PROGRAMMED LEARNING IN CHEMICAL ENGINEERING EDUCATION

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The application of programmed learning to the teaching of high school and beginning college courses has grown at an astounding rate in the last few years. In September 1962, 122 programs ranging from music to mathematics could be obtained on a routine basis from the nation's publishers (A 3). In addition, several hundred more programs are being prepared. Research in programmed learning is actively pursued in leading colleges throughout the country (A1, A12).

In view of this intense development of programmed learning in high schools and colleges, the Education Projects Committee initiated a brief study of programmed learning as it might apply to teaching chemical engineering. This report is a preliminary survey of the field, with a few suggestions for applications. Because no programs are currently available in college-level chemical engineering, the report is necessarily rather general and speculative.

As the name implies, programmed learning attempts to more thoroughly structure written instructional material. The mechanical teaching machine is perhaps the best known technique of programmed learning; however, the programmed textbook may offer more promise for advanced college courses. A third type of programmed instruction utilizing closed-circuit television and a digital computer is in an early stage of development. One authority (A13) believes that the simple programmed textbook (because of its low cost) and the very complex computer-controlled teaching machine (because of its tremendous versatility and capacity) are the two techniques which offer the greatest promise.

Basic Procedures in Programmed Learning

All programmed learning techniques are designed to present the material to be learned in a sequence of short steps. Usually each step consists of one or two sentences and perhaps a figure or diagram. The learner is most often required to fill in a blank with a word or phrase or to answer a question. Most programs require that the answer be written out either on the program or on a separate sheet. In some cases the answer is fed to the machine by a keyboard or typewriter. Each step requires the learner to make only a small increment in learning and clues to the correct answer are given. As a result, errors are seldom made. After answering an item, the learner proceeds to the next step, which wasn't visible when he answered the previous item. Here the answer to the earlier item is given, and another item with a question is presented. The learner proceeds step-by-step, answering questions or filling in blanks at each step, until he reaches the end of the program. Programs range in length from several hundred to a few thousand items. For example, a programmed textbook on introductory statistics contains 1700 items and requires 15 to 25 hours to complete. The basic sequential pattern of programmed learning described here has many variations, several of which will be described here in a later section.

The proponents of programmed learning claim that it has three major advantages over conventional teaching methods (A-6):

1. Programmed learning requires continuous, active student participation. His response to each question gives him practice at each item, so that each step in the learning sequence is properly learned. It is difficult to be passive or indifferent when reading and responding to a program. The continuous demand for answers maintains student interest.

2. The student learns whether his answer is right or wrong with minimum delay. This tends to make him remember correct responses and quickly forget erroneous answers. In a conventional classroom situation a student often waits several days to learn whether his homework or examination answers are correct. Of course, he may obtain immediate reinforcement of his correct answers from the teacher in classroom discussion, but not all students can participate. Programmed learning gives immediate reinforcement to every student -- just as though each student had an individual human tutor.

   Educational psychology has shown that immediate reinforcement facilitates learning. A student will remember an answer which he knows is correct better than one he is uncertain of. Conversely, his learning immediately that an answer is wrong encourages him to forget the wrong response before he has a chance to learn it. Supplying the correction for the wrong response also aids in learning.

3. Each student can proceed at his own individual rate. Fast learners are not held back by the slow student, as sometimes occurs in the conventional classroom. Conversely, the slower student is allowed all of the time he needs.

Do these claimed advantages actually lead to better learning using programmed instruction? Much research is in progress to compare programmed and conventional instruction. The results seem to show that programmed learning is at least as effective as conventional classroom — textbook instruction in some areas (A-13). That is, the student learns as much, and in some cases more. However, these conclusions cannot be applied to all levels of college courses, because no studies have been made on advanced college courses.

Since programmed learning requires a sequential presentation of information, the material to be taught must be of a type that can be broken into a sequence of steps. The most enthusiastic proponents of programmed learning claim that anything that can be taught can be programmed. More realistic observers emphasize the need for defining the objectives of the proposed program before an attempt is made to write it (A-9). It is necessary to state very carefully exactly what the program is to teach. This is done by stipulating what the student should be able to do at the end of the program. For example, statement 1 is a much more appropriate goal for part of a higher algebra program than statement 2.

1. The student must be able to solve 5 pairs of simultaneous algebraic equations in 15 minutes.
2. The student should have developed an understanding of simultaneous algebraic equations and their solution.

How can "understanding" be measured? Only by requiring an overt response such as that suggested in statement 1.

The precise delineation of what is to be learned is an indispensible first step in writing a program. This delineation must state the overt behavior expected of the student at the end of the program. If this cannot be done, there is no point in writing a program because there will be no way to determine whether the student has learned anything. In high school courses, which usually emphasize learning of specific facts and techniques, the goals often can be precisely defined in terms of overt behavior. On the other hand, such definition is much more difficult in advanced college courses. It may even be undesirable or impossible in courses where the student is encouraged to think for himself and set his own goals. As a result, it may not be possible to program many advanced college courses. Published programs include only subjects which are well-structured, such as elementary mathematics, or subjects which require the learning of many facts and rules, such as English grammar, usage, and spelling. Many advanced college courses do not seem to fit into these categories.

Most of the effort in programmed learning to date has been concentrated on high school courses (7th through 12th grade). Much more work is needed before the value of programmed learning in college courses is established. However, the dramatic success of some high school programs appears to make college studies desirable.

Types of Programmed Instruction

Various devices are being developed to present the sequence of items required in programmed learning. Three major types are teaching machines, programmed textbooks, and computer-controlled devices. Before these are discussed, a few comments on the program itself are necessary.

Programs and Programming:

The program is the heart of programmed instruction. Writing a program is a difficult chore. Although several hundred programs have been written, there seems to be little consensus on how it should be done. A programmed primer on the subject gives a few suggestions (A-10). It is also an interesting example of a programmed textbook.

Most psychologists feel that learning is more efficiently accomplished by reinforcing correct answers than by correcting erroneous answers. As a result, most programs are written to elicit a correct response. This is accomplished by providing sufficient "cues" to the student. The answers to the first several items on a specific subject may be made obvious with various cues. The cues are then slowly eliminated in succeeding items until the student is able to answer questions about the subject without the benefit of cues.

Most programs require written responses. The reader could simply formulate the response in his mind, but many programmers believe that the overt action of writing the response gives a more active role to the reader; and hence he learns better. Another important use of written responses is in correcting the program. If an item in the program is too difficult, many students will answer it wrong. The programmer can then check these responses and modify the item to assure correct responses.

Not all programmers believe that incorrect responses are necessarily bad. They may be advantageous if they can be used as a sign that the student needs more training on the subject of the question. The additional training can be added to the program by "branching". Depending upon his answer, the reader is told to go to one of several following items. If his answer is correct, he goes on to a more advanced item. If he answers incorrectly, he goes on to a sequence which will correct his mistaken ideas. There may be more than one branch from a given item.

Branches may also be used to skip items when a quick learner demonstrates a superior grasp of the material. The other branch then includes more practice for the slower learner. Branching is used in many other situations where the programmer wishes to offer more than one alternative sequence of items. A branch may sometimes be taken at the option of the reader, if he feels he needs the additional knowledge in the branch. Branches may be of equal difficulty, where the choice between them is based on an opinion of the reader, which is neither right or wrong.

Figures, graphs, and long quotations may be included in a program. They are often placed on separate pages and the student is asked to refer to them when he comes to a given item. There is no limit to the length of such additional material. It would be possible to include an entire article or book, and then ask detailed questions about the selection using the programmed items. In this way the teacher can test the student's understanding of what he has read.

<u>Devices for Presenting Programs:</u>

The program itself is the core of programmed instruction. The mechanical devices for presenting the program and necessary supplementary material are really secondary. However, the various devices are sometimes suitable for different types of programming, so they will be discussed briefly. A good survey of these devices is given in Reference (A-12).

<u>Teaching Machines</u> are mechanical devices for presenting one item at a time to the student. They usually require that the student make his response (by writing the answer, pressing buttons for multiple-choice questions, etc.) before the correct answer and the next item appear. Often the machine is designed to make it impossible for the student to change his answer once he has seen the correct answer. Teaching machines range from a simple metal box costing a few dollars to complex devices including motion picture or slide projectors costing several hundred dollars.

<u>Programmed Textbooks</u> are essentially "paper teaching machines". There are several methods of programming texts. The resulting books look radically different from a conventional textbook.

In the <u>horizontally-programmed</u> text, each page is divided into a number of "frames", arranged from the top to the bottom of the page. Each frame contains a single item and the answer to the previous item. The reader starts at the top of the page, reads the first item, and answers it (usually on a separate sheet of paper if the book is to be re-used). He then turns the page and reads the frame at the top of the <u>next</u> page. Here he finds the answer to the first item; and the second item is presented. He continues through the book, reading only the top item on each page. After the last page, he returns to the first page and reads the <u>second</u> frame from the top. He continues this procedure, moving down one frame each time he reaches the last page. There may be as many as seven frames per page, so the reader will thumb through the book seven times.

Since the answer to any given question is always on the following page, the answer is not available to the reader until he has answered the question. Of course, "cheating" is possible. The reader may look ahead to the answer, but he gains little because he isn't taking a test. Since there is little advantage to looking ahead, few readers would do so. It would be somewhat like looking up the solution to a newspaper crossword puzzle while working it out. It just spoils the fun.

Obviously, the back of each page cannot be used for the following item, because it would face the <u>next</u> item and the answer would be visible. As a result, items are arranged to use only the <u>front</u> of each page from first to last page; and then the program continues from page to page on the <u>back</u> of each page.

The <u>vertically-programmed</u> text divides each page into a series of frames running from top to bottom. The reader starts at the top and reads to the bottom. Obviously, the answers to the items are visible on the same page, so some sort of shielding device is needed. This can be simply a sheet of paper that is lowered on the page as each item is answered; or it may be a special plastic cover that serves the same function. The vertical arrangement permits a once-through reading of the book; but it requires some sort of shield.

A particularly intriguing programmed book is the scrambled text. Here the reader starts on the first page, where there is a discussion followed by a multiple-choice question with answers. Depending on the answer he chooses, the reader is told to turn to a specific page (never page 2). If he chooses the correct answer, the page he turns to tells him he is correct, and presents more material and another question. If he chooses a wrong answer, the page he turns to tells why his answer is wrong and gives remedial work, perhaps extending through several more questions and branches until it finally returns to the main (correct) branch of the program. There may be several wrong answers in the multiple-choice question, each with its own remedial branch. Obviously such programs may become quite involved, with multiple branching. Reference (B-5) is an example of a scrambled text.

Generally, programmed texts are less expensive than programmed teaching machines, because the former doesn't involve expensive mechanical equipment. For example, a programmed text on elementary electronics costs $26.25. A machine program for the identical material costs $70, and the necessary teaching machine costs $700. (Ref. A-3). Texts are more easily adaptable to branched programs.

Computer-controlled teaching machines offer great promise for the future (A-2). Such devices could "tailor-make" programs, taking into account individual student differences in learning rate, educational background, and aptitude. The computer could be responsive to each student's needs while it is handling a large number of students. At each step in the program, the computer may modify the remaining program by considering such factors as

1. Promptness and correctness of the student's answer.
2. Specific errors in the answer.
3. Data on the student's previous learning habits; such as reading rate.
4. Personal data, including intelligence, special aptitudes, sex, etc.
5. Nature of the material being studied.
6. Level of student motivation.

Recent developments in computer-controlled teaching machines are discussed in Ref. (A-4).

An interesting example of the computer-controlled teaching machine is Plato II,(Programmed Logic for Automatic Teaching Operations) developed at the University of Illinois. Reading material, figures, and questions are presented on a television screen. The student types his answers using an electric typewriter. The answer may be in numbers, algebraic expressions, words, or sentences. When the student completes his answer he presses the "Judge" button and the computer judges the correctness of the answer, flashing "OK" or "No" beside the answer on the screen. If the answer is wrong, the student may ask for additional help by pressing the "Help" button. He then follows the computer which selects easier related material until the student indicates he understandsby pressing the "Aha" button. He then returns to the question missed.

Plate II has been used to teach mathematics and French. At present it is set up to handle two students simultaneously, but plans call for a larger number. The number of steps in the "Help" sequences is somewhat limited.

Computer teaching may eventually handle a large class, using only one computer for storage of the program and control. Each student could proceed at his own rate with his own television screen and typewriter. The cost of such an installation would be very high. Writing a teaching program for such a complex operation would be extremely difficult. The goal would be a program which would anticipate every possible student error and would include sufficient corrective material for even the slowest student. The result would be a machine which acted very much like a human tutor, in that it would be almost completely adaptable to the needs of any specific student.

Programming in College Courses

Of the 122 programs commercially available in the fall of 1962, only ten are appropriate for college classroom use (A-3). These include two elementary courses in statistics, two in general psychology, and one each in set theory, vectors, probability, chemistry, physics, and "Fortran" computer programming. In addition another half-dozen programs of post-high school level are listed. These include a series of short electronics programs published by Varian Associates covering capacitors, klystrons, relays, and switches; one on mathematical logic, and one on basic electronics.

There are certainly more than ten college-level programs in existence, but many have been locally-developed and are not yet commercially available.

An excellent survey of programming activities presently under way in engineering courses is given in Reference A-1. The survey shows considerable interest in programmed instruction in engineering courses. Included is a list of nearly 100 individuals preparing programs of interest to engineers; but most of these are in the early stages of development. Programs in preparation include elementary courses in chemistry, physics, mathematics, statistics, mechanics, drawing, electrical engineering, computer programming, and a few others. Several programs are being prepared in advanced mathematical subjects, such as matrix theory, Boolean algebra, Laplace transforms, and vector analysis.

Many of these programs cover a limited subject which would be a small part of the full course. Undoubtedly some of these programs will be sufficiently well-developed and tested so that they can prove to be of widespread use in engineering colleges.

The survey indicates that many engineering colleges would use programs if they were available. The interest centers on mathematics, engineering mechanics, and electrical engineering, but very little interest was shown in chemical engineering. Programming of engineering subjects is being encouraged by the Committee on Programmed Instruction of the American Society for Engineering Education. They have announced plans for a workshop in programming techniques for engineering faculty to be held in the summer of 1963 (A-1).

To be appropriate for programming, a college course must have a clearly-defined objective which can be stated in terms of overt behavior of the student. Well-structured subjects such as elementary mathematics, and natural science seem to have well-defined objectives. On the other hand, advanced courses in engineering design do not have specifically-defined objectives and could not be programmed.

It is not necessary to program an entire course. Only those parts which are well-structured need be programmed. The teacher can use programs along with traditional teaching techniques. For example, programmed Fortran instruction could be inserted in the beginning of an engineering design course which required solution of design problems on the computer.

Programming, even with branching, seems to force the student into a highly-structured pattern. In advanced engineering courses emphasizing independent thought such structuring often would be undesirable.

Engineering has emphasized the application of physical principles to the solution of complex problems. Although the student may learn the physical principles by programs; it appears that the teaching of the solution of complex engineering problems is often too unstructured to be appropriate for programming.

What courses in a typical chemical engineering curriculum could be at least partially programmed? Any attempt to answer this question is, of necessity, pure speculation. Elementary thermodynamics would appear to be sufficiently defined to permit programming. Some of the basic concepts and definitions of mass and energy balances might be programmed, although the more complex balances could not and should not be. Many of the basic concepts of stage and rate operations could be programmed, but it might be difficult to integrate the programs with non-programmed material and homework. Similarly, basic concepts in kinetics and process dynamics might be programmed although most of these courses would not be.

In basic courses which are prerequisite to chemical engineering, programmed instruction appears to have many applications. Most of freshman mathematics, chemistry, and physics could be programmed. Reference (B-6) is a college physics program consisting of 12,000 items. An experimental freshman chemistry program is given in Reference (B-10). Basic engineering mechanics can be programmed. (An experimental program in Kinematics is given in Reference B-7). Elementary organic and physical chemistry appear to be appropriate for some degree of programming. An excellent program for basic instruction on the slide rule is available in experimental form (B-9).

A survey of several of the major publishers of engineering books indicates considerable interest in programmed college texts, but there are very few definite announcements of programmed engineering books to be published in 1963 or 1964. No programmed chemical engineering texts have been announced. The problem would appear to be one of finding authors sufficiently familiar with engineering <u>and</u> with programming.

Interested engineering teachers might try writing a program for a section of one of their courses to evaluate the utility of programmed instruction. Guides on programming techniques are available (for example Ref. A-8, A-10), Unfortunately, the techniques of programming are not sufficiently developed to make it either easy or enjoyable.

Conclusions

Most effort on programmed instruction has been devoted to high school courses. As a result, it is impossible to state whether programmed instruction can be successfully applied to college engineering courses. No conclusions can be drawn until extensive experimental studies have been made in engineering courses. In addition, much more research is needed to clarify the psychological principles of programmed instruction, so that the practice can be put on a sound theoretical basis.

Programming is still an art. Although the various schools of programmers can cite psychological principles which they believe support their methods, few parametric studies to investigate their claims have been made. Greater understanding of programming methods should precede any major effort to program engineering courses. Methods developed for high school use are not necessarily the most appropriate for college courses. Some educational psychologists have questioned the criterion that requires most student responses to be correct. Perhaps more error would be desirable. One study (A-6) indicates that the activity of filling in blanks or writing out the answer may not be necessary. Possibly the value of a program is in the carefully-developed sequential arrangement of the important concepts to be learned.

Most of the studies to date have compared independent programmed learning with instruction using conventional texts and classroom discussion. Possibly studies using both programmed textbooks and classroom discussion would show that the combination is superior to either above. There is no need to substitute programmed texts for other techniques of teaching. In engineering courses particularly, a combination might be quite effective. A programmed text could be substituted for a conventional text in, for example, an existing thermodynamics course. Class discussion and homework could continue as before.

Can programmed learning be used in chemical engineering education? It is too early to tell. The final answer to this question can be obtained only with the active participation of engineering faculties. Engineering professors must work closely with educational psychologists in developing and testing suitable programs. Although such cooperation would be a novel experience for both groups, it could prove very beneficial to teaching in chemical engineering.

The potential of programmed learning is neatly summarized by R. D. Patton (A-11): "The enfant terrible of the moment is the teaching machine. No one can say for sure what kind of adult it may grow up to be. Meanwhile, it has struck fear into the hearts of all but the bold and perhaps the foolish. The fear is that it may subvert the teaching art into a slick kind of game-playing, or at best so attenuate the humane aspects of the teacher-student relationship as to cause the loss of the contagious joy of discovery which has so often sustained the intellectual life in the past. Yet there is much routine learning which must precede and accompany discovery; and it is quite probably that auto-instruction devices may perform this function as well or better than the teacher in the flesh. Fortunately, many of the older and saner heads in this area of instruction are urging caution and avoidance of extravagant claims until more experience is gained and more research completed. If good sense can carry the day, there is a very real possibility that the self-teaching device, whether it is a true machine or a programmed textbook, may relieve the human teacher of much drudgery and permit even more intimate contact between the older and younger learner".

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A 13. Stolurow, L.N.: "Implications of Current Research and Future Trends", J. Educ. Res. 55:519 (1962)

B. A Selection of Commercially-Available Programmed Textbooks of Interest to Engineering Teachers

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B 2. Colman, H.L., and C.P. Smallwood: "An Auto-instructional Introduction to Fortran Programming" McGraw-Hill Book Co., New York College Level; 1000 frames; $3.95

B 3. Evans, J.L., and L.H. Homme: "Introductory Statistics" TMI - Grolier, New York. Advance high school - beginning college level; 1700 frames; $10.00

B 4. General Education staff: "Probability Models of Random Processes" General Education, Inc. Cambridge, Mass. College level; 800 frames; $15.00

B 5. Hughes, R.J., and P. Pipe: "Introduction to Electronics" Doubleday, New York.
Intended for self-instruction in electronics for people with little mathematics background. Not a college text, but an interesting example of the scrambled textbook. $4.95.

B 6. Joseph, A., and D. Leahy: "Programed College Physics" John Wiley and Sons, New York. College level, but at a low mathematical level; 12,000 frames; $15.00

B 7. Leahy, D., "Kinematics" Center for Programed Instruction, New York (Experimental Edition)

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