The Student The Teacher The Psychologist View Programmed Instruction*

CHARLES E. WALES
Wright State University
Dayton, Ohio 45431

The potential of programmed instruction as an educational device is demonstrated by its present use in the classroom, industrial training programs, the continuing education program of the medical profession, and by the recent interest of several large corporations who have entered the education business with systems based on programmed instruction. This paper describes a set of thermodynamics programs developed at Purdue University and examines their potential from the viewpoint of the student who used them, the teacher, and the psychologist. Various aspects of the design of these programs are examined including linear versus branched style, step size, concrete illustrations of abstract concepts and perceptual organizers. The programs and the textbook are compared in terms of their ability to transmit information to the student. The program is described as pschologically superior because it shapes behavior from the simple to the complex and guides the student so he avoids misconceptions which must be unlearned. Finally, the value of the programs in freeing class time for more valuable activities is described.

If you asked Harvard psychologist B. F. Skinner[1] what programmed instruction can do for education he would reply, "What is now taught by teacher, textbook, lecture, or film can be taught in half the time . . . by a teaching machine" using programmed instruction. Before you dismiss Skinner's claim you should carefully consider the fact that RCA, IBM, GE, Westinghouse and several other large corporations have recently staked a claim in the education business with systems that involve programmed instruction materials. In addition, many industrial firms already use programmed instruction to teach basic skills to their employees. And the medical profession is using programmed instruction in a program of continuing education. While Skinner's claim of a 50% gain may be a little unrealistic, it should be clear that programmed instruction has definite potential as an educational device. In the discussion that follows I will examine this potential from three view points: that of the educational psychologist who applies the theories of psychology to the classroom; my own viewpoint as a teacher who has written, experimented with and used programs in my teaching over a period of five years; and the viewpoint of the student who has studied from my programs.

*Presented at the Annual Meeting of ASEE, June 19-22, 1967.

WHAT IS PROGRAMMED INSTRUCTION?

The concept of programmed instruction was introduced by Skinner in 1954. Since that time three methods of presentation and two different styles have been developed. The three methods are:

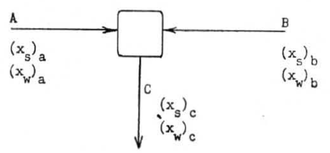
1. Computer assisted instruction: the student operates a typewriter linked to the computer which contains the programmed material.
2. Teaching machines, any device which mechanically controls the presentation of the program to the student.
3. Programmed texts, which place the material in the hands of the student.

Each method has its advantages, but the programmed text is basic to the other two. Therefore, this discussion will be limited to that method.

The two program styles are called linear and branched. Table I shows an example of a simple linear program, a series of questions and answers. To use this program the student covers the answer with a sheet of paper, reads the question and thinks or writes his answer. He then uncovers the program answer and checks his work. Table II shows a branched program. In this case the student reads the question, selects one of the given answers, and then checks his choice against the answer given in the program. When he selects the correct answer he proceeds to the next question.

Table I. Simple Linear Program.

Consider the open system, steady state process shown below, mixing operation with salt and water.



5Q. How many **flow rate** unknows are there?

5A. **Three** flow rate unknowns: A, B, C.

6Q. How many composition unknowns?

6A. **Six** composition unknowns, two in each stream. The total number of flow rate and composition unknowns is 9.

7Q. What is the **total** number of material balance equations that can be written?

7A. **Three** material balance equations can be written:
salt balance
water balance
stream balance

8Q. How many of these material balance equations are **independent?**

8A. **Two** material balance equations are independent.

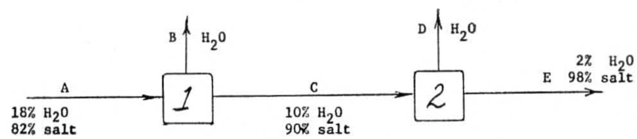
Program Versus Text

If you have had no previous personal contact with programs your first question will probably be, why a program instead of a text? The answer to this question is provided by the psychologist Ausubel[2] who identifies the most crucial condition affecting the acquisition and transfer of knowl-

TABLE II. Physical Material Balance Calculations

Two or more process units may be included in the system chosen for a material balance calculation. For example, Figure 8 shows two driers used in series to remove water from salt. In this problem it is possible to write material balances not only for each unit but also for the pair of units combined

Figure 8



Section 1

Q. 1220 lbs/hr of wet salt (A) are supplied to the two-stage drier system shown in Figure 8. Assume steady state operation. How many unknown flow rates are there in this system:

Your A.

5 unknowns	See section 4
4	7
8	9

Section 2

A. 6 equations. No. You counted material balances around unit 1 and unit 2. What about balances around both units?
Go to section 7.

Section 3

A. 4 independent equations. Correct. All the other equations are dependent, they can be derived by adding or subtracting the four independent equations.
Is it possible to solve a salt and a stream balance around unit one, a stream balance around unit two, and a stream balance around both units?

Your A.

Yes	See section 6
No	11

Section 4

A. 5 unknowns. Check the problem again, you probably counted the flow rate of stream A as an unknown. The flow rate of this stream is given and should be used as the "basis" for your calculations.

Section 5

A. 9 equations. Correct. You can write a stream, salt, and water balance around each unit and around both units combined.
Now, how many of these equations are independent?

Your A.

4 equations	See section 3
6	8

Table II. (Continued)

Section 6

A. Your answer is yes. The correct answer is no. It is impossible to get an answer if you use three equations of the same kind (i.e., stream balances). Try it if you have doubts.
Go to section 3.

Section 7

A. 4 unknowns. Correct. The unknowns are stream flow rates B, C, D, and E. Streams B and D are pure water so there are no composition unknowns in this problem.

Next, what is the **total** number of equations that relate these 4 unknown variables?

Your A.

4 equations	See section 10
6	2
9	5

Section 8

A. 6 independent equations. No. You have correctly reasoned that not all three equations in one set (i.e., unit one) may be used. But it is also impossible to use all three equations of one kind(i.e., salt balances).
Go to section 5.

Section 9

A. 8 unknowns. No. You have counted 4 composition unknowns for the water streams which are pure water.
Go to section 1.

Section 10

A. 4 equations. No. You didn't read the question carefully. What is the total number of equations you can write for this system that involve the stream flow rate unknowns?
Go to section 7.

edge as the internal logic and the organization of the material. The usual text is logically sound but psychologically incongruous because it segregates material by topic, does not clarify the relationship between topics, and presents material at a uniform level of abstraction instead of building from the simple to complex. As a result the student treats meaningful material as if it were rote in character. He memorizes formulas, learns type problems, performs mechanical manipulations and both learning and retention are reduced.

By contrast, Ausbel identifies the program as a psychologically correct device because it is constructed around the basic organizing concepts of the discipline and ideas are arranged sequentially to build the hierarchial structure that matches the way in which psychologists believe knowledge is organized and stored in the human nervous system. The method used to construct a program illustrates Ausubel's point. First, the basic concepts of the course must be identified and organized into a logical pattern. Second, a detailed set of performance objectives such as those shown in Table III are prepared for each concept. Then the teacher begins the final step, the writing of the questions and answers that will lead the student from the objectives he learned in the previous program to the objectives of the new program. It is the combination of all these steps that gives the program its great strength.

Table III. First Law of Thermodynamics—Summary*

A. **State Properties** (Q 1-3)
   1. Define a state property: a property that depends only on a point's location, not on the path used to get there.
   2. Name 5 state properties: P,T,V,U,H.

B. **Path Properties** (Q 4-12)
   1. Define a path property: A property that depends on the path used. Q and W are path properties.
   2. Use a P-V diagram to prove that W depends on the path used.

C. **First Law of Thermodynamics for a Closed System** (Q 13-32)
   1. State the first law of thermodynamics for a closed system:
      $Q - W_c = U_2 - U_1 = \Delta U$
   2. Define internal energy
      a. $Q - W = \Delta U$ for any closed system, any material.
      b. $\Delta U = C_v(T_2 - T_1)$ for any ideal gas process and for an isometric process for any material which has a constant C_v.
      c. Units, BTU/lb mole or BTU/lb
      d. Zero point, arbitrary
   3. Apply the First Law to a Closed System

Ideal Gas	**Real Material**
a. Closed Isothermal Process	
$Q - W_c = U_2 - U_1 = C_v(T_2 - T_1)$	$Q - W_c = U_2 - U_1$
$Q - W_c = 0$, $Q = W_c$	$U = \phi(P,T)$
b. Closed Adiabatic Process	
$Q - W_c = \Delta U = C_v\Delta T$; $-W_c = C_v\Delta T$, for $Q = 0$.	$Q - W_c = \Delta U$
$+W_c = \frac{R}{\gamma - 1}(T_1 - T_2)$	$U = \phi(P,T)$
$+W_c = \frac{P_1V_1 - P_2V_2}{\gamma - 1}$	

*Part of the Performance Objectives for the program on the first law.

By its Socratic form the program provides the student with many of the best features of fine tutorial instruction. The program *shapes* the student's understanding by establishing simple behaviors which are gradually combined and modified until they lead to the final performance objectives which include both abstract concepts and concrete applications.

Programs were the primary vehicle for transmitting information in the thermodynamics course I taught at Purdue last semester. The students also had the regular text and they were told which sections of the text they should study. At the end of the semester they were given a questionnaire which asked, "If you had to choose between good programs or a good text as the basis for study in a class, which would prefer? Some of their anonymous replies were:

"The program, you can understand it rather than memorize it."

"In a program a person can usually tell which points he did not understand, whereas in a text he may not understand the whole material."

"The program, it forces you to stop and think and not just read, I tend to read over things in a text."

As you can see, the students identified many of the factors predicted by the psychologists. In all, twenty-five students preferred the program while three preferred the text. One of those who picked the text gave the following reason. "I would probably choose a good text because that is more familiar, but I never read a text that left me with as clear an understanding of the subject as the programs did." Because the material in the programs is not exactly the same as that in the text I asked the students the additional question, Would you have preferred to have the material in the programs written in text form without the questions and answers?" Twenty-six replied no; two were undecided.

Linear or Branched Programs

As he creates the program, the teacher must make many decisions. First he must choose the style of the program, either linear or branched. The linear style was chosen for my thermodynamics material because it provides the most direct control of the shaping process. In addition, the linear program makes the student a more active learner. To answer each question he must reformulate the material in terms of his own vocabulary, background and structure of ideas. According to the psychologists these acts are crucial to the learning process. In a sense the linear program is an experience in guided discovery. The student participates in the development of the first law and in the application of the law to different reversible and irreversible processes. The students find this participation stimulating. In response to the question, "What is the greatest strength of the programs? they replied: "Having the student answer the questions to work out the principles for himself." "I got into the act of actually developing equations."

In a branched program the student does not construct answers to the questions. Instead, he demonstrates that he has learned something by choosing the correct answer from a set of given answers. This behavior is most appropriate for a testing situation and that is exactly how the branched program has been used here. Table IV

Table IV. First Law of Thermodynamics—Self Quiz*

7. The flow work terms do not appear in the equation $Q - W_o = \Delta H$, the first law of thermodynamics for an open system. Does one of the terms in this equation include the flow work energy? If so which one?
   a. Q
   b. W_o
   c. ΔH
   d. none of the above

7a. The term Q accounts for the energy transferred to or from the system as heat. Flow work is not included in this term. Return to question No. 7.

7b. The term W_o accounts for the energy transferred to or from the system as shaft work. Flow work occurs when a stream crosses the boundary of a system. Some of the flow work energy may be converted to shaft work in a given process but the two types of work energy are not directly related. Reread the program from just after A31 to Q33, then return to question No. 7.

7c. This answer is correct. The flow work is accounted for by the enthalpy $H = U + PV$. The terms U and PV are added because U represents the energy carried by a stream that enters (or leaves) and PV represents the flow work done at the boundary when that stream enters (or leaves) the system.

7d. This answer is not correct. In an open system, flow work occurs whenever a stream enters or leaves the system. One of the terms in the first law must account for this energy. Reread the program from just after A31 to Q33, then return to question No. 7.

*Sample Self-Quiz question for the program on the first law.

is part of the branched program used as the Self-Quiz at the end of the program on the first law. A branched program requires that each question have one correct answer and two or three reasonable alternates or distractors. Since each incorrect answer must provide some feedback information to the student, more effort is required to construct a branched program. In some types of material there are no logical alternates and the branched program cannot be used. However, when these alternates exist, the branched program can be very effective in teaching the student to discriminate between similar ideas.

Step Size

The second decision the teacher must make is one of step size. Skinner's original concept of a linear program involved a short, one or two sentence question properly cued or prompted to insure the correct answer would be forthcoming. Recently, several, psychologists have questioned the wisdom of the small step. For example, Resnick[3] has said "good students become bored with too many small steps and come to resent the time spent on such programs." Ausubel[2] also supports this conclusion with the thought that small steps often artificially and unnecessarily "fragment ideas so that their interrelationships are obscured and their logical structure destroyed." By a trial and error process I came to the same conclusion, the small step does not suit the ability of the engineering student. Using feedback from my students I finally evolved the program style shown in Table V. These programs involve relatively large steps, meaningful, unprompted questions combined with uninterrupted sections of explanatory material. This style integrates the best features of a textbook, the lecture that fills in the gaps left by the text, and the recitation or discussion that supplements both.

Guiding the Student

Some of you may question the idea of carefully guiding the student through derivations, proofs and sample problems. In fact you may prefer the incomplete ideas presented in textbooks because you want the student to provide the necessary clarification for himself. I agree that the student should learn to think for himself but I would argue that this struggle should not take place when the student is learning basic concepts. This reasoning is supported by Ausubel who says, "Excessively difficult material makes for an undesirably large number of initial errors and misconceptions that have to be unlearned." This interferes with further learning, it lowers the student's self confidence and motivation, and promotes task avoidance. It is not that the student doesn't want to learn on his own, but rather that he lacks the necessary self-critical ability. The student usually finds it easy enough to manipulate words so as to create an appearance of knowledge and thereby to delude himself and others that he really understands. Does that sound like some

Table V.—Sample Page from the first law programs

Since we can always use a path such as (1-a-2) between any two points, this equation can be used to evaluate ΔH for any ideal gas process. This is an important characteristic of a state property, any path **between two points can be used to evaluate the change in a state property.**

37Q. An ideal gas is compressed adiabatically in an open system process, can the work for this process be evaluated with the following equation?

$$-W_o = \Delta H = \int C_p dT = C_p(T_o - T_i)$$

37A. Yes, the ΔH of an ideal gas always equals $C_p(T_o - T_i)$.

38Q. If a real material is compressed **adiabatically** in an open system process, can the work for this process be evaluated with the equation

$$-W_o = \Delta H = \int C_p dT$$

38A. No. The equation $-W_o = \Delta H$ is valid for any material, but $\Delta H = \int C_p dT$ is valid only for an isobarbic process for all real materials.

The enthalpy of an **ideal gas** is a function of only the temperature. The definition $\Delta H = C_p(T_o - T_i)$ proves that when $T_o = T_i$, $\Delta H = 0$. Pressure has no effect on the enthalpy of an ideal gas. We can reach the same conclusion by noting that both U and the (PV) product (note $PV = RT$) are functions of only the temperature. Since $H = U + PV = U + RT$ the enthalpy of an ideal gas must also be a function of only the temperature.

2. Isothermal Process

39Q. Write the first law for an open system, combine it with the definition of ΔH for an ideal gas and prove that $Q = W_o$ for an isothermal process involving an ideal gas.

39A. $Q - W_o = H_o - H_i = C_p(T_o - T_i)$
Since $T_o = T_i$
$Q - W_o = 0$
$Q = W_o$

of your students? By contrast, consider the following reactions of my students to the programs:

"They don't let you get a misconception."

"We could go back over a question to clarify points."

"Being able to correct ideas before going on to new material."

"You can't go on unless what came before is understood."

Other Factors

We have considered several of the factors the psychologist considers crucial to effective learning. They are: organization around the broadest principles, systematic sequential organization which shapes the students behavior, and an active learner who reformulates ideas in his own words. There are two additional factors to be considered.

First the psychologists say that new, abstract subject matter should include concrete—empirical illustrations and analogies to clarify meanings. For this reason, my programs include both theory and example problems. The student's reaction to this combination is very positive. Their response to the question, "What is the greatest strength of the programs?," was:

"Working with the material as it is introduced."

"Seeing how each concept can be related to a problem right after the concept is presented."

The second factor to be considered is what the psychologist would call an integrative perceptual organizer, a device which helps the student relate similar concepts and discriminate between overlapping ideas. In my thermodynamics programs this organization is accomplished by relating each concept and calculation to an appropriate phase diagram. As each subject is introduced it is related to a process line on a projection of the three dimensional surface for an ideal gas. For example, the concept of reversible shaft work is related to the area under a process curve drawn on a P-V diagram. The concept of reversible heat transfer is related to the area under a process curve drawn on a T-S diagram. When real materials are introduced the appropriate three-dimensional models and projections of the models are used to relate the process conditions to the change in a state property. The students response to the question, "Did you find the emphasis on the graphical representation of each process helpful in understanding the material?" varied from "definitely"; and "very helpful"; to "yes, I can picture what is happening"; "yes, it was something basic to refer to"; and 'yes, I need a physical feeling for something to really understand it." In all, twenty-six students found this graphical approach helpful, two others liked the approach but were confused by the great number of graphs presented.

Programs Free the Teacher

Designed as carefully as they are, you would expect programs to teach a subject and teach it well. The response of my students to the question "Do you think the programs helped you learn more than you usually do?", bears this out. The students' reply was a unanimous yes.

When asked if the programs helped them understand more than usual, twenty-seven students said yes; one was undecided. Part of the students' reactions can probably be attributed to the Hawthorne effect, but I'm not willing to admit that this is a major factor. I don't think engineering students are that naive. The fact that graduate students ask me for copies of my programs to study for their qualifying exams is further support for the value of the programs.

Hopefully, by now I have convinced you that programs can be of significant value in an engineering course. If not, let me tempt you with one final attribute of programmed instruction. During the past semester I taught an entire course in thermodynamics using the set of programs I have developed. Each program and its accompanying problem set were assigned as homework. There were no lectures in this course, class time was completely free for other activities. In a typical class meeting I spent from five to twenty minutes answering the students' questions about the material in the program and discussing the homework problems. During the rest of the period we did a variety of things; we probed the concept to greater depth, we extended the concept to new situations and we applied the concept to industrial type problems. Those of you who would like to find time to put some engineering in the engineering curriculum should be especially eager to try programs. By increasing the efficiency of the transmission of knowledge, the programs can give you the time you need for other activities.

This, I might point out, is exactly the role the psychologists predict for programmed instruction. Ernest Hilgard, a former chemical engineer, head of the Department of Psychology and dean of the Graduate Division at Stanford put it this way[4]. "... the program does not replace the teacher but can hopefully free the teacher from routine exposition, and give time for doing the things that only the teacher can do," teaching students to think for themselves.

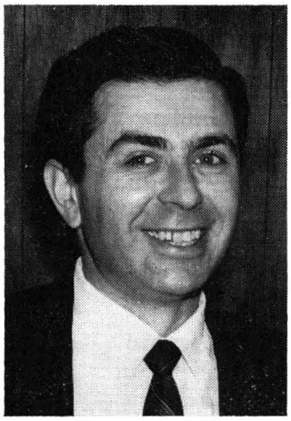
Programmed instruction can help you give your students a better education; I hope the information I have presented here will encourage you to try programs in your classroom.

References

1. Skinner, B. F., **Harvard Educational Review, 31,** (4), 1961.
2. Ausubel, D. P., The Psychology of Meaningful Verbal Learning, Grune & Stratton, New York, 1963, (pp. 213, 208, 212).
3. Resnick, L. B., **Harvard Educational Review, 33,** (4), 1963.
4. Hilgard, E. R., **Stanford Today,** Series 1, (6), Sept. 1963.

Dr. Charles E. Wales is an associate professor of engineering and the President's assistant for educational research and development at Wright State University. His present assignment includes organizing and presenting a series of seminars on effective teaching techniques for the Wright State faculty. He was educated at Wayne State (BSChE), University of Michigan (MSChE), and Purdue University (PhD).

Professor Wales has written programmed instruction material in the areas of material balance calculations and basic thermodynamics. His programs have been or are being used on an experimental basis at Purdue, Kansas State, West Virginia, Ohio, and Wright State universities, at the Universities of Texas and Missouri (Columbia), and at Ohio College of Applied Science.



ChE book reviews

Engineering Thermodynamics
M. W. Zemansky and H. C. Van Ness,
McGraw-Hill (1966).

Professors Zemansky and Van Ness have written a text on thermodynamics with the "common core" course in mind. As such, the text represents a combination of and selection from the material offered in the conventional beginning courses in thermodynamics in the chemical and mechanical engineering curricula. In following this path, the authors had to judge that certain topics included in these portions of the typical chemical engineering program would either be deleted, or discussed in other courses. A similar statement, but with different topics in mind, applies equally well to the typical mechanical engineering program.

Viewed against the background of the typical chemical engineering program, there are certain features which make this book different. First, there are a number of applications discussed in the text which are not presently included in this part, if indeed in any part, of the chemical engineering program. In this category are such topics as "bars in tension and compression" (chap. 2), "work in straining a bar" (chap. 3), "work in changing the polarization of a dielectric in a parallel plate capacitor" (chap. 3) "work in changing the magnetization of a magnetic solid" (chap. 3) and some of those discussed in "applications" (chap. 14).

Secondly, a number of the classical experiments are discussed. This includes the determination of "J" factor mechanical equivalent of heat (chap. 4), determination of $(\partial U/\partial P)_T$ of a gas (chap. 5), reversible change of volume of a gas (chap. 7), and the measurement of latent heat of vaporization (chap. 11) to cite a few. By the discussion of experimental methods and the inclusion of experimental data in some figures, I believe the authors are attempting to impress on the student the physical significance of the quantities which are later used in the solution of problems. This is a part of education which is apparently being phased out in the fundamental sciences and mathematics.

Looking at the other side of the coin, the missing material, the chemical engineer will note that "fugacity" is not mentioned. The theorem of correspondence states is introduced and used only in one problem—11.1. Also, only mixtures of ideal gases are considered. Nothing is included on heats of solution, or properties of real mixtures, and very little on thermochemistry. Also, the development and use of the humidity