of them.

CONCLUSIONS

As in any pioneering venture, some individuals, both students and staff, are strongly attracted to programing, some find it objectionable, and the majority simply accepts it and gives it a "fair trial." In our department, four years after incorporating programed lessons with three years' prior experimentation, the advantages and disadvantages continue to be debated. A complicating factor has been the growth of the staff from about 40 to nearly 60 persons in 7 years, and consequent shifts of opinion. The effectiveness of programing for the vast majority of properly oriented students has been acknowledged here by most students and instructors. But it is a technique with limitations: the expensive bulky books, the "saturation point" reached after several weeks' continuous use of programing techniques each term, and the superiority of "regular" texts for certain kinds of subject matter.

According to Vogt (1965), Soviet educators disapprove of programed instruction for the following characteristics: "(1) The monotonous and wearisome procedure of filling in missing words and numbers. (2) Division of the material into such small units that the subject matter is difficult to grasp as a whole. (3) Copious use of reinforcement, which tends to weaken students' habits of working through material and thinking through ideas *independently*. (4) Linear programing which employs numerous small steps but does not provide a means by which a student may omit material he finds unnecessarily repetitious or nonessential." Nevertheless, Soviet educators are industriously experimenting with programing.

Students have still not learned to (or possibly prefer not to) detach themselves for extended periods from the sociable, interpersonal activities of group laboratory work. They continue to need some of the traditional person-to-person educational experience in lectures and group discussions.

Programed instruction offers exceptionally good opportunities for developing logical processes of thought in a natural science course such as ours, designed for this aspect of general education (the changing nature of scientific knowledge). For any large, general course, programing offers many practical advantages: thoroughness, repetition, self-testing, and reward for self-discipline. The total effect, if used sparingly, appears to be an increase in value received for the time spent. Nevertheless, the advantages are not yet overwhelmingly favorable for the kind of course described here.

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