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1973

A CAI LANGUAGE FOR MINI-COMPUTERS  
WITH SAMPLE DIALOGUE AND PROBLEMS  
RELATING PHYSICS AND WILDLAND HYDROLOGY

by

William Otto Rasmussen

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A Dissertation Submitted to the Faculty of the  
DEPARTMENT OF WATERSHED MANAGEMENT  
In Partial Fulfillment of the Requirements  
For the Degree of  
DOCTOR OF PHILOSOPHY  
In the Graduate College  
THE UNIVERSITY OF ARIZONA

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THE UNIVERSITY OF ARIZONA

GRADUATE COLLEGE

I hereby recommend that this dissertation prepared under my  
direction by William Otto Rasmussen  
entitled A CAI LANGUAGE FOR MINI-COMPUTERS  
WITH SAMPLE DIALOGUE AND PROBLEMS  
RELATING PHYSICS AND WILDLAND HYDROLOGY  
be accepted as fulfilling the dissertation requirement of the  
degree of Doctor of Philosophy

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## ABSTRACT

Various teaching techniques and methodologies have evolved in education. Among the most recent are those usually attributed to S. L. Pressey and B. F. Skinner. Their contributions, while differing from each other in format, are presently bound together by the term Programmed Instruction. These basic ideas have been utilized on numerous types of teaching machines; the most recent is the computer. The computer methods are usually referred to as CAI (Computer Assisted Instruction). One drawback in using CAI has been the need of a large computer, often with time-sharing capabilities.

A CAI package has been developed for mini-computers (eight thousand words of core or less) such that it is now economically feasible for small university departments, small educational institutions, and medium-sized companies to buy outright or lease a mini-computer and the necessary peripheral equipment to engage a CAI method in teaching.

An explanation of a working CAI system for mini-computers in conjunction with a detailed lesson of programmed text amenable to this system are the body of this work. The lesson involves the principles of physics as manifested in wildland hydrology. It covers a wide range of concepts. The lesson is also written to illustrate various techniques of presenting programmed instruction. The CAI language has been made as portable as possible so that it may be transferred to other types or

brands of mini-computers. The language has also been developed to involve a minimum of coding symbolism for the author to learn in order to write a lesson. The basic computer language which supports the CAI language is FORTRAN II.

An additional feature of the language is that it is essentially multilingual. Only four statements in the language are linked to a given language. These can be changed in a matter of minutes so that the CAI language would be completely dedicated to a new tongue.

The mini-computer utilized need not be dedicated entirely to educational purposes. The system might be used for data acquisition or other purposes. In its free time it could be used for education. A system of this type was used in the development and testing of the CAI language over the past two years.

## CHAPTER 1

### INTRODUCTION

Mini-computers are becoming more numerous as technology progresses. Their cost is now such that all universities, departments, and small commercial firms can afford them. The term mini-computer is used to mean computers with a core of approximately eight thousand words of sixteen bits each.

The problem that has confronted the potential user of a mini-computer for educational purposes is that a language for Computer Assisted Instruction, hereafter referred to as CAI, did not exist (Entelek Information Exchange 1965-1972, Hickey 1968). A large number of CAI languages have been produced, but all require medium to large computers. With the current state of the art in programmed instruction and computer assisted instruction, it would be extremely useful to have a CAI language for various mini-computers.

The primary goal of the work presented herein was to produce a portable, generalized, and compact CAI author language for mini-computers. The larger languages (Entelek 1965-1972, Hickey 1968, Meadow 1970, Orr 1968) possess some features which had to be omitted for a compact language due to the size of the computer core. However, these omissions were not to affect seriously the flexibility and power of the resultant language. The development of this language has been a matter of many process trade-offs. Therefore, an author language was designed

to fulfill, as nearly as possible, the following set of requirements:

- (1) Written in a language easily transferred to other computers;
- (2) Small number of operation codes for an author to learn;
- (3) Numeric response may be integer, floating point, or exponential;
- (4) Alphanumeric response;
- (5) Multiple choice questions;
- (6) Multiple pass through 3 and 4 above;
- (7) Calculation ability at any time;
- (8) Exit and restart a lesson at any time;
- (9) Use of student's name in communication;
- (10) Use by another tongue.

A major problem was to "student proof" the language (i.e., unforeseen student responses should not be able to hinder the running of a given lesson using the language. Much of the design criteria was biased by the constraint that the language was to be used primarily by undergraduates in an empirical area of science.

Many mini-computers are used for specialized purposes. However, they may not be completely dedicated. It is for these periods of non-dedication to other duties that the computers may be used for educational purposes.

One detriment to using a one terminal mini-computer is that only one student can be handled at a time. This does not become a serious problem with classes of less than thirty students.

With only slight modifications, this new CAI language can be dedicated to a specific computer to provide more power and flexibility. This would allow the student to use stored computational programs and to write and execute his own programs. The student would exit the lesson to do these things, then re-enter at the point he left to continue on through. It would also have nearly equal abilities to larger computer installations in general programmed instruction. Several frilly features will still remain only available on larger computers.

A second objective of the project was to write a lesson relating concepts of physics to wildland hydrology. This lesson was written using the author language coding. In this form, it can be directly transcribed into punched tape at a teletype console and then run on the computer using the developed author-language program. The lesson was also written to exemplify various methods of linear and branching programmed instruction.

Various terms with which the reader may be unfamiliar are defined in the back.

## CHAPTER 2

### FRAMEWORK OF PROGRAMMED INSTRUCTION

Programmed instruction, with which CAI is integrally involved, is generally held to have evolved from the works of Pressey (1926) and Skinner (1954). In 1924, Pressey (1926) invented a small machine (Deterline 1962) that would score a multiple-choice examination automatically at the time the response button was engaged. The machine was originally designed to test students on material which they had already covered. He noticed that, by a slight modification, it could be used as a teaching device. This modification was to arrange the device such that the correct answer button had to be pushed before a subsequent question would appear. Each question had, of necessity, a multiple choice format. This simple device was the beginning of what are called teaching machines. They are defined by Cram (1961) to have the following three characteristics in common:

1. They present information and require frequent response by the student.
2. They provide immediate feedback to the student, informing him whether his response is appropriate or not.
3. They allow the student to work individually and to adjust his own rate of progress to his own needs and capabilities.

The machine does not teach. It simply brings the student into contact with the person who composed the material it presents. In this respect, the teaching machine is mostly excluded from being judged good

or bad, as these modifiers belong mainly to the programmed material and finally to the ability of the programmer to produce a lesson in a programmed instruction format.

An educational program (Anderson et al. 1969) consists of a series of small units called frames. Each frame is based on some previous knowledge possessed by the student, and each frame adds a small increment to his knowledge, moving the student steadily toward the terminal behavior or knowledge of the subject. A frame ordinarily introduces only one concept at a time along with an identifying characteristic or partial definition of it.

In the following, linear programs and branching programs will be mentioned. A linear program is one in which all frames are traversed by each student. A branching program is one in which reinforcement branching from some frames is used to better project the concept to the student. In this type of program, a more intelligent student may not encounter any of these reinforcement loops in going through the lesson, whereas the slower student may go through several of the reinforcement or review loops in his traverse through the lesson.

The device developed by Pressey (1926) used a multiple-choice linear program. His programming procedure is exemplified by frames 79 through 84 of Chapter 5 in this dissertation. Pressey (1926) was criticized by Skinner (1954) who contended that the relation of the answer with an incorrect response would tend to reinforce this linkage in the student's mind even after the correct response was later determined by the student. Skinner believed that recalling an answer was

superior to recognizing an answer in the process of learning or memorizing. Because of the research results by Skinner (1968), all of his programs were written to enable the student to construct his own response to a given question. He further stipulated that a frame should be small (approximately 30 words in length). Skinner's approach was limited to linear programming, as typified by frames 34 through 43 of Chapter 5 in this dissertation.

Crowder (1960) developed an approach to programming which calls for comparatively few responses for relatively large masses of stimulus material. A Crowder frame may be several paragraphs in length followed by a single multiple-choice question. The student is able to select the correct answer only if he has successfully dealt with the principles described at length in the paragraphs of the frame. The student takes a route through the program which is determined by his response to each question. This is an example of a branching program, as exemplified by frames 101 through 122 of Chapter 5 in this dissertation.

Another type of branching is opinion branching (Cram 1961). This is used when questions have more than one possible correct answer or have no correct answer at all, but rather express opinion. With a branching program, differing opinions may be given as alternatives, the subject being treated differently or in greater detail, depending on the branch chosen.

The permutation of linear branching, general branching, and opinion branching types of programs allows a programmer a great variety of frames in programming from the start of a lesson to the conclusion.

This approach was used most commonly in developing the wildland hydrology lesson.

The most versatile teaching machine available at this time is the computer (Anderson et al. 1969, Meadow 1970). Among its principal advantages is the speed of reaction, or the delay between student response and computer reaction, which is essentially imperceptible to the student. The computer can feed new information to a student as rapidly as it can be absorbed. A private tutor is the only other alternative. The computer modification or updating a text is rapid in contrast to producing new editions of textbooks or to reprinting a program disc for a teaching machine. A correction of a lesson using paper or magnetic tape for master lesson storage requires only a few minutes.

## CHAPTER 3

### AUTHOR LANGUAGE ELMIC

The author language, written in FORTRAN II for this project, allows the author and the student to interface with the computer and, therefore, with each other. The computer is assumed to be interfaced with a magnetic tape unit for support of ELMIC.

The author language (those codes which the instructional programmer uses, but the learner never sees) consists of the following material:

The text of a frame may be any length desired, and it is input just as it is output to the student with the exception of the code represented by the group of symbols `b#####b` (the `b`'s represent blanks). This code interjects the name of the learner at the point of encounter in the dialogue. It is limited to six characters. A frame at the beginning of the lesson asks the learner to type his name so that it may be stored in the computer.

All operation codes and other material contained in the logic portion of the frame begin adjacent to the left margin with the exception of the `b#####b` code.

Each logic code consists of two alphanumeric characters written on one line with a definition on the following lines.

- @@: This signifies the end of text for a given frame and the beginning of the logic to be used with the student's response.
- &&: This code implies that the logic portion of the frame has ended.
- >>: The >> operations code is used in place of && on the last frame to signify the end of the lesson.
- I0: This code implies a direct link to a frame the number of which is on the following line. An example of a direct link to frame 23 is:
- I0  
23.
- I1: The I1 operation means that a numeric answer response is expected from the student. The correct answer, as well as the respective frames to branch to for a correct and an incorrect response, are separated by commas on the following line. The language accepts integer, floating point, or exponential notation responses. It sorts out the type of response expected and adjusts the input to be compatible with it.

The language has been designed to accept a numeric response as correct if it is within  $\pm 2\%$  of the expected answer. The language also accepts a response which is off by a factor of ten, either high or low, as being a correct response, and branches as if a correct response were given after typing the following

to the student:

DECIMAL POINT ERROR. THE ANSWER SHOULD BE (expected answer). LET'S CALL IT CORRECT.

An example for a correct answer of 2.54 with branching to frame 27 for a correct response and frame 28 for an incorrect response would be:

I1  
2.54, 27, 28.

I2: This code is used when branching to a frame more than once. The first and second time the frame is encountered, there may be different answers as well as different frames to branch to for a correct and incorrect response. An example of the I2 code, where the first encounter with the frame branches logically, is the same as the example used for the I1 code. The second encounter has a correct answer of 2.54, branching to frame 30 for a correct response and to frame 33 for an incorrect response.

This is coded:

I2  
2.54, 27, 28  
2.54, 30, 33.

I3: This operation code is used for a multiple-choice response by the student. A maximum of ten answers is possible. The student response is a number between one and ten. The frames correspond to each of the total number of answers in the question posed the student. An example might be branching to frame

38, 39, 37, or 26 for a student response of 1, 2, 3, or 4 and would appear as:

I3  
38, 39, 37, 26.

- A1: This operations code implies an alphanumeric response of 1 to 72 characters. The frame number of the correct and the incorrect response appears on the following line. An example would be an answer of WEDNESDAY, with a correct answer branching to frame number 22 and an incorrect answer branching to frame 20 as shown by:

A1  
WEDNESDAY  
22, 20.

- A2: This operation code is the alphanumeric equivalent of I2, where the frame has different branching if it is passed through more than once. As an example of the use of this operation code, assume that the correct response is SUNDAY with the correct first pass response branching to frame 28 and incorrect response to frame 21. Assume the second pass has SUNDAY as a correct response and, associated with it, branching to frame 29 and to frame 38 for an incorrect response. The coding would appear as:

A2  
SUNDAY  
28, 21  
SUNDAY  
29, 38.

The above is the total repertoire of operation codes used in the author-language.

The learner has the following operation codes at his disposal for use at any time the teletypewriter is not outputting material from the computer:

**STOP:** This causes the program to sequence automatically to the end of the lesson where the student is queried if he or someone else wishes to repeat the lesson. If he answers yes, then the magnetic tape will be positioned such that the lesson begins again; otherwise, the lesson stops.

**MATH:** This command temporarily halts execution of the lesson and allows the student to use the computer as a calculator. The student has at his command the operations of addition, subtraction, multiplication, division, and exponentiation to a real number.

Each operation has a numeric code. The operations are done one at a time with the answer being output as ANS = (whatever the answer is appears here). The numeric code of each operation is:

1 = Addition	5 = Exponentiation
2 = Subtraction	0 = Return to program
3 = Multiplication	-1 = Do another operation
4 = Division	

For example, in order to take the square root of sixteen, add 6, and return to the main program to give the response requested by the current lesson frame, the sequence of operations would be:

16, 5, 15, 1	(student response)
ANS = 4.00	(computer response)
4.0, 1, 6, 0	(student response)
ANS = 10.00	(computer response)
Frame response requested	(student response to lesson frame).

The Hewlett-Packard 2114 B computer with magnetic tape system which was utilized in the work described herein, has a subroutine for handling magnetic tape called PTAPE. This routine was used extensively in the language to handle positioning of the magnetic tape. This subroutine handles up to 256 files. The first two files are used to store computer programs, while the next two are filled so that they might be used in the future for storing other data appertaining to the CAI language. Each instructional frame and accompanying logic compose one file. The configuration used allows a lesson of 252 frames.

A subroutine similar in function to PTAPE might easily be written by anyone not using a Hewlett-Packard machine. All that would be required is an operation code to be interjected in place of an EOF (end-of-file) mark, such that the new subroutine would treat these characters as PTAPE treats EOF marks. In such a new arrangement, all of

the lesson would be contained in one file, provided the total number of individual records is not beyond the file capacity.

Experience has shown that a lesson containing 252 frames would last well over an hour and, in all likelihood, beyond the attention span of the student.

## CHAPTER 4

### ANALYSIS OF ELMIC OPERATION

The functioning of the language begins with reading the various frames and their associated logic from paper tape to magnetic tape. Each educational frame plus logic is stored as one file on magnetic tape. The first two files are skipped over, as these contain other programs written in machine language and a library of subroutines. The next three files are not filled with data at this time. In the future they will be used when the language is dedicated to the Hewlett-Packard 2114 B computer. This dedication will greatly increase the power of this educational facility.

The first file is entered line by line as it is to appear on output to the student; however, #### is inserted wherever the student's name is to be used in execution of the program. As stated before @@ denotes end of text, and && the end of a frame. When && is encountered, the current record is replaced by a scratch record for use later in the program. Following this, an end-of-file mark is written. The text of the next frame is then read. A file counter called III (Appendix B) is used to determine the number of frames in the lesson. A >> in place of && is used to mean the end of the last frame in a lesson.

The magnetic tape is next positioned to the beginning of frame 1 of the lesson which is used to welcome the student and acquaint him with what the lesson will encompass. The student is then asked to type his

name is six characters or less. His response is stored by the program in the array NAME (Appendix A). This will overlay the textual portion of a frame when the symbols ## are encountered. After the student types his name, the program links with frame 2 where the lesson begins in educational context.

Frame 2 and all succeeding frames are handled as follows. The text portion of a frame is given to the student via a teletype. When the symbols @@ are encountered, the remaining portion of the frame is stored in the computer as the controlling logic for handling the student response to the current frame. This reaction from the logic is the number of the next frame to be presented to the student. The variable names listed below, unless otherwise mentioned, are described in subroutine LJGIC (Appendix E). The operation code of frame sequencing, as previously mentioned, is equated to a variable called ICODE in the program. If this variable is I1, I2, or I3, then a numeric response is expected from the student. If it is A1 or A2, an alphanumeric reply is anticipated.

In the case of I2 and A2, a switch is set using the variable ISP to tell if this is the first or second pass through the frame. In the event that ISP does not equal the frame number ITLK (Appendix A), the first branching in the logic will occur and ISP will be made equal to ITLK. If ISP is the same value as ITLK, the second portion of the logical branching will be brought into effect.

This double pass feature is not employed with operation code I3. In the case of I1 and I2, the correct numeric answer FNT1, the number of

the correct response frame IY, and the incorrect response frame INN are read from the magnetic tape and stored. The response is then input from the student by way of the subroutine REED and called AN (Appendix C).

If AN is within the range  $\pm 2\%$ , the answer is accepted as correct.

If the student response AN is off by one decimal point, either high or low, the following message is output to the student and his answer considered correct:

DECIMAL POINT ERROR. THE ANSWER SHOULD BE (FNT1). LET'S  
CALL IT CORRECT.

The reason for allowing a margin of error of 2% is to overcome an exact bit match of AN and FNT1. The two percent error allowance and the decimal point error are used to alleviate the student's fear of exactness which is required by a computer, and to give him a margin of error that was felt reasonable for undergraduate level students in a field which is not highly precise in regard to numeric answers.

In the case of A1 and A2, the correct response is recorded as the array JAN, which consists of up to 72 characters on one line. Following this, the correct and incorrect frame numbers to be branched to are read as IY and INN, respectively. The student response, again, is input through the subroutine REED as an array named IA to determine if a match is achieved. Before this comparison is made, JAN is trimmed of all trailing blanks.

The function of the multiple-choice operation I3 is to read into an array IB up to ten frame number choices that may be made in student input to a multiple-choice question. The student input comes through

subroutine REED and is an integer IN between one and ten which tells the element, or frame number, of the array IB to which branching will occur.

When IO is encountered in the logic section of a frame, that frame is linked with the frame the number of which is associated with IO. No answer is expected by the language at the end of the first frame.

The subroutine REED (Appendix C) is used as an intermediary between the student input and logic branching portion of the program. The scratch record produced by LOOD (Appendix B) just before the end-of-file mark was written is used to temporarily store and analyze the student response. The response is read in as alphanumeric with one character per word and written on magnetic tape. The first character of the input array IA is checked to determine if it is a letter or not. If the response begins with a letter, the program then rereads the array IA from magnetic tape under a two character per word alphanumeric format. If the first two words spell MATH, the math routine MATZ is brought into play. If the first two words spell STOP, the frame number to be branched to for ending or beginning a lesson is communicated to LOGIC for its activation. In the event neither of these words are encountered, the subroutine returns the array IA, the student response to the frame, to subroutine LOGIC (Appendix E) for use in A1 or A2 operations. In the event the first character of the student response is numeric, the array IA is reread from tape under a real number format.

The real number is called AN. The real number is then converted to an integer number IN. Both AN and IN were initially equated to 0.0

and 0, respectively, in REED so that as they are returned to subroutine LOGIC (Appendix E) they will have a meaningful value. Real numbers AN are normally used with I1 and I2 operations, while an integer number IN is used with the operation I3. This flexibility in REED allows the student to input an integer where a real number is being sought by LOGIC and a real number will be transmitted to LOGIC. The same is true for the student responding with a real number where an integer is expected, such that an integer is transmitted to LOGIC.

Subroutine TALK (Appendix D) is used to output to the student the text of each lesson frame. It begins by reading the array IA from magnetic tape. A check is made for @@, which would signify the end of text. If these characters are not found, the array is searched from left to right for the character combination ##. In the event the word ## is found, the word number in which this occurred is noted and one word is subtracted from it. The program then replaces eight characters in the array IA by those in NAME. The reason for backing up one extra word is that a word of two characters might have # as its second character. This is why, when a name is to be used in the text, a space is used before the five # characters. Once the student's name has or has not been placed in IA, the array undergoes a reverse search for blanks in a line 72 characters long. This search is from right to left. As soon as a word containing a non-blank character is found, the word position in the array is noted. The array is then output to the student in the form of a line of type up to and including the last two-character word containing a non-blank character. This is done to speed up the

output of a frame to the student by alleviating the necessity of printing a full line of 72 characters on every line. Trailing blanks are truncated, thereby reducing the line length and time to produce it.

The subroutine MATZ (Appendix F) was written to allow the student to use the computer as a calculator in solving numeric problems. The subroutine performs only one operation per input from the student. The student has at his disposal five mathematical operations. These are addition, subtraction, multiplication, division, and exponentiation to a real number, which are coded one through five, respectively. In addition, a numeric key must also be included to specify if additional calculations are to be done (negative number) or a return to the current frame (positive number) is desired. The subroutine begins with initializing the second computational number to 1.0. This is to avoid a division by zero or exponentiation to zero which would cause errors. The input is one line with the various numbers separated by commas. The format is: number 1, operation code; number 2, key number. The above format has program variables designated as FT, NC, FR, and NR, respectively. The calculation is carried out on FT and FR with the answer stored in BS. The program then outputs: ANS = BS. Following this, the key number is checked and, either another calculation is performed, or a return is made to a point where the answer to the question posed by the current frame is input by the student.

## CHAPTER 5

### PHYSICS IN WILDLAND HYDROLOGY CAI LESSON

The frame coding as outlined in Chapter 3 will be used for the following lesson. This will both exemplify the use of the coding and shorten the logic instructions at the end of the frame. The frame number has been introduced to facilitate the reader in going through the lesson. This number does not appear in normal use on a computer. (Appendix G). The material output by the teletype appears in upper case.

---

1

Hello!

Welcome to the first lesson of Physics of Wildland Hydrology. I know it sounds complicated, but we will try to keep it as simple as possible.

I (the person who wrote what the teletype prints) would like you to try to stretch your imagination and pretend I am sitting inside the computer and typing these messages to you.

Don't worry about getting an answer wrong, as this will not be held against you, just as correct responses are for your knowledge only. Try to keep in mind that errors are what lead to learning.

There is no rush, even if the teletype does respond rather quickly when you enter an answer. Just relax and go at your own pace.

All answers are input to the computer by typing the answer, then hitting the carriage return (CR) and then the line feed (LF) keys. This is necessary each time for the lesson to continue. As an example, to input the answer of 4.2, you would hit the following keys: 4 key, . key, 2 key, CR key, and LF key. For very large or very small numbers, they will be written in exponential notation (e.g., 4.3E-6, which is 4.3 times ten raised to the -6 power).

Now that you are probably tired of reading what I have written, would you please type your name so I will know what to call you. If your name is longer than six characters, please shorten it to six characters or less. Be sure to hit the carriage return and line feed keys after your name.

@@  
A2  
YU  
2, 2  
&&

---

2

Very good, ##### .

There are two things that you may type during the course of the lesson at any time the teletype is not chattering away. One of these is the word STOP, which will then allow you to end or start the lesson over again. The other word is MATH, which interrupts the lesson and allows you to use the computer as a calculator. When you have determined the answer you desire from calculations and have notified the math routine you want to return to the main lesson, you will then input the answer to the question which was previously posed to you.

Do you know how the routine MATH works, that is, how to do the calculations? Answer yes or no.

@@  
A1  
NO  
3, 4  
&&

---

3

The MATH routine uses the following codes:

1 = Addition	2 = Subtraction	3 = Multiplication
4 = Division	5 = Exponentiation	

To divide 8.0 by 3.0, type 8.0, 4, 3.0. Notice the commas separating the numbers.

Another number must be added at the end of the problem to tell whether you wish to return to the previous problem in the lesson or do more calculating. This is coded:

-1 = Continue            0 = Return to give answer to question

If you wanted to do more calculating, the above would be written:

8.0, 4, 3.0, -1

Follow by a carriage return and line feed.

@@  
 IO  
 4  
 &&

---

4

Let's start off the lesson discussing raindrops. For a particle (raindrop) falling through the atmosphere, the sum of the forces acting on the body equals the mass of the body (m) times its acceleration (a). This can be written as:

force due to gravity - force due to atmospheric  
 drag = net force on the body.

If the net force on the body is zero, then:

force due to gravity = force due to atmospheric drag.

Solving the differential equation of this relationship, the highest velocity of a raindrop of diameter (d), of a hemispherical shape, and drag coefficient (c) of .4 is called the terminal velocity. This is given by the relation

$$TV = (((2.22E4)D)/C)**(1/2)$$

where

TV = Terminal velocity (ft/sec)  
 D = Diameter of a spherical drop of the  
 same volume (feet)  
 C = Drag Coefficient = .4

Note: \*\* means raised to the following numeric power. As an example, 2.22E4 is exponential notation meaning 2.22 times ten raised to the fourth power, and may also be written as (2.22)(10\*\*4).

G. Chapman measured the following data for a red pine during a rainstorm which has already totally wet the tree.

AVG. RAIN INTENSITY (in/hr)		MEDIAN DROP SIZE (mm)	
<u>Open Field</u>	<u>Under Pine</u>	<u>Open Field</u>	<u>Under Pine</u>
.47	.48	1.56	3.47

@@  
I0  
5  
&&

---

5

Determine the terminal velocity in ft/sec for a raindrop of diameter 3.47 mm. Remember: 1 inch = 2.54 centimeters.

@@  
I2  
24.8, 8, 6  
24.8, 8, 7  
&&

---

6

Sorry, ##### , that is not correct.

Remember to take the square root, change all lengths to feet, and use .4 as the drag coefficient.

@@  
I0  
5  
&&

---

---

7

No, ##### , your answer is incorrect again.

To change from millimeters to feet, multiply by 3.28E-3.  
This gives the terminal velocity as

$$\begin{aligned} TV &= (((2.22E4)(3.47)(3.28E-3))/.4)**(1/2) \\ &= 24.8 \text{ ft/sec.} \end{aligned}$$

@@  
I0  
9  
&&

---

8

Good work, ##### , the terminal velocity for a raindrop  
3.47 mm in diameter is 24.8 ft/sec.

@@  
I0  
9  
&&

---

9

Now, what is the terminal velocity of a raindrop which has  
a diameter of 1.56 millimeters?

@@  
I1  
16.9, 10, 11  
&&

---

---

10

That is not right. The terminal velocity is 16.9 ft/sec for a raindrop 1.56 millimeters in diameter. You should have gotten this correct, as it is almost the same as the previous problem. Be more careful.

@@  
I0  
12  
&&

---

11

You are doing great. The terminal velocity for a raindrop which has a diameter of 1.56 millimeters is 16.9 ft/sec.

@@  
I0  
12  
&&

---

12

From what you have just done, you see that two raindrops have different terminal velocities. Which entity below is the main reason for this?

- 1) Shape
- 2) Size
- 3) Density
- 4) Evaporation

Answer with a number!

@@  
I3  
I3, 14, 13, 13  
&&

---

---

13

No, ##### , the correct term is size. The dissimilar size of the drops helped allow for the large difference in terminal velocities.

@@  
 IO  
 15  
 &&

---

14

Correct. The reason for the difference is due to the frictional term in the equation of motion. The size difference of the drops helped allow for the large difference in terminal velocities.

@@  
 IO  
 15  
 &&

---

15

The velocity of a particle at a distance X from the start of fall is

$$V = TV (1 - (E)^{-((2GX)/(TV^2))})^{1/2}$$

where

V = Velocity of particle (ft/sec)  
 E = Base of natural logarithms  
 G = Acceleration of gravity  
 X = Distance of fall  
 TV = Terminal velocity

To reach 90% of the terminal velocity, the distance of fall reduces to which of the following?

- 1)  $X = (2.59E-2)(TV^{**2})$  feet
- 2)  $X = (8.62E-2)/(TV^{**2})$  feet
- 3)  $X = (2.59E-2)/(TV^{**2})$  feet
- 4)  $X = (8.62E-2)(TV^{**2})$  feet
- 5)  $X = (1.66)(TV^{**2})$  feet

Answer with a number!

@@  
I3  
17, 16, 16, 16, 16  
&&

---

16

Well, you gave it a try, #####, but you were wrong. The correct answer is 1. This comes from

$$.9TV = TV (1 - (E)^{**(-(2GX)/(TV^{**2}))})^{**}(1/2).$$

Squaring the above and rearranging terms gives

$$E^{**}((2GX)/(TV^{**2})) = 1/(1-.81).$$

By taking the natural logarithm (LN) of both sides, the result is

$$\begin{aligned} \text{LN } 5.26 &= (2GX)/(TV^{**2}) \\ \text{LN } 5.26 &= 1.66 \end{aligned}$$

$$\begin{aligned} X &= (1.66/(2)(32))(TV^{**2}) \\ X &= (2.59E-2)(TV^{**2}) \text{ feet} \end{aligned}$$

@@  
I0  
18  
&&

---

---

17

That was an excellent choice, as it is correct.

@@  
I0  
18  
&&

---

18

Let's see how good you are at multiplying. What is the distance a raindrop, which has a diameter (d) of 3.47 mm, must fall to reach 90% of its terminal velocity? The terminal velocity is 24.8 ft/sec.

@@  
I1  
15.9, 20, 19  
&&

---

19

Sorry, ##### , you didn't fare so well. The correct answer is 15.9 feet.

@@  
I0  
21  
&&

---

---

20

Sure enough, ##### , the distance required is 15.9 feet.

@@  
I0  
21  
&&

---

21

Now, please find the distance to reach 90% of terminal velocity for a raindrop which has a diameter of 1.56 mm. The terminal velocity is 16.9 ft/sec.

@@  
I1  
7.38, 23, 22  
&&

---

22

Wrong, ##### , you can do better than that. The answer is 7.38 feet.

@@  
I0  
24  
&&

---

---

23

Yes, the distance required to reach 90% of terminal velocity is 7.38 feet.

@@  
10  
24  
&&

---

24

If you will look back where the original data was presented, you will notice that a fall of 15.9 feet under the pine will bring the drop's velocity (3.47 mm in diameter) up to 90% of its terminal velocity. It requires only 7.38 feet for drops characteristic of those in the open (1.56 mm in diameter) to acquire 90% of their terminal velocity.

@@  
10  
25  
&&

---

25

Assume the rain storm lasts for 1 hour at an average intensity of .48 in/hr. Determine the kinetic energy per square foot per hour imparted to the ground under the tree canopy? Assume that the average height to the bottom of the tree canopy is 15.9 feet. Give the answer in kilowatt hours per square foot per hour, and use exponential notation for the number. Remember: 1 foot-lb =  $3.766E-7$  kilowatt-hours. Water weighs 62.4 pounds per cubic foot.

@@  
12  
7.32E-6, 28, 26  
7.32E-6, 28, 27  
&&

---

---

26

No, ##### , that is not correct. Check your units to see that you are using mass and not weight. The kinetic energy is  $(1/2) M ((V)**2)$ . Also check that your dimensions are in feet.

@@  
I0  
25  
&&

---

27

No, Charlie Brown, you have erred again.  
The mass (M) equals the volume times the mass per volume.

$$M = (.48/12 \text{ ft})(1 \text{ ft}**2)((62.4/32)(\text{slugs}/\text{ft}**3))$$

The velocity equals 22.3 ft/sec. The kinetic energy/square foot/hour equals  $7.32\text{E}-6$  kilowatt-hours/square foot/hour.

@@  
I0  
29  
&&

---

28

Well done, ##### , the correct answer is  $7.32\text{E}-6$  kilowatt-hours/square foot/hour.

@@  
I0  
29  
&&

---

---

29

An aid in the comprehension of how much energy is contained in a kilowatt-hour is to think of it being equal to the energy used by ten 100-watt light bulbs left on for one hour.

For a second problem, assume the rainfall lasts for one hour at an average intensity of .45 in/hr. Determine the kinetic energy per square foot per hour for the ground in the open.

@@

I2

3.92E-6, 32, 30

3.92E-6, 32, 31

&&

---

30

That is not correct. Check your units and try again.

@@

I0

29

&&

---

31

Wrong! What are we to do with you? The answer is 3.92E-6 kilowatt-hours/square foot/hour.

@@

I0

33

&&

---

---

32

Well done, ##### , the problems are not as hard as you might have believed, I hope.

@@  
IO  
33  
&&

---

33

The two previous problems show that the energy per area per time being imparted to the ground via rainfall impact from the same storm is nearly twice as large under the tree canopy per square foot as in an open field.

This is caused by the drops being larger under the canopy due to drops coalescing and dripping from the leaves and branches. These drops have not had a chance to be broken up by oscillation and turbulence, as do other drops falling over long distances in the open.

@@  
IO  
34  
&&

---

34

I know it is possible to get up to this point and not know the difference between mass and weight. Let's see if you do know the difference.

If a man gets on a scale, on earth, he may find his \_\_\_\_\_ is 150 pounds.

@@  
A1  
Weight  
35, 35  
&&

---

---

35

##### , his weight is 150 pounds.

@@  
I0  
36  
&&

---

36

Weight is a measure of an attractive force. On earth it is the force of attraction between an object and the \_\_\_\_\_.

@@  
A1  
Earth  
37, 37  
&&

---

37

On earth weight is the force of attraction between an object and the earth.

@@  
I0  
38  
&&

---

---

38

Gravitational force is equal to mass times the acceleration due to gravity. If a body weighs 128 pounds, and the acceleration of gravity is 32 feet per second per second, then the \_\_\_\_\_ of the body is 4 slugs.

@@  
A1  
Mass  
39, 39  
&&

---

39

The mass of the body is 4 slugs.

@@  
I0  
40  
&&

---

40

The mass of a body is the constant which relates the force applied to a body with the resulting acceleration. For a given body, if the acceleration due to gravity changes, the \_\_\_\_\_ will not change.

@@  
A1  
Mass  
41, 41  
&&

---

---

41

The mass of a body will not change; it is an inherent property of the body.

@@  
IO  
42  
&&

---

42

Weight is measured in pounds (lb), and mass is measured in slugs in the English system of measurements. The acceleration due to gravity on the earth's surface is 32 feet per second per second. Thus, the mass of a body is its \_\_\_\_\_ divided by 32 feet per second per second.

@@  
A1  
Weight  
43, 43  
&&

---

43

Mass (in slugs) is the weight (in pounds) divided by the acceleration due to gravity of 32 feet per second per second.

@@  
IO  
44  
&&

---

---

 44

The next topic we will discuss is the amount of energy imparted to the ground by way of radiation from the sun. The units usually used are langleyes per time. Langleyes are equal to energy per area; therefore, langleyes per time is equal to energy per area per time. The time periods usually involved are minutes or days, so that the energy input is expressed as langleyes per minute or langleyes per day. You should see from this that langleyes per time is equal to kilowatt-hours per area per time with the use of a conversion factor.

One langley is equal to one calorie per square centimeter.

##### , let's see if you can deal with the units involved. If the average radiation in March is 310 langleyes per day, what is the amount of energy in kilowatt-hours per square meter after striking the ground for a time period of 24 hours?

Remember: 1 calorie equals  $1.163\text{E}-6$  kilowatt-hours. Don't worry about diffuse radiation, earth radiation, etc.

@@  
 I2  
 3.54, 46, 45  
 &&

---

45

I'm afraid not, ##### . The correct answer is 3.54 kilowatt-hours per square meter. Be more careful with the units involved.

@@  
 I0  
 47  
 &&

---

---

46

Good going, ##### . The answer is 3.54 kilowatt-hours per square meter.

@@  
I0  
47  
&&

---

47

Can you now tell me the energy in kilowatt-hours falling on an area 30 by 25 feet in the course of a day, when the average irradiance is 310 langleys per day?

One square foot equals  $9.29E-2$  square meters.

&&  
I1  
246.0, 49, 48  
&&

---

48

You are having problems with your math or units, as the correct answer is 246 kilowatt-hours.

&&  
I0  
50  
&&

---

---

49

The energy would be 246 kilowatt-hours. You are handling the math and units very well.

@@  
I0  
50  
&&

---

50

As a digression, if the above area was the roof of a small home which was 100% absorptive and the energy used in the house during one day was 7 kw-hr of electricity and 1 therm = 29.3 kw-hr of gas for a total of 36.3 kilowatt-hours, do you think the collection of solar energy could be a major energy source?

Answer yes or no.

@@  
A1  
Yes  
51, 52  
&&

---

51

I feel that it could also be a major source of energy in the future.

@@  
I0  
53  
&&

---

---

52

You are welcome to your opinion, but I feel that solar energy could be a major source of energy in the future. You may ask, what about night, when the sun is not shining? There is now a very efficient method of storing electrical energy; this is by electrolysis of water and later the burning of the hydrogen and oxygen formed with no noxious byproducts. The heat produced would run a power plant as the burning of coal does now.

Let's get back to wildland hydrology.

@@  
I0  
53  
&&

---

53

If the latent heat of vaporization of water is 580 calories per gram, how many areal inches of water could be evaporated in a day when the solar irradiance is totally used for this? Assume the solar irradiance is 310 langley's per day.

@@  
I2  
.211, 54, 55  
&&

---

54

Good, ##### , there would be .211 inches evaporated per day.

@@  
I0  
56  
&&

---

---

55

No, ##### , there would be .211 inches evaporated per day.

Energy for 1 day: 310 langleys = 310 calories/square centimeters. Now, 580 cal/square centimeters would evaporate 1 centimeter, so 310 will evaporate

$$\begin{aligned} 310/580 &= .534 \text{ cm} = (.534/2.54) \text{ inches} \\ &= .211 \text{ inches.} \end{aligned}$$

@@  
10  
56  
&&

---

56

Power (P) is the rate of change of energy (E) with respect to time (t). This can be approximated by  $P = E/t$ .

If average irradiance is 310 langleys per day, what is the power density in units of calories per hour per square centimeter?

@@  
11  
12.9, 57, 58  
&&

---

57

Yes, ##### . I hope that was simple enough.

@@  
10  
59  
&&

---

---

58

No, ##### . The answer is 12.9 calories per hour per square centimeter. This comes from

$$P = E/t = (310 \text{ cal/square centimeter})/(24 \text{ hours}) \\ = 12.9 \text{ calories/square centimeter/hour.}$$

@@  
I0  
59  
&&

---

59

Air movement or wind is very important in many of the processes occurring on a watershed. It is involved with evaporation, transportation, dynamic stressing of trees, snow melt, etc.

&&  
I0  
61  
&&

---

60

As an example of the magnitude of wind pressure on a tree, assume we are making calculations on a 100 foot red maple subjected to a 20 mile/hour wind. The problem is to find the force exerted on the crown which is 90 feet in diameter. The crown also will be assumed spherical in shape. It will only absorb 50% of the kinetic energy portion of the impingent wind.

I want you to do this in three steps. First, what is the kinetic pressure of a 20 mile per hour wind in terms of newtons per square meter?

Remember: The density of air is 1.293 kg/cubic meter at 0 degrees centigrade and 1 atmosphere of pressure. One mile per hour equals 0.447 meters/second. Treat the air as a fluid to simplify things.

@@  
I1  
51.5, 64, 65  
§§

---

61

Kinetic pressure of a fluid is defined as  $(1/2)(C)(V^{**2})$   
where

C = Density of the fluid  
V = Velocity of the fluid.

The fluid here is air.

Pressure is also defined as force per area. We have assumed the direction of the force is perpendicular to the plane of the area.

If the density and the area remain the same, but the velocity doubles, what happens to the force?

- 1) Remains the same
- 2) Doubles
- 3) Decreases by one-half
- 4) Increases by a factor of four
- 5) Decreases by a factor of four
- 6) Decreases by a factor of two

Answer with a number!

@@  
I3  
62, 62, 62, 63, 62, 62  
§§

---

---

62

Nope, the force increases by a factor of four, which is answer 4. This is shown by

$$(1/2)(C)(V^{**2}) = F/A$$

If C and A are constant, then doubling V will cause F to increase by a factor of 4 to keep the equality true.

@@  
I0  
60  
&&

---

63

Very well done. The force increases by a factor of four when the velocity is doubled and the other variables are held constant.

@@  
I0  
60  
&&

---

64

Yes, ##### . The answer is 51.5 newtons per square meter.

@@  
I0  
66  
&&

---

---

 65

That is wrong, ##### . The answer is 51.5 newtons per square meter. This answer comes from putting the values in the kinetic pressure equation of

$$(1/2)(C)(V^{**2})$$

where

C = 1.293 kilograms per cubic meter  
V = 8.94 meters per second.

@@  
I0  
66  
&&

---

66

Now, ##### , what is the cross sectional area in square meters of a sphere which has a diameter of 90 feet? (One square foot equals .0929 square meters.)

@@  
I1  
590.0, 68, 67  
&&

---

67

The correct answer is 590 square meters for the cross sectional area. Be more careful with your units, ##### .

@@  
I0  
69  
&&

---

---

68

That is correct. The cross sectional area is 590 square meters.

@@  
I0  
69  
&&

---

69

Will you now tell me the force in pounds that is acting on the tree? Assume that only 50% of the force is acting on the tree. One newton equals .2248 pounds.

@@  
I2  
3.43E3, 71, 70  
&&

---

70

#### , the correct force is 3.43E3 pounds. This is arrived at by  $F = PA$  where

F = Force  
P = Kinetic pressure  
A = Cross sectional area.

In this case, we only want 50% of F, so the answer is (.5)PA.

@@  
I0  
72  
&&

---

---

71

Good. I see you are handling things quite well.

@@  
I0  
72  
&&

---

72

If one wanted to compute the torque due to this force on the tree about a point at the surface, how long would the moment-arm be in feet?

@@  
I1  
55.0, 74, 73  
&&

---

73

I'm afraid not, ##### . The center of the crown is where all the force may be assumed acting. Since the main crown begins 10 feet from the ground and is 90 feet in diameter, the moment-arm or distance to the center of the crown from the ground is 55 feet.

@@  
I0  
75  
&&

---

---

74

That is right. The moment-arm is 55 feet.

@@  
I0  
75  
&&

---

75

Assuming the moment-arm is perpendicular to the force, what is the torque about the surface in ft-lb? Use exponential notation for your answer.

@@  
I1  
1.88E5, 77, 76  
&&

---

76

That is not correct, ##### . Torque about the ground in the above case is the product of force and moment-arm length. This gives 1.88E5 ft-lb as the answer.

@@  
I0  
78  
&&

---

77

Very good, #####! You remembered that torque in this case is just the product of the force and the moment-arm length.

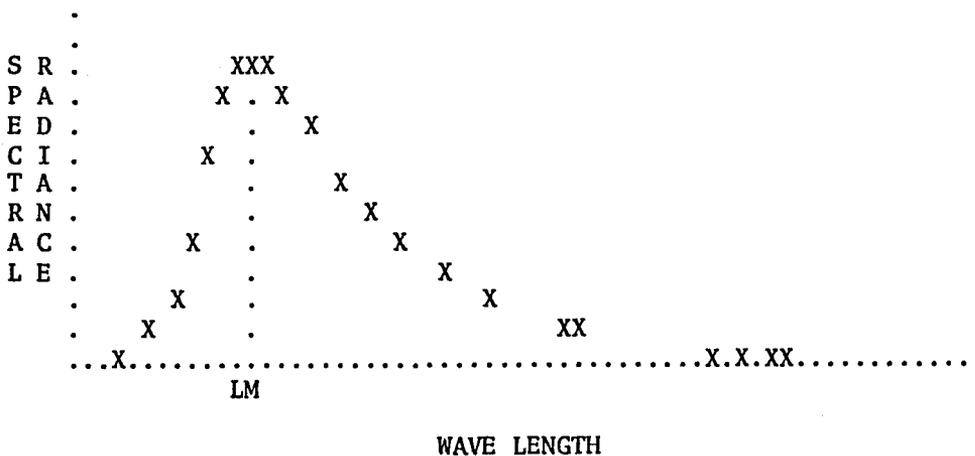
@@  
IO  
78  
&&

78

Wind is a very important process in relation to evaporation, transpiration, and several other things.

##### , I'm going to present material to you in a little different format. We will be talking about snow and some of the processes or concepts related to it.

A graph of Spectral Radiance of a black body at a particular temperature against wavelength would look somewhat like this:



The equation of this curve is given by Planck's law, with which we will not deal. The maximum spectral radiance is at a wavelength  $\lambda_m$ . Another gentleman by the name of Wien determined the relation that the product of the wavelength, in microns, at maximum spectral radiance ( $\lambda_m$ ) times the temperature ( $T$ ) of the black body was a constant. This is stated as

$$\lambda_m(T) = 2897.0$$

where

$$\begin{aligned} \lambda_m &= 10E-6 \text{ meters} = \text{microns} \\ T &= \text{degrees kelvin.} \end{aligned}$$

@@  
I0  
79  
&&

---

79

For a black body at a temperature of 32 degrees F., what is the wavelength ( $\lambda_m$ ) at maximum spectral radiance in microns? You will get another problem when you make the correct choice. Answer with an integer.

- |            |         |         |            |
|------------|---------|---------|------------|
| 1) 1.06E-5 | 2) 5.5  | 3) 90.5 | 4) 905.0   |
| 5) 1.06    | 6) 10.6 | 7) 7.3  | 8) 9.05E-5 |

@@  
I3  
79, 79, 79, 79, 79, 80, 79, 79  
&&

---

80

Integrating the above curve over all wavelengths gives the radiant emittance of a black body at temperature T. The results of this are given by Stefan's Law:

$$E = S(T^{**4})$$

where

S = Stefan's constant = .826E-10 langleys per  
minute per degree kelvin  
to the fourth power

T = Temperature in degrees kelvin

E = Radiant emittance in langleys per minute.

@@

10

81

88

81

For a black body which has a temperature of 0 degrees C., the radiant emittance in langleys per minute is

- |            |            |            |
|------------|------------|------------|
| 1) 7.65E-3 | 2) 5.38E-2 | 3) 0.459   |
| 4) 4.59    | 5) 1.38E-2 | 6) 7.65E-3 |

Answer with an integer. A correct answer will send you on.

@@

13

81, 81, 82, 81, 81, 81

88

---

82

##### , a gray body is one which, at a given temperature, emits a fixed proportion of black body radiation at that temperature in all wavelengths. Snow has low reflectance for long wave radiation and high reflectance for short wave radiation.

@@  
I0  
83  
&&

---

83

From what is given above, snow radiates like:

- 1) A gray body
- 2) A black body
- 3) Not enough data given
- 4) Neither a gray nor a black body
- 5) A white body

Answer with an integer. Again, a correct answer will send you on through the lesson.

@@  
I3  
83, 84, 83, 83, 83  
&&

---

---

84

Yes, ##### , snow is very nearly a perfect black body with respect to long wave radiation. This is physically due to the rough texture due to snow crystals and that the maximum temperature can only be 32 degrees F. As such, a snow pack will radiate according to Stefan's Law.

@@  
I0  
85  
&&

---

85

also \_\_\_\_\_ A snowpack will absorb radiation from the sun and will radiate due to its own temperature.

@@  
A2  
Emit, 86, 85  
&&

---

86

Good going, ##### . You used the magic word and got to this point.

One source of energy input to a snowpack is the radiation of the sun; others are: convective heat transfer (sensible heat) from the air; latent heat of vaporization released by condensate of water vapor; heat of rain water; and some other processes which involve negligible amounts of heat and thus will not be examined.

Most of what follows deals with melt of the snowpack when it is ripe. A ripe snowpack is one which is isothermal at 0 degrees C., and has approximately 3 percent by weight free water (i.e., has its free water holding capacity satisfied).

Convection melt is a function of temperature, wind velocity, and atmospheric pressure.

Condensation melt is a function of vapor pressure difference between air and snow surface, and wind velocity.

Rainfall melt is a function of temperature of the rain and the amount of rainfall.

From May on, let us assume radiation melt per day is about four times the amount of the sum of convection and condensation melt. This seemed to hold for an area in the central Sierras and will probably vary with location.

After all that, I hope you haven't fallen asleep, ##### . Let me give you a couple of problems regarding snow to see if you are still awake.

The latent heat of fusion for water is 80 calories per gram. How many calories are required to melt 20 grams of ice?

@@  
I2  
1600.0, 88, 87  
&&

---

87

No, ##### , the product of the latent heat of fusion with the number of grams is the answer. This gives (80 calories/gram) (20 grams) which equals 1600 calories.

@@  
I0  
89  
&&

---

88

There certainly are 1600 calories required.

@@  
I0  
89  
&&

---

89

---

#### , assume 200 grams of snow at -10 degrees C. and 0 free water content. How many calories are required to bring this to a ripe condition which has a free water content of 3 percent? Free water content is the weight of liquid water retained by a snowpack and is expressed as a percentage of the total weight. The heat capacity of snow is 0.5 calories per gram degree C.

- 1) 1000 cal.          2) 1240 cal.          3) 2480 cal.  
4) 820 cal.          5) 1960 cal.          6) 1480 cal.

Answer with an integer from 1 through 6.

@@  
I3  
90, 90, 90, 90, 91  
&&

---

90

Bad choice, #### . The correct answer is number 6 (1480 calories). It takes  $(200)(.5)(10) = 1000$  calories to warm the snow to 0 degrees C. Three percent free water content is  $(.03)(200) = 6$  grams. It takes  $(80)(6) = 480$  calories to change the 6 grams of ice to water. The total heat required is  $1000 + 480 = 1480$  calories.

@@  
I0  
92  
&&

---

---

91

Good choice, ##### . I hope you worked this out and did not just guess.

@@  
I0  
92  
&&

---

92

Let me see how well you do with this, ##### .  
Assume in the open there is a net all-wave radiation gain measured to be .12 langley per minute. Let this radiation continue at this level for 6 hours. It falls on a ripe snowpack with a 3 percent free water content satisfied. How much melt in inches will be produced?

@@  
I2  
.219, 95, 93  
&&

---

93

Not quite; the heat input is 43.2 calories per square centimeter. Try the problem again.

@@  
I1  
.219, 95, 94  
&&

---

94

---

Wrong again. The answer is .219 inches of melt due to 43.2 calories per square centimeter of heat flux. At a 3 percent free water content, the heat required to produce 1 centimeter of melt is (.97)(80) calories and 43.2 calories will give

$$(43.2)/(.97)(80) \text{ cm} = .556 \text{ cm} = .219 \text{ in.}$$

@@  
I0  
96  
&&

---

95

Very nice, ##### ; the answer is .219 inches of melt, which will be produced from 43.2 calories per centimeter input to a ripe snowpack of 3 percent free water content.

@@  
I0  
96  
&&

---

96

How much melt in inches is produced due to rainfall heating by a 1.0 inch storm on a ripe snowpack which has a free water content of 3 percent? The temperature of a wet bulb thermometer two feet above the snow is 20 degrees C.

@@  
I1  
.256, 98, 97  
&&

---

---

97

No, the rain would input 50.8 calories per square centimeter. The rest of the problem would be the inches melt that is given by  $(50.8)/(.97)(80)(2.54) = .256$  inch. The key to this is that the temperature of rain just above the ground is very close to that of a wet bulb thermometer.

@@  
I0  
99  
&&

---

98

Yes, the answer is .256 inches of melt. You did very well in getting this answer.

@@  
I0  
99  
&&

---

99

##### , do you know why water runs downhill? Answer yes or no.

@@  
A1  
No  
100, 101  
&&

---

---

 100

The flow downhill is due to the force of gravity. Gravitational force is due to the attraction of the mass of the earth with each mass element of the stream. The mass of the earth may be supposed to be concentrated at a point at the center of the earth. The line between the mass element of the stream and the center of the earth is the direction of attraction between the two bodies. Water being a fluid allows deformation or movements of its components in response to this attractive force.

There are other forces which also operate on the motion of the particles of mass in a stream which are due to the rotation of the earth. These will not be considered here.

@@  
 IO  
 101  
 &&

---

101

I think it is time we looked at open channel flow.

In order to deal with this process, we must know a few equations.

From an equation for the conservation of mass, which states that the integral over an arbitrary surface of the rate of mass flow is equal to the change of mass inside the surface, we obtain the relation:

$$(D1)(V1)(A1) = (D2)(V2)(A2) = \text{the rate of change of mass.}$$

For a volume with only two viable portions of area denoted by areas (A1) and (A2) mass can only enter there or leave the surface. The density (D) remains constant for an incompressible flow.

If we now assume we are dealing with an open channel carrying water of density  $(D1) = (D2)$ , then the product of the average velocity by the cross sectional area is equal at the two points 1 and 2 and equals the discharge (Q). This gives the equation:

$$Q = (A1)(V1) = (A2)(V2).$$

If the cross sectional area of a stream at the downstream end of a channel is twice the upstream end, what is the downstream velocity in terms of the upstream velocity?

- 1) Twice
- 2) One-half
- 3) Neither

Answer with a number!

@@  
I3  
102, 103, 102  
&&

---

102

No! The answer is one-half. You're not thinking.

@@  
I0  
104  
&&

---

103

Right, the velocity is halved. On we go.

@@  
I0  
104  
&&

---

104

An equation which is used quite extensively in fluid mechanics is that of Bernoulli. A modification of this equation to deal with open channel flow and also the addition of a term to account for viscosity is given by

$$(1/2)(V_1^{**2}) + (G)(Z_1) = (1/2)(V_2^{**2}) + (G)(Z_2) + E$$

or

$$(1/2)(C_1^{**2} - V_2^{**2}) + G(Z_1 - Z_2) = E.$$

This equation is for a length of streamline with an upstream position given as position 1 and downstream as position 2. Multiplying by the mass (M) between positions 1 and 2 on the stream gives:

$$(1/2) M(V_1^{**2} - V_2^{**2}) + MG(Z_1 - Z_2) = ME$$

where

- V<sub>1</sub> = Average upstream velocity
- G = Acceleration due to gravity
- Z<sub>1</sub> = Upstream elevation from datum plane
- V<sub>2</sub> = Average downstream velocity
- Z<sub>2</sub> = Downstream elevation from datum plane
- E = Energy loss per unit mass between points 1 and 2
- M = Mass between points 1 and 2.

This equation is the common conservation of energy equation:

$$\text{Change in Kinetic Energy} + \text{Change in Potential Energy} = \text{Change in Energy Due to Other Sources.}$$

In what follows I want you to use the latter energy equation and the equation for the conservation of matter.

In a channel which has a fluid cross sectional area of 500 square feet with a velocity of 6 feet per second, what do you think the discharge is in cubic feet per second?

@@

11

3000.0, 106, 105

§§

---

105

#### , if you use the conservation of mass equation, you will get the discharge as the product of velocity and cross sectional area. The correct answer is  $(6)(500) = 3000$  cubic feet per second.

@@  
I0  
107  
&&

---

106

That is correct. It also should have been simple to do using the conservation of mass equation.

@@  
I0  
107  
&&

---

107

Let me give you another similar problem.  
Assume a stream goes 3 miles with an elevation change of 10 feet. What is the velocity (feet per second) at the end of this stretch of river if it is 6 feet per second at the top? Assume an ideal fluid (no friction or viscosity involved).

@@  
I1  
26.0, 109, 108  
&&

---

---

108

Nope, the correct answer is 26 feet per second. This comes by assuming kinetic energy is gained from the loss of potential energy.

$$(1/2)M(V_2^{**2} - V_1^{**2}) = MG(Z_2 - Z_1)$$

Dividing this by (M/2) and, putting in the known values, we get:

$$V_2^{**2} = 36 + 640 = 676$$

$$V_2 = 26 \text{ feet per second.}$$

@@  
 IO  
 110  
 &&

---

109

Fine, ##### , the velocity at the lower end will be 26 feet per second.

@@  
 IO  
 110  
 &&

---

110

From the answer to the above problem, and assuming the cross sectional area at the upper end of the stream stretch is 500 square feet, what is the cross sectional area at the lower end in square feet?

@@  
 I1  
 115.0, 112, 111  
 &&

---

---

111

No, ##### , the problem is similar to the one you did a bit ago. The answer is 115 square feet.

@@  
I0  
113  
&&

---

112

Good show! The area is 115 square feet at the lower end of the stream stretch.

@@  
I0  
113  
&&

---

113

Now, I want you to put together some of the things we have been talking about.

Assume we have a stream which has an elevational change of 100 feet in 6 miles. Assume also that the average velocity of 6 feet per second remains constant throughout the 6 miles, and let the average cross sectional area of the stream be 500 square feet. The water now has a viscosity.

How long (in seconds) would it take a particle to go the 6 miles traveling at the average velocity?

- |              |                |             |
|--------------|----------------|-------------|
| 1) 5280 sec. | 2) 31,700 sec. | 3) 880 sec. |
| 4) 8800 sec. | 5) 3170 sec.   | 6) 528 sec. |

Answer with an integer from 1 through 6.

@@  
I3  
115, 114, 114, 114, 114, 114  
&&

---

114

Come now, ##### , distance divided by velocity gives time. The correct answer is 5280 seconds.

@@  
I0  
116  
&&

---

115

Sure enough, ##### , the time taken for such a travel would be 5280 seconds.

@@  
I0  
116  
&&

---

116

Will you now tell me which of the following is the mass (in slugs) of the same stream for a length of 6 miles? (One cubic foot of water weighs 62.4 pounds.)

- |                 |                 |                 |
|-----------------|-----------------|-----------------|
| 1) 5.24E8 slugs | 2) 5.24E7 slugs | 3) 3.11E5 slugs |
| 4) 3.11E7 slugs | 5) 9.90E8 slugs | 6) 9.90E5 slugs |

Answer with an integer from 1 through 6.

@@  
I3  
117, 117, 117, 118, 117, 117  
&&

---

117

Sorry. The best answer is 3.11E7 slugs. This is the volume multiplied by the density. The density is  $62.4/32 = 1.95$  slugs per cubic foot.

@@  
I0  
119  
&&

---

118

Right. The answer is the volume times the density, which gives 3.11E7 slugs.

@@  
I0  
119  
&&

---

119

How much potential energy (in megawatt-hours) was lost if one assumed each particle of mass in the 6 mile stretch went 6 miles at the given slope? (One foot-pound equals  $3.766E-10$  megawatt-hours.)

@@  
I1  
37.2, 122, 120  
&&

---

---

120

No, ##### . Be sure to convert your answer to megawatt-hours. Try again.

@@  
I1  
37.2, 122, 121  
&&

---

121

Wrong again. The correct answer is 37.2 megawatt-hours. Take your time and think these things out a little more.

@@  
I0  
123  
&&

---

122

Good job, ##### . The correct answer is that 37.2 megawatt-hours of potential energy were released. Try the following problem having to do with the same stream.

@@  
I0  
123  
&&

---

---

123

Now, treat the 6 mile stretch of stream as a block on an inclined plane of slope equal to that of the stream. Using the time taken to go the 6 miles at the velocity of the stream, what is the power produced during this time? Give your answer in megawatts.

@@

I1

25.0, 125, 124

&&

---

124

That is incorrect. Power is approximately energy divided by time (rate of change of energy with respect to time). In this case, the time is 5280 seconds = 1.49 hour, and the energy is 37.2 megawatt-hours. The answer is 25 megawatts.

@@

I0

126

&&

---

125

Yes, ##### , the power is energy divided by time, which gives 25 megawatts. You are doing well.

@@

I0

126

&&

---

---

126

If we assume the average evaporation rate of the stream to be .05 inch per hour, then how many inches of water are evaporated in the time it takes the stream to flow 6 miles?

@@  
I2  
.075, 128, 127  
&&

---

127

No, the correct answer is .075 inches.

@@  
I0  
129  
&&

---

128

Yes, there would be .075 inches evaporated.

@@  
I0  
129  
&&

---

129

Now, assume the average width of the stream is 50 feet. What is the total surface area (square feet) of the stream for a length of 6 miles?

- |                       |                       |
|-----------------------|-----------------------|
| 1) 4.59E6 square feet | 2) 1.59E6 square feet |
| 3) 3.17E4 square feet | 4) 2.64E5 square feet |

Answer with an integer from 1 through 4.

@@  
I3  
130, 131, 130, 130  
&&

---

130

Not so, ##### . The area is just the width by the length,  
which is 1.59E6 square feet.

@@  
I0  
132  
&&

---

131

Right! The area is 1.59E6 square feet.

@@  
I0  
132  
&&

---

132

By assuming the heat of vaporization to be 580 calories  
per gram, determine the energy in megawatt-hours used to evaporate  
.075 inches on six miles of the stream. (One calorie equals  
1.163E-9 megawatt-hours and one slug equals 1.459E4 grams.)

@@  
I1  
191.0, 135, 133  
&&

---

---

133

Sorry, ##### , this is wrong. As a hint, there are 2.82E8 grams being evaporated. Now, how many megawatt-hours are required to evaporate this mass of water?

@@  
I1  
191.0, 135, 134  
&&

---

134

Still wrong, ##### . The answer is 191 megawatt-hours. I hope you do better with this next problem.

@@  
I0  
136  
&&

---

135

The correct answer is 191 megawatt-hours which are required for the evaporation, so you are correct.

@@  
I0  
136  
&&

---

136

##### , there is energy input to the stream due to solar radiation, convection in relation to the atmosphere, conduction from the ground, and other sources. I don't want to treat these processes separately now. Instead, they will be lumped into one term and called solar-sensible energy.

Assume the stream has an average energy albedo of 5 percent. Let the average energy density per time be 310 langleys per 12 hours. How many megawatt-hours of energy are absorbed by the 6 mile length of stream in the time of 1.49 hours? (One langley equals one calorie per square centimeter, one calorie equals  $1.163\text{E-}9$  megawatt-hours, and one square foot equals 929.0 square centimeters.) Assume zero transmission.

@@  
I1  
62.8, 138, 137  
&&

137

Sorry, #####, that is not correct. It is a difficult problem, if that is any consolation. The answer is 62.8 megawatt-hours. This comes from the product of the following:

Absorption coefficient times area times energy density,

which is

$$(.95)((1.59\text{E}6)(929))((310/12)(1.49)(1.163\text{E-}9)).$$

@@  
I0  
139  
&&

138

Excellent, #####. The answer is 62.8 megawatt-hours. That was a difficult problem.

@@  
I0  
139  
&&

---

139

By adding up the energies associated with potential energy change, evaporation, and solar sensible heat, would the stream cool off? Answer yes or no.

@@  
A1  
No  
141, 140  
&&

---

140

I'm afraid it is the other way. The stream will cool. If you look at the energies and remember that potential and solar-sensible heat are going into the stream while the energy of evaporation is being withdrawn, there results  $(37.2) - (191.0) + (62.8) = -91.0$  megawatt-hours. Thus, the stream is losing energy and, hence, cooling.

@@  
I0  
142  
&&

---

141

Right. If you add the various energies up, you find the stream lost 91 megawatt-hours, which means it cooled.

@@  
I0  
142  
&&

---

---

142

The mass of the 6 mile stretch of stream is  $4.52E11$  grams. If the specific heat of water is 1 calorie per gram per degree C., how many degrees C. will the stream cool? (One calorie equals  $1.163E-9$  megawatt-hours and one megawatt-hour equals  $8.601E8$  calories.)

@@

I1

.173, 144, 143

&&

---

143

Wrong, the correct answer is .173 degrees C. That was quite easy. You must not have multiplied correctly or kept your units straight.

@@

I0

145

&&

---

144

Well done. The stream temperature would drop .173 degrees C. from the analysis we have made.

@@

I0

145

&&

---

145

An equation often used to determine or approximate the discharge of a channel is that attributed to Manning. Manning's equation is:

$$Q = (1.49/N) (A) (R^{2/3}) (S^{1/2})$$

where

Q = Discharge  
 A = Cross sectional stream area  
 R = Area divided by wetted perimeter  
 S = Slope  
 N = Roughness factor (empirical).

If we assume a channel measures 50 feet wide and 10 feet deep, discharges 3000 cubic feet per second, and has a slope of 100 feet in six miles, this implies the roughness factor (N) is equal to .0515, which is too high. A more realistic value of N would be .02, which is supposed to correspond to a fairly competent rock with some gravel. In this case, the discharge is 7220 cubic feet per second. If the cross sectional area remains the same (500 square feet), what average stream velocity (feet per second) would be applicable?

@@  
 I1  
 14.5, 147, 146  
 &&

146

No, ##### , the corresponding average stream velocity would be 14.5 feet per second.

@@  
 I0  
 148  
 &&

---

147

Yes, the corresponding average stream velocity would be 14.5 feet per second.

@@  
I0  
148  
&&

---

148

The evaporation and solar sensible heat energies were figured over the length of time it would take to go 6 miles traveling at the average stream velocity. Using the velocity computed above to adjust the energies, would the stream cool off? Answer yes or no.

@@  
A1  
Yes  
150, 149  
&&

---

149

That is wrong. Under the conditions stipulated, the stream would still cool. The energy balance for potential, evaporative, and solar sensible heat would be 37.2, -78.9, and 26.0 megawatt-hours, respectively, which add up to -5.7 megawatt-hours.

@@  
I0  
151  
&&

---

---

 150

Correct. The stream would still cool off. The new energy terms for potential, evaporative, and solar sensible energies would be 37.2, -78.9, and 26.0 megawatt-hours, respectively, which add up to -5.7 megawatt-hours.

@@  
 IO  
 151  
 &&

---

151

So far, in dealing with water movement, it has been only on the surface. There is another component of water flow, which is into the ground. This is called infiltration. A number of equations have been put forward for describing infiltration into soil which does not already contain all the water it can hold. This is called unsaturated flow, with which we will not deal at this time. Rather, we will look at water movement in soil which is saturated.

The equation attributed to Darcy is generally used for this case. This equation is:

$$Q = KA (HI-HO)/L$$

where

Q = Rate of fluid movement  
 K = Hydraulic conductivity  
 A = Cross sectional area  
 HI = Pressure inflow head + gravity inflow head  
 HO = Pressure outflow head + gravity outflow head  
 L = Distance between inflow and outflow.

The pressure head is measured from heights of water columns relative to a reference level. The gravitational head is measured from soil sample heights and position from a reference level.

Darcy's equation is analagous to Ohm's Law: hydraulic conductivity is a measure of the ease with which water moves through a given soil, just as (1/resistance) is a measure of the ease of flow of charged particles through an object. The driving force in our case is the hydraulic gradient, while voltage is used in the electrical case. Rate of fluid movement (Q) is analagous to rate

of charge movement (current).

As an example of the use of Darcy's equation, assume a vertical column of soil with reference level at the bottom. Let  $L = 6$  feet,  $A = 1$  square foot, and  $Q$  was measured to be  $9.15E-6$  cubic feet per second. Determine the hydraulic conductivity of the soil in the column in terms of feet per second. (Express your answer in exponential notation.)

@@

I1

9.15E-6, 154, 152

&&

152

No, ##### . As a hint, the pressures are

$$H_I = 0 + L$$

$$H_O = 0 + 0$$

where pressure is measured in terms of feet.

Now, choose the correct answer for the hydraulic conductivity.

- |                              |                              |
|------------------------------|------------------------------|
| 1) $3.04E-5$ feet per second | 2) $3.04E-6$ feet per second |
| 3) $9.15E-6$ feet per second | 4) $9.15E-5$ feet per second |

Answer with an integer from 1 through 4.

@@

I3

153, 153, 154, 153

&&

---

153

You are wrong again. The correct answer is  $9.15E-6$  feet per second. This comes from

$$\begin{aligned} K &= QL/(A(HI-HO)) \\ &= (9.15E-6)(6)/(1)(6-0). \end{aligned}$$

@@  
I0  
155  
&&

---

154

Yes indeed, the hydraulic conductivity is  $9.15E-6$  feet per second.

@@  
I0  
155  
&&

---

155

I have just a few things left to cover in this lesson, ##### . We are almost done.

A variation of the Manning formula used for overland flow of thin layers is:

$$Q = (1.486/N)D^{5/3}S^{1/2}W$$

where

Q = Discharge in cubic feet per second  
N = Manning coefficient for overland flow  
D = Depth of layer in feet  
S = Slope in feet per feet  
W = Width of layer in feet.

The value N is often referred to as the

- |                             |                              |
|-----------------------------|------------------------------|
| 1) geometric coefficient    | 2) acceleration coefficient  |
| 3) infiltration coefficient | 4) retardance coefficient    |
| 5) velocity coefficient     | 6) transmittance coefficient |

Answer with an integer 1 through 6!

@@  
I3  
156, 156, 156, 157, 156, 156  
&&

---

156

Sorry, ##### , that was a bad choice. The N value is often referred to as the retardance coefficient.

@@  
I0  
158  
&&

---

157

Retardance it is. Good going, ##### .

@@  
I0  
158  
&&

---

---

158

The name retardance is used because the value

- 1) reflects the amount of litter on a hillside
- 2) reflects the surface properties over which the water must flow
- 3) reflects properties of a non-ideal fluid in movement
- 4) reflects the degree of vorticity encountered
- 5) all of the above
- 6) something other than above.

Answer with an integer 1 through 6!

@@  
I3  
161, 161, 161, 161, 160, 159  
&&

---

159

No, the correct answer is number 5, as retardance is a function of all the things listed.

@@  
I0  
162  
&&

---

160

Very good choice, ##### .

@@  
I0  
162  
&&

---

---

161

#### , you are partially correct. The value of N is a function also of the other factors listed. The best choice would be number 5.

@@  
IO  
162  
&&

---

162

You might think of N as a sort of friction coefficient. This may make its use a bit easier to understand. This should also help to show the empirical nature of the Manning formula.

Some values of N used for overland flow are:

Heavy timber	N = .100
Light brush and trees	N = .055
Firm gravel	N = .020
Smooth earth	N = .018.

Assuming precipitation on a 10% slope of firm gravel which has a width of 500 feet with a resultant discharge of 55.3 cubic feet per second, what was the average depth in inches?

@@  
IO  
167  
&&

---

---

163

That surprised me. You are correct and handled it very well.

@@  
I0  
167  
&&

---

164

Sorry, #####, you are not correct. Try rearranging the formula to solve for D as:

$$D = (Q(N/1.486)S^{**(-1/2)}(1/W))^{**(3/5)}.$$

Remember: This gives you the depth in feet, and I want the depth in inches. Now, what do you calculate the depth to be?

@@  
I1  
.48, 165, 166  
&&

---

165

Good, you got the correct answer that time.

@@  
I0  
167  
&&

---

---

166

That is not correct, ##### . The correct depth is .48 inches. Try to see where you went wrong.

@@  
I0  
167  
&&

---

167

Since you now know the depth to be .48 inches, tell me what the average velocity is in feet per second.

@@  
I1  
2.77, 168, 169  
&&

---

168

Sure enough, the average velocity is 2.77 feet per second. I hope you used the easy way of determining this; namely, discharge equals cross sectional fluid area times average velocity.

@@  
I0  
170  
&&

---

---

169

##### , that is wrong. The correct answer is 2.77 feet per second. This can easily be obtained from the relation that discharge equals the cross sectional fluid area times the average velocity.

I hope you do better in the future.

@@  
I0  
170  
&&

---

170

An effect which I feel is rather interesting is the pressure due to rain.

Let's assume a similar storm as we did at the beginning of this lesson. Let the precipitation in the open be of a uniform intensity to give .47 inches per hour. Also, let the average raindrop velocity be 16.9 feet per second.

First, tell me what the kinetic energy of this storm is in terms of foot-pounds per square foot per hour.

@@  
I1  
10.9, 171, 172  
&&

---

171

That is good, ##### . The kinetic energy is one-half times mass times velocity squared. This gives 10.9 foot-pounds per square foot per hour.

@@  
I0  
173  
&&

---

---

172

No, you are incorrect. The kinetic energy is one-half times mass times velocity squared. This gives:

$$(1/2)(.47/12)(62.4/32)(16.9^{**2}) = 10.9$$

foot pounds per square foot per hour.

@@  
I0  
173  
&&

---

173

The next thing I want you to tell me is the density of the fluid (rain and air) in terms of slugs per cubic foot. (Use exponential notation.)

@@  
I1  
1.26E-6, 174, 175  
&&

---

174

You're getting the hang of it. The correct density is 1.26E-6 slugs per cubic foot.

@@  
I0  
176  
&&

---

---

175

Not so, ##### . The density is the mass divided by the volume this mass is dispersed in. The volume over one square foot is the velocity of fall times the duration of fall. This gives the volume as  $(16.9)(60)(60)$  cubic feet. The mass is  $(.47/12)(62.4/32)$  slugs. The density is, therefore,  $1.26E-6$  slugs per cubic foot.

@@  
I0  
176  
&&

---

176

The kinetic pressure of a fluid is one-half times the density times the velocity of movement squared. What is the kinetic pressure exerted on the ground by the rainfall in pounds per square foot? (Use exponential notation.)

@@  
I1  
1.8E-4, 177, 178  
&&

---

177

Yes, the kinetic pressure is  $1.8E-4$  pounds per square foot.

@@  
I0  
179  
&&

---

---

178

No, the kinetic pressure is  $1.8E-4$  pounds per square foot.  
This comes from

$$(1/2)(1.26E-6)(1.69^{**2}).$$

@@  
I0  
179  
&&

---

179

Since there are 144 square inches in one square foot, the  
pressure could be described as

$1.25E-6$  pounds per square inch.

Is that right or wrong?

@@  
A1  
Right  
180, 181  
&&

---

180

Yes, of course, that is right.

@@  
I0  
182  
&&

---

---

181

Wrong! The pressure I gave you, in pounds per square inch, was right. You can divide, I hope.

@@  
IO  
182  
&&

---

182

The above is dynamic pressure, not static pressure. The main distinction between these is, in the case of dynamic pressure, energy is being transferred, which does not happen for static pressure.

Don't forget that pressure is force per area.

Just for the heck of it, what is the velocity of the earth relative to an average raindrop used above? (Give your answer in feet per second.)

@@  
II  
16.9, 183, 184  
&&

---

183

Right! Einstein's principle of relativity isn't so hard after all.

@@  
IO  
185  
&&

---

---

184

Wrong. The velocity of the earth, if you are moving with the raindrop, appears to be 16.9 feet per second. Einstein's principle of relativity isn't so hard after all.

@@  
IO  
185  
&&

---

185

Soil compaction is a problem in some areas. It is the packing together of soil particles by instantaneous forces exerted at the soil surface, resulting in an increase in soil density through a decrease in pore space.

Infiltration is the passage of water into the soil through the surface.

Does soil compaction increase or decrease infiltration?

@@  
A1  
Increase  
186, 187  
&&

---

186

No, after compaction the soil has less voids for water to enter and, thus, decreases infiltration.

@@  
IO  
188  
&&

---

---

187

Yes, after compaction the soil has less voids for water to enter and, thus, decreases infiltration.

@@  
I0  
188  
&&

---

188

Soil compaction, in general, tends to encourage surface erosion. Yes or no?

@@  
A1  
Yes  
189, 190  
&&

---

189

Correct, ##### .

@@  
I0  
191  
&&

---

---

190

That is not correct, ##### .

@@  
I0  
191  
@@

---

191

Soil compaction decreases infiltration and, thus, increases surface runoff, which encourages more surface erosion.

The static pressure exerted by several creatures was measured to be:

Sheep	9.2 pounds per square inch
Cattle	23.9 pounds per square inch
Man	6.5 pounds per square inch

Compaction from grazing has been determined to be limited, mainly to the 1-inch surface layer.

Infiltration by woodland grazing in western North Carolina in the cove-hardwood type of vegetation was found reduced by which of the following percentages?

- |                  |                   |
|------------------|-------------------|
| 1) Ten percent   | 2) Thirty percent |
| 3) Sixty percent | 4) Ninety percent |

Answer with an integer 1 through 4!

@@  
I3  
192, 192, 192, 193  
@@

---

---

192

No, believe it or not, infiltration was found to be reduced by ninety percent.

@@  
IO  
194  
&&

---

193

Yes, the infiltration was found to be reduced by ninety percent.

@@  
IO  
194  
&&

---

194

This shows that the effect of grazing is very much related to infiltration and should be kept in mind.

In what follows, answer each question with true or false. The correct answer will be given to you after your reply. Most of these principles are given by H. W. Lull in his analysis of compaction.

The amount of compaction depends on the degree to which the stress applied to the soil overcomes the resistance the soil offers to deformation.

True or false?

@@  
AI  
True  
195, 195  
&&

---

---

195

The correct answer is True.

The resistance that the soil offers depends on its moisture content, texture, structure, density, and organic content. True or false?

@@  
A1  
True  
196, 196  
&&

---

196

The correct answer is True.

As this resistance is overcome, the effect is to pack individual soil particles closer together and to crush soil aggregates, thereby increasing pore space.

True or false?

@@  
A1  
False  
197, 197  
&&

---

197

The correct answer is False. Pore space is reduced.

Resultant additional solid materials per unit volume decrease the resistance of the soil to deformation to a point where resistance and stress are in equilibrium and no further compaction occurs.

True or false?

@@  
A1  
False  
198, 198  
§§

---

198

The correct answer is False. Additional solid materials per unit volume increase the resistance of the soil to deformation.

As soil-moisture content increases, resistance to stress decreases and compaction can be achieved with progressively reduced leads.

True or false?

AA  
A1  
True  
199, 199  
§§

---

199

The correct answer is True.

Maximum density is obtained at a moisture content about midway between field capacity (water content at which capillary forces begin to predominate over gravitational forces) and wilting point (water content at -15 bars of pressure).

True or false?

@@  
A1  
True  
200, 200  
§§

---

---

200

The correct answer is True.

Increasing the moisture content beyond that point mentioned above, further lowers the resistance to compaction and reduces the maximum density.

True or false?

@@  
A1  
True  
201, 201  
&&

---

201

The correct answer is True.

Soils that have the greatest range of particle-size (i.e., medium textured soils) compact to lesser densities, the finer particles fill the voids between coarser particles.

True or false?

@@  
A1  
False  
202, 202  
&&

---

202

The correct answer is False. These soils compact to greater densities.

The less dense the soil, the greater the opportunity for compaction.

True or false?

@@  
A1  
True  
203, 203  
&&

---

203

The correct answer is True.

The greater the organic content, the smaller the maximum compaction and the greater the moisture content required for maximum compaction.

True or false?

@@  
A1  
True  
204, 204  
&&

---

204

The correct answer is True.

Soil freezing tends to compact soil by breaking down water-stable aggregates and tends to loosen compacted soils.

True or false?

@@  
A1  
True  
205, 205  
&&

---

---

205

The correct answer is True.

The length of time a soil remains in a compacted state doesn't depend on the stresses the soil undergoes by swelling and shrinking from changes in moisture content and temperatures.

True or false?

@@  
A1  
False  
206, 206  
&&

---

206

The correct answer is False. The duration of compaction depends largely on the stresses undergone by the soil in swelling and shrinking.

Compaction increases bulk density, reduces total pore space by the same proportion, reduces noncapillary pore space a greater amount, and has its greatest effect on infiltration.

True or false?

@@  
A1  
True  
207, 207  
&&

---

207

The correct answer is True. This is somewhat of a reiteration of previous statements.

Erosion and sediment transport are two of the most complex processes on a watershed. Due to this, I will have you play with several simple problems. The solutions you obtain are not intended to be general or complete.

Erosion starts because of many things, among which are impact, breaking, plucking, bouyant lifting, or chemical decomposition. Surface erosive agents are falling rain and flowing

---

Try guessing at the correct word to complete the sentence.

@@  
A1  
Water  
208, 209  
&&

---

208

Yes, water is the key word to the type of erosion we are dealing with.

@@  
I0  
210  
&&

---

209

No, water is the magic word.

@@  
I0  
210  
&&

---

210

Soil particles cling to each other by relatively strong forces of adhesion and cohesion. Falling rain works mainly to detach soil particles and the resulting sheet, rill, gully, and channel flow works principally to transport them.

The critical erosion velocity (competent velocity) is the lowest velocity at which grains of a given size, loose on the bed of a channel, will move. Assume that grains of 0.5 mm in diameter have an erosion velocity of 20 cm/sec. Is the erosion velocity of smaller grains higher or lower?

@@  
 A1  
 Higher  
 212, 213  
 &&

---

211

The erosion velocity is greater for the finer grains because of strong cohesive forces which bind the grains. Also, with smaller grains making up the bottom of the channel, the bed tends to be smooth. There are, thus, no protruding grains to aid entrainment by forming local eddies or turbulence. Entrainment means to collect and transport by a fluid, as I have used it here and later on.

Is the erosion velocity higher or lower for grains larger than 0.5 mm in diameter?

@@  
 A1  
 Higher  
 214, 215  
 &&

---

212

Yep, you are right. Sure you didn't guess?

@@  
 IO  
 211  
 &&

---

---

213

No, the correct reply is higher.

@@  
IO  
211  
&&

---

214

Right answer. I wonder if your reasoning was correct.

@@  
IO  
216  
&&

---

215

Wrong! Try thinking your answer out a little more.

@@  
IO  
216  
&&

---

216

Grains larger than 0.5 mm are hard to entrain simply because of the size and weight of the particles. Therefore, they require a higher fluid velocity.

It is rather interesting that once grains below 0.5 mm in diameter (silts and clays) are entrained, they can be transported at much lower velocities.

Grains of 0.5 mm in diameter and larger are moved by the stream (competence) as a function which varies as the sixth power of the velocity. Particles how many times larger can be moved by doubling the stream velocity?

Give your answer as a number.

@@  
 I1  
 64.0, 217, 218  
 &&

---

217

Very good. You can raise two to the sixth power quite well.

@@  
 I0  
 219  
 &&

---

218

No, all you have to do is raise two to the sixth power, which is 64.

@@  
 I0  
 219  
 &&

---

219

This so-called sixth power formula you just used is valid for only limited cases. It must be modified for small particles.

The settling velocity of a spherical particle is given by Stokes Law as:

$$V = 2(G)(R^{**2})(D1-D2)/(9*B)$$

where

V = Settling velocity  
 G = Acceleration of gravity  
 R = Radius of particle  
 D1 = Density of particle  
 D2 = Density of liquid  
 B = Absolute viscosity of liquid.

Deposition occurs when the upward components of velocity fall is \_\_\_\_\_ the settling velocity for a given grain size and the particle drops out of suspension.

Above or below?

@@  
 A1  
 Below  
 220, 221  
 §§

220

Yes, when the net velocity is down, the particle is dropped.

@@  
 I0  
 222  
 §§

221

No, you need to have a net downward velocity to deposit the particle. The answer is below.

@@  
 I0  
 222  
 §§

---

222

Stokes Law holds only for small grains which are spherical in shape. For larger grains, the forces of inertia have to be taken into account, and much more complicated formulas apply. In brief, for small grains, settling velocity is proportional to the square of the diameter; whereas, for larger particles of a diameter greater than 0.1 mm, the settling velocity is proportional to the square root of the grain diameter.

We can go on with more equations relating various aspects of sediment transport, but I am getting tired.

I think we will not look at any other processes in this lesson. We will leave them for another time.

This concludes this lesson. I hope you now have a better understanding of some of the processes which are occurring on a wildland watershed.

@@  
I0  
223  
&&

---

223

no.) Do you or someone else wish to repeat the lesson? (Yes or

@@  
A1  
Yes  
1, 1  
>>

---

## CHAPTER 6

### USE OF ELMIC AND RESULTS

The educational language for mini-computers (ELMIC) has been used for two years as a teaching aid for several courses in the Department of Watershed Management. Three lessons were written for a course in forest mensuration (WSM 215). The class was composed of approximately twenty students, each of whom went through a given lesson at some time on the same week. Due to the system configuration, only one student could be handled at a time. The students of the first year were instructed to give their comments on the particular lesson and turn it in for evaluation of the program branching and clarity of frames. The second year students used lessons which had been slightly modified due to first year student criticism. The second year students were allowed to keep their copies of the teletype output. The student reaction was highly enthusiastic to the second year approach, where they could review later what was covered in the CAI lesson.

An extensive lesson appertaining to precipitation interception by vegetative cover has been written and tested on students of academic levels varying from sophomore to graduate. Their reactions to the lesson varied from greatly enthusiastic to lack of interest. Some graduates and sophomores liked it and had little trouble going through it; others complained of its difficulty and did not like this type of

instruction. These latter students also varied across the board in academic level.

A portion of the interception dialogue mentioned above has been translated into Spanish (Appendix G). This example of CAI has been shown to several groups from Mexico and other countries. The outcome of these demonstrations initiated considerable interest in using mini-computers for instruction in other countries and languages. Examples of the English and Spanish versions of a segment of the interception lesson are given in Appendix G. An example is also given there of the student-machine interaction for this same portion of the lesson.

The language was used in a large portion of a professional paper by a graduate student in the Department of Watershed Management (Hekman 1972). The lesson subject material used in this case was mathematical linear programming. Four lessons were utilized in introducing the student to this subject.

Determining the merit of a CAI author language is difficult (Deterline 1962, Markle 1967, Skinner 1968). Given an average language and excellent author, the overall result the student will see is very similar to that of an excellent language used by an average author. Because of this ambiguity, any analysis performed at the student level may not strictly imply the merit of the author language.

## CHAPTER 7

### CONCLUSIONS AND RECOMMENDATIONS

The CAI author language, ELMIC, has the flexibility and power to meet all the requirements of any teaching machine. It has the additional ability of being further developed on a par with the most advanced CAI systems. The possibility now exists of taking practically any programmed text now in existence and immediately transferring it to a lesson or group of lesson which could be used with ELMIC. The greatest limitation of the system used is the number of students that can be handled at any one time. However, with time sharing, this limitation could be greatly reduced.

The use of the student's name in the printout by the computer appears to be quite successful in establishing intimacy in the student-computer relationship.

Since the educational concepts were determined more important than the exactness of the answer, the limits of plus or minus two percent on the numeric answers, as well as allowing for one decimal point error, are subject to change by the user of ELMIC. This is felt appropriate at an undergraduate level; whereas, other limits may be more applicable in other fields.

ELMIC requires only about 4500 words of computer core using words of sixteen bits each. The program for ELMIC is written and input to the Hewlett-Packard computer using ASCII coding in a slight

variation of the FORTRAN II computer language. Abundant documentation is included so that ELMIC can be rewritten should other formats be required.

ELMIC has been used for two years within the Department of Watershed Management with good results.

ELMIC is not designed to replace a teacher; but rather, it is designed for teacher backup by exploring in greater detail certain aspects of a subject which would otherwise require too much class time. In this respect, it would be used during a laboratory period of a class and would act as a pseudo teaching assistant.

A combination of all types of linear and branching programming seems to hold the student's attention better than an entire lesson of one type.

The version of ELMIC described herein was written for general use on most computers. It is to be dedicated, in the future, to a Hewlett-Packard computer so that additional techniques might be incorporated. A desirable technique is to allow the student to use the computer as a computer per se, as well as other programs, during a lesson sequence. This feature has rarely been incorporated into CAI, even in sophisticated systems such as PLATO (Blitzer and Johnson 1971). This dedication will allow various types of programs to be run within a lesson. This immensely increases the power of ELMIC, or the overall teaching ability of a terminal. It will then have certain types of teaching abilities which are beyond many of the large installations. This dedication could be modified for use on other brands of mini-computers.

Since the procedures being used in the dedication might benefit computer programmers in CAI, these are outlined as follows:

- (1) The subroutine LOOD is made a program in itself with a chain to ELMIC at its completion;
- (2) A frame number is read from file three;
- (3) File four asks if one wants to enter the program where it was left previously or at the beginning of the lesson. If the answer is where it was left, then ELMIC advances to the frame number which was read in file three and continues in a normal fashion for the rest of the lesson;
- (4) At any point in the lesson, if a student wishes to exit to do another program and then return, the ← key is used;
- (5) The current frame number is then written in file three, and he is free to choose any stored program he wishes;
- (6) A chain back to ELMIC is at the completion of every stored program on the tape;
- (7) The lesson does not need to be reentered from paper tape using subroutine LOOD;
- (8) The number of the exit frame is read from file three, and flow continues as outlined above.

Due to the large number of frames needed to adequately present a concept, the example showing the relation of physics to watershed hydrology was shortened, both in the concepts presented and in the reinforcement branching per concept. In an actual teaching situation, the size of the lesson example presented would probably be doubled for the same number of concepts.

The language has successfully been used to assist in teaching several concepts in forest mensuration, rainfall interception, and

mathematical linear programming. The general student interest and degree of learning from these lessons implied the language was achieving its goal.

A fundamental problem in the development of all CAI programs is testing their effectiveness. Since the effectiveness of the material is a function of the author and the computer language, methods and feedback systems need to be developed so that one may increase the effectiveness of the other.

## CHAPTER 8

### SUMMARY

The beginning of programmed instruction is ensconced in antiquity (Corey 1967). The modern movement in this area is generally held to have started in the mid-1950's (Dale 1967). This was largely due to the work of Skinner (1954). He was the first to use the term programmed instruction with computers and teaching machines. A number of techniques for presenting material in programmed instruction have been developed (Crowder 1960, Pressey 1926, Skinner 1954). A majority of these techniques can be termed either linear or branching programs. A linear program is one in which every segment or frame is covered by a student. A branching program allows students of varying abilities to pass through different numbers of frames; the brighter student may pass through half the frames the slower student will encounter. Progression through a branching program is determined by answers given to questions where reinforcement loops are often used after an incorrect answer.

The physical form of a teaching machine may be a book, a box with a window containing a disc or drum with questions and answers on it, a computer, or several other devices. The form used in this work is the computer. The computer allows for presentation of information and frequent response by the student, with immediate feedback to the student informing him of the validity of his response. It also allows the student to work at his own rate. These are the features common to

all teaching machines at this time (Anderson et al. 1969, Meadow 1970).

The computers used in the past for teaching machines employed extensive author languages. This necessitated large- to medium-sized computers. Only in the last few years have small computers been used. The author language presented in this work, named ELMIC, is for use on very small or mini-computers. It requires only 4500 words of core of sixteen bits each. At the same time, it may be used on larger computers, up to the largest.

The design of an author language this compact necessitates setting priorities and determining trade-offs on the features to be implemented in the language. ELMIC was designed to have the following features:

- (1) Written in a language easily transferred to other computers;
- (2) Small number of operation codes for an author to learn;
- (3) Numeric response may be integer, floating point, or exponential;
- (4) Alphanumeric response;
- (5) Multiple choice;
- (6) Multiple pass through 3 and 4 above;
- (7) Calculation ability at any time;
- (8) Exit and restart lesson at any time;
- (9) Use of student's name in communication;
- (10) Use by another tongue.

The author language, ELMIC, described in this work contains or fulfills all of these requirements.

The portability of the language greatly influenced the configuration in which ELMIC was written, a slightly modified FORTRAN II computer language. ASCII coding was used for the various operation codes of ELMIC.

ELMIC stores a given lesson on magnetic tape. Each frame is stored in a separate file. The maximum size of a lesson is 252 frames. Each file consists of text followed by logic appertaining to student response for that frame.

The author need learn only ten codes in order to use the language.

Once coded, the lesson is easily transcribed to punched paper tape by anyone who can type (Appendix G). The text is input just as it is to appear to the student.

ELMIC has been used for two years to teach concepts in forest mensuration, wildland hydrology, interception, and, recently, linear programming.

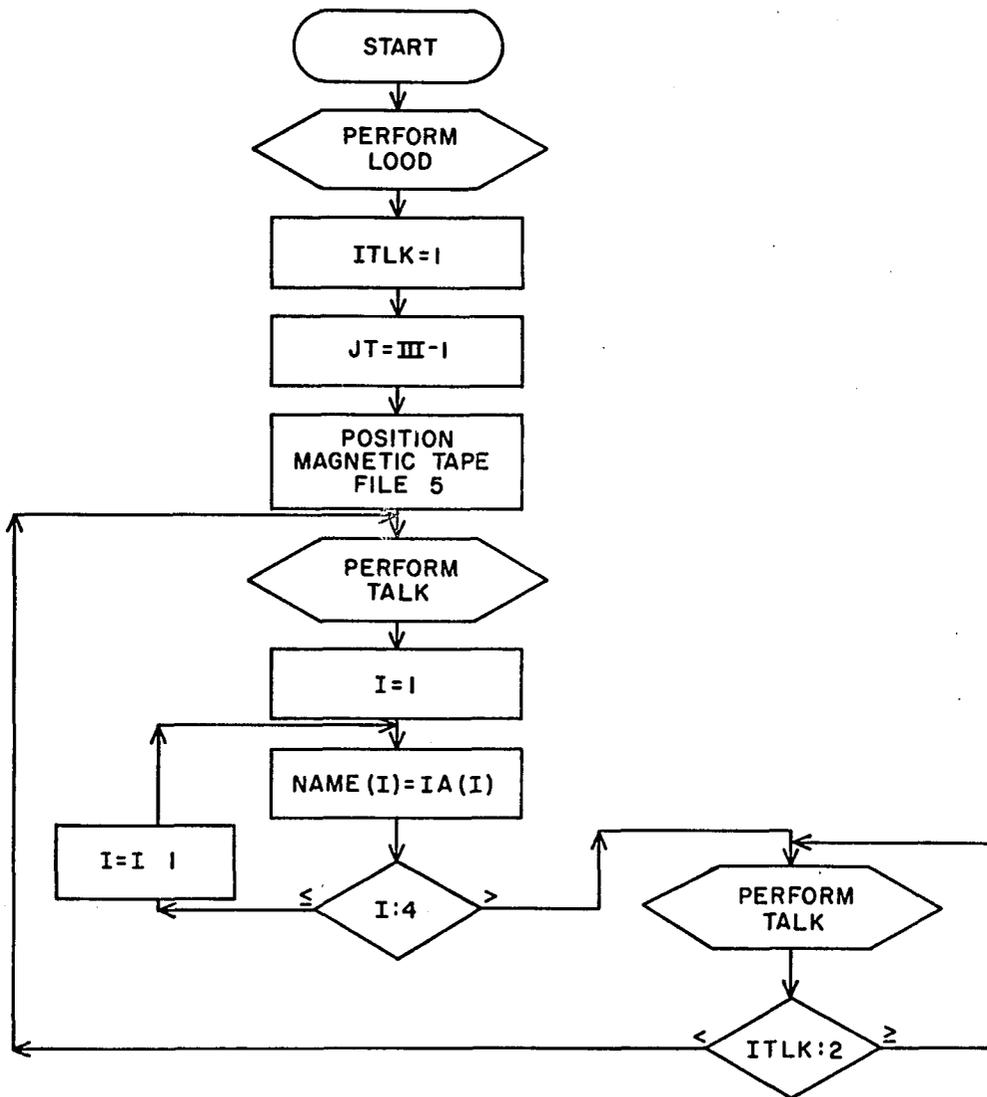
The power and flexibility of the language meets all design requirements. The dedication of ELMIC to a particular computer would result in an educational facility that is as powerful as many of the larger installations. The student would have the ability to leave a lesson and execute any of a number of stored programs or write his own, and then return to the lesson at the point he left so that he can continue the lesson. Also, it is well accepted by the majority of students using it. A mixed mode of programming appears to hold a student's attention better than an all linear or all branching program.

A lesson of physics in wildland hydrology was written to illustrate various techniques of programming as well as to teach the relation of physics concepts to an applied area. The material was covered in a fashion that allowed the student to abstract various processes. The approach was to reduce a given process to its most elementary or approximate form. In this form, complex processes were dealt with using relationships for simple systems. This is believed to aid in de-emphasizing the rote memorization of equations and to help the student to quantitatively approximate actual processes in nature.

APPENDIX A

LISTING AND FLOWCHART OF PROGRAM ELMIC

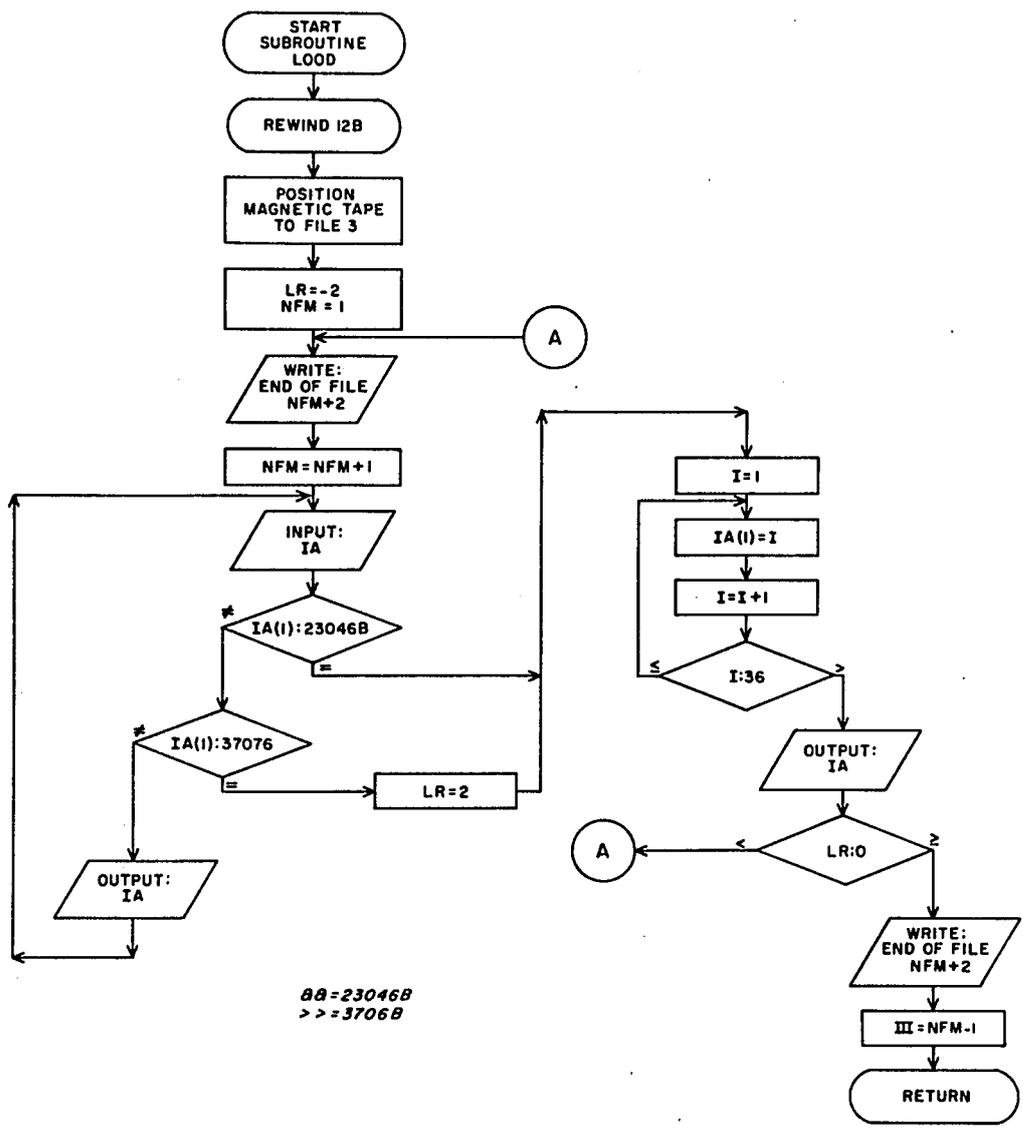
```
PROGRAM ELMIC
COMMON IA(36),III,AN,IN,NAME(4),ITLK,MP
C THIS SUBROUTINE LOADS THE LESSON FROM PAPER TO
C MAGNETIC TAPE
CALL LOOD
C ITLK IS THE LESSON FRAME NUMBER
ITLK=1
C III IS THE TOTAL NUMBER OF FRAMES IN THE LESSON
JT=III-1
C SUBROUTINE IS USED TO POSITION THE MAGNETIC TAPE
CALL PTAPE(12B,-JT,0)
C TALK IS A SUBROUTINE TO OUTPUT A LESSON FRAME TEXT
7 CALL TALK
DO 6 I=1,4
C NAME IS THE NAME OF THE STUDENT
6 NAME(I)=IA(I)
5 CALL TALK
IF(ITLK-2) 7,5
END
```



APPENDIX B

LISTING AND FLOWCHART OF SUBROUTINE LOOD

```
      SUBROUTINE LOOD
C      THIS SUBROUTINE LOADS THE LESSON CONTAINED ON
C      PAPER TAPE TO MAGNETIC TAPE
      COMMON IA(36),III
      REWIND 12B
C      SKIP THE FIRST TWO FILES
      CALL PTAPE(12B,2,0)
      LR=-2
      NFM=1
21  ENDFILE 12B
      NFM=NFM+1
C      READ A LINE FROM PAPER TAPE
42  READ(5,17) IA
17  FORMAT(36A2)
C      CHECK FOR && WHICH IS THE END OF FRAME MARK
      IF(IA(1)-23046B) 39,20,39
C      CONSTRUCT SCRATCH RECORD AT FIRST OF FILE
20  DO 15 I=1,36
15  IA(I)=I
C      WRITE SCRATCH RECORD ON MAGNETIC TAPE
      WRITE(12B,17) IA
      IF(LR) 21,24
C      CHECK FOR >> WHICH IS THE END OF LAST FRAME OF
C      LESSON MARK
39  IF(IA(1)-37076B) 40,19,40
19  LR=2
      GO TO 20
C      WRITE LINE FROM PAPER TAPE TO MAGNETIC TAPE
40  WRITE(12B,17) IA
      GO TO 42
24  ENDFILE 12B
      III=NFM-1
      RETURN
      END
```



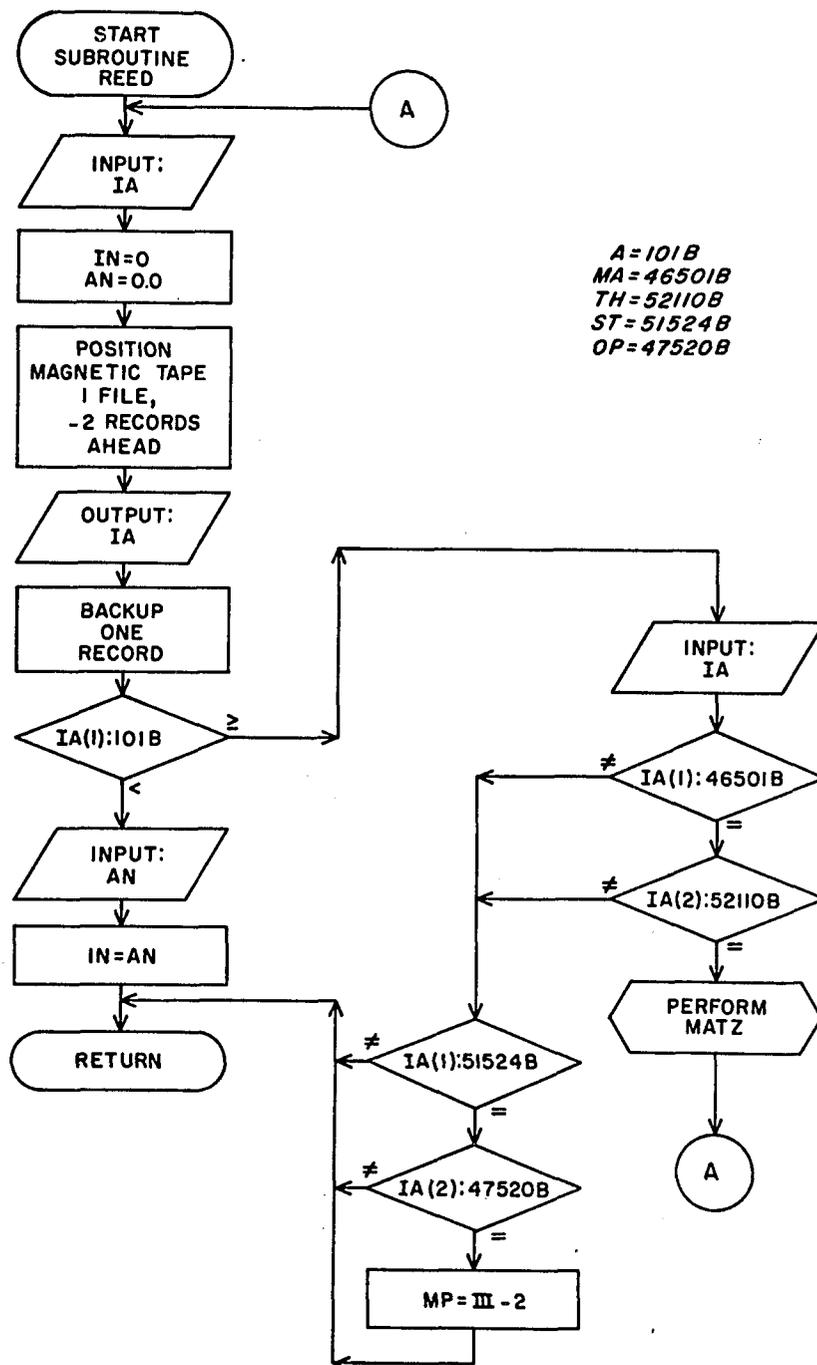
APPENDIX C

LISTING AND FLOWCHART OF SUBROUTINE REED

```

SUBROUTINE REED
C   THIS SUBROUTINE ANALYSES THE STUDENT INPUT
COMMON IA(36),III,AN,IN,NAME(4),ITLK,MP
C   SPACE A LINE ON TTY
WRITE(2,82)
82 FORMAT(" ")
C   READ STUDENT INPUT
9 READ(1,1) IA
C   INITIALIZE INTEGER AND FLOATING POINT NUMBER TO 0
IN=0
AN=0.0
C   POSITION MAGNETIC TAPE TO SCRATCH LINE OF CURRENT
C   FRAME
CALL PTAPE(12B,1,-2)
1 FORMAT(36A1)
C   WRITE STUDENT ANSWER ON SCRATCH LINE
WRITE (12B,1) IA
C   BACKUP MAG TAPE ONE RECORD
CALL PTAPE (12B,0,-1)
C   CHECK IF FIRST SYMBOL OF ANSWER IS ALPHABETIC OR
C   NUMERIC
IF(IA(1)101B) 42,
C   READ INPUT AS FLOATING POINT NUMBER
42 READ(12B,*) AN
C   EQUATE NUMBER READ IN FLOATING POINT TO INTEGER
IN=AN
GO TO 53
C   READ INPUT AS ALPHANUMERIC
5 READ(12B,22) IA
22 FORMAT(36A2)
C   CHECK FOR WORD MATH
IF(IA(1)-46501B) 47,48,47
C   CHECK FOR COMPUTER WORD MA
C   CHECK FOR COMPUTER WORD TH
48 IF(IA(2)-52110B) 47,49,47
C   CALCULATION SUBROUTINE
49 CALL MATZ
GO TO 9
C   CHECK FOR WORD STOP
C   CHECK FOR COMPUTER WORD ST
47 IF(IA(1)-51524B) 53,54,53
C   CHECK FOR COMPUTER WORD OP
54 IF(IA(2)-47520B) 53,55,53
C   SET MP SO AS TO GO TO LAST FRAME OF THE LESSON
55 MP=III-2
53 RETURN
END

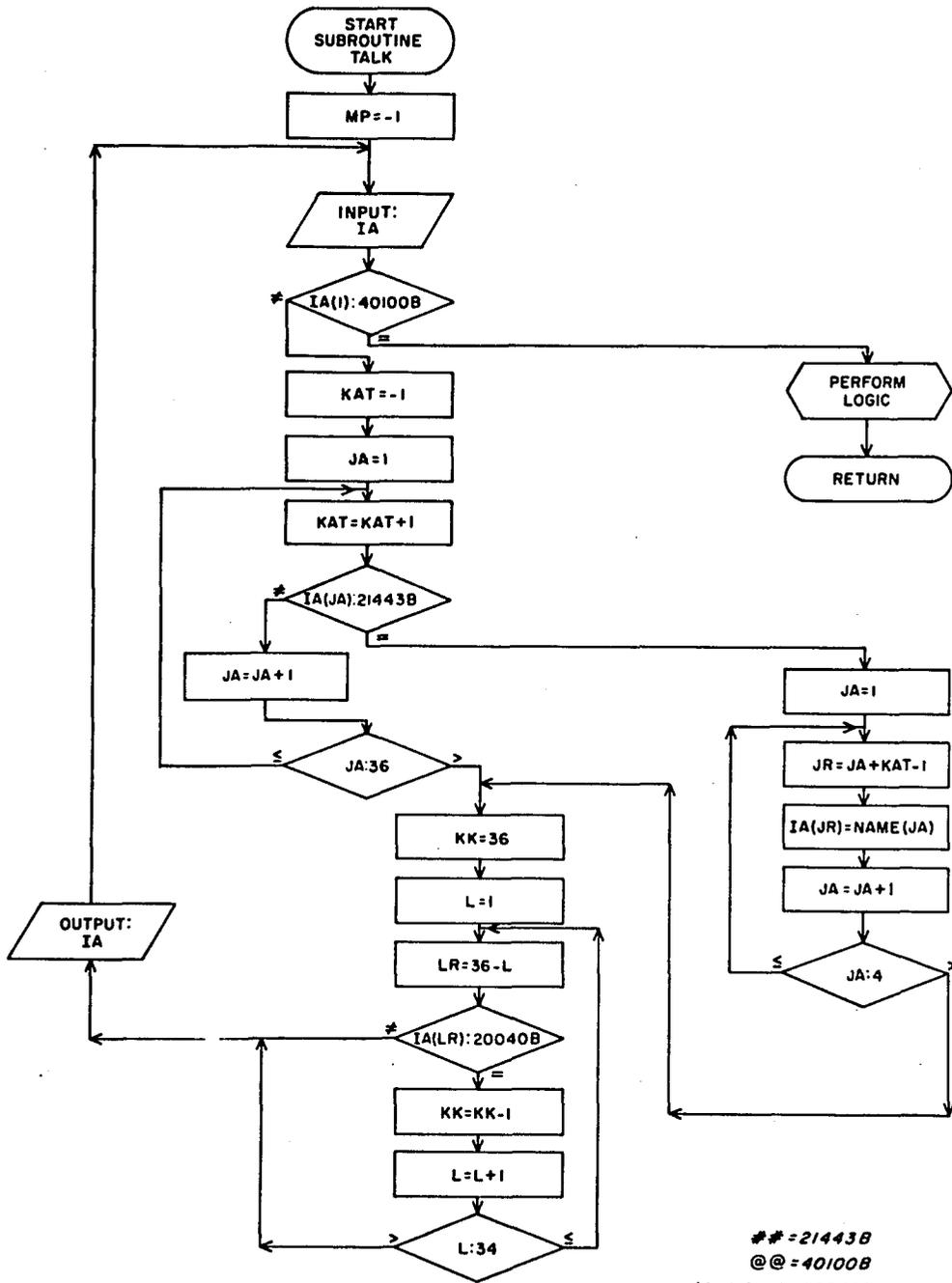
```



APPENDIX D

LISTING AND FLOWCHART OF SUBROUTINE TALK

```
      SUBROUTINE TALK
C      THIS SUBROUTINE IS USED TO OUTPUT A LESSON TEXT
C      TO THE TTY
      COMMON IA(36),III,AN,IN,NAME(4),ITLK,MP
C      MP IS A NUMBER OF A FRAME WHEN IT IS ON THE
C      SECOND TIME THROUGH DUAL PASS FRAME
      MP=-1
C      SPACE A LINE
      WRITE(2,61)
61  FORMAT(" ")
17  FORMAT(36A2)
51  READ(12B,17) IA
C      CHECK FOR @@ WHICH SIGNALS THE END OF TEXT FOR
C      THAT FRAME
      IF(IA(1)-40100B) 53,72,53
53  KAT=-1
      DO 54 JA=1,36
      KAT=KAT+1
C      SEARCH FOR ## WHICH IMPLIES A NAME IS TO BE INSERTED
      IF(IA(JA)-21443B) 54,55,54
54  CONTINUE
      GO TO 58
55  DO 59 JA=1,4
      JR=JA+KAT-1
C      INSERTION OF NAME IN CURRENT LINE OF FRAME
59  IA(JR)=NAME(JA)
58  KK=36
      DO 41 L=1,34
      LR=36-L
      IF(IA(LR)-20040B) 42,41,42
41  KK=KK-1
C      WRITE THE CURRENT LINE OF TEXT AS MODIFIED ABOVE
42  WRITE(2,17) (IA(KZ),KZ=1,KK)
      GO TO 51
C      THIS SUBROUTINE HANDLES THE FLOW OF THE STUDENT
C      THROUGH THE LESSON
72  CALL LOGIC
C      SPACE A LINE
      WRITE(2,61)
      RETURN
      END
```



APPENDIX E

LISTING AND FLOWCHART OF SUBROUTINE LOGIC

```

SUBROUTINE LOGIC
C   THIS SUBROUTINE COMPARES THE LOGIC OF A GIVEN LESSON
C   FRAME WITH THE STUDENT RESPONSE
      DIMENSION IB(10),JAN(36)
      COMMON IA(36),III,AN,IN,NAME(4),ITLK,MP
C   ICODE IS THE OPERATION CODE FOR THE FRAME
      READ(12B,2) ICODE
      2  FORMAT(A2)
C   CHECK FOR I1 ONE PASS NUMERIC
      IF(ICODE-44461B) 3,8,3
C   CHECK FOR I2 TWO PASS NUMERIC
      3  IF(ICODE-44462B) 9,8,9
C   CHECK FOR A1 ONE PASS ALPHANUMERIC
      9  IF(ICODE-40461B) 11,12,11
C   CHECK FOR A2 TWO PASS ALPHANUMERIC
      11 IF(ICODE-40462B) 13,12,13
C   CHECK FOR I3 MULTIPLE CHOICE
      13 IF(ICODE-44463B) 90,30,90
C   CHECK FOR I0 DIRECT LINK
      90 IF(ICODE-44460B) 91,92,91
      92 READ(12B,*) JX
      69 IF(MP) 57,56
      57 IF(JX-ITLK) 86,87
      86 JT=JX-ITLK-1
          GO TO 88
      56 JX=MP
      87 JT=JX-ITLK
      88 ITLK=JX
          CALL PTAPE(12B,JT,0)
      91 RETURN
      8  IF(ICODE-44461B) 39,40,39
C   CHECK TO SEE IF SECOND PASS THROUGH A DUAL PASS
C   QUESTION
      39 IF(ISP-ITLK) 45,46,45
C   SET DUAL PASS INDEX
      45 ISP=ITLK
C   READ EXPECTED ANSWER, FRAME TO BRANCH FOR CORRECT
C   RESPONSE, FRAME TO BRANCH FOR INCORRECT RESPONSE
      40 READ(12B,*) FNT1,IY,INN
      38 CALL REED
C   INPUT STUDENT RESPONSE AN
      IF(AN-FNT1) 17,18,17
C   CHECK FOR STUDENT RESPONSE WITHIN TWO PERCENT
C   EXPECTED VALUE
      17 IF(AN-1.02*FNT1) 32,32,33
      32 IF(AN-0.98*FNT1) 33,18,18

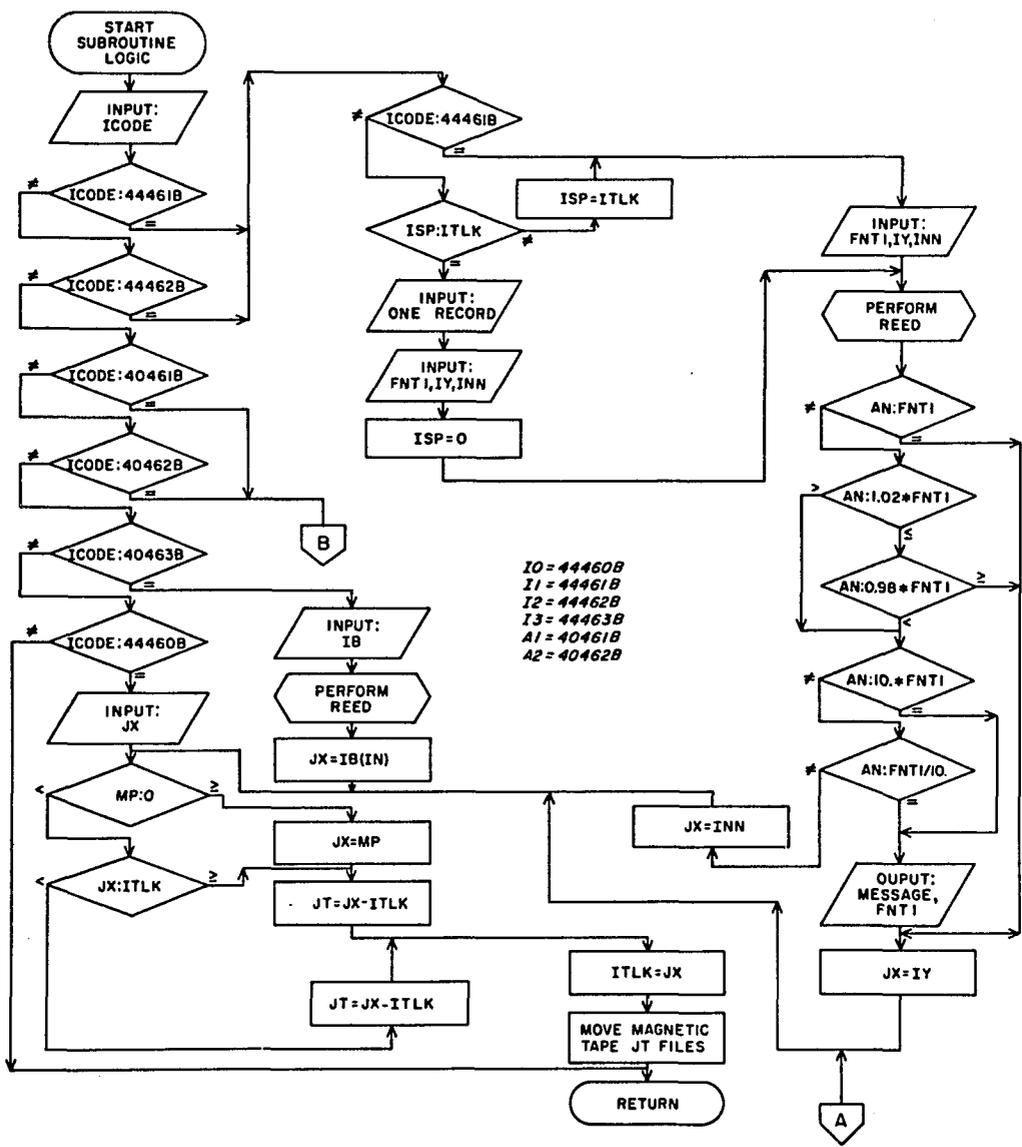
```

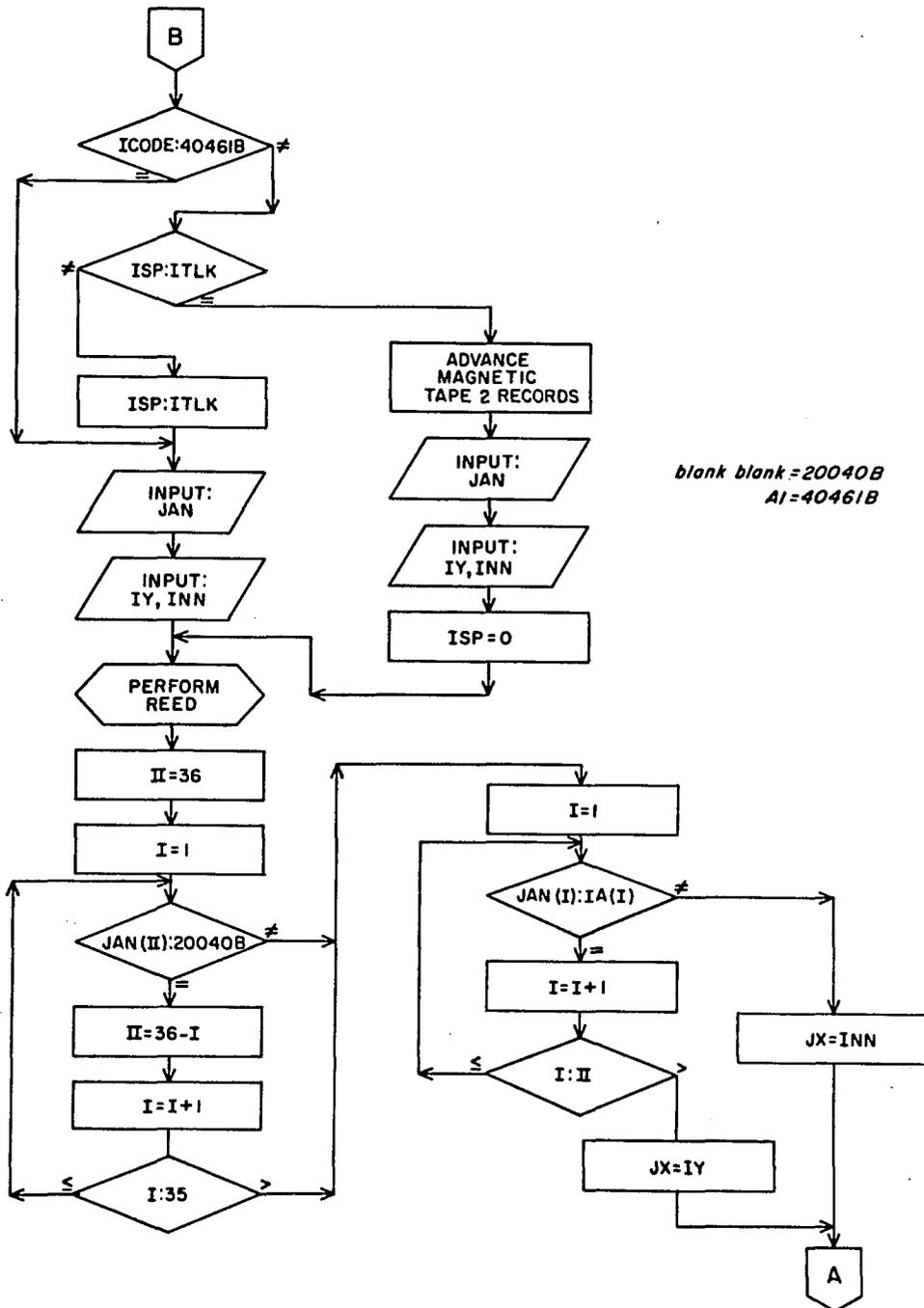
```

C     CHECK FOR STUDENT RESPONSE OFF BY A FACTOR OF 10
C     FROM EXPECTED NUMBER
33  IF(AN-FNT1*10.) 19,20,19
19  IF(AN-FNT1/10.) 21,20,21
C     ANSWER WAS WRONG AND WILL BRANCH TO FRAME INN
21  JX=INN
    GO TO 69
C     ANSWER OFF BY A FACTOR OF 10 OUTPUT THIS
20  WRITE(2,22) FNT1
220 FORMAT(" /"DECIMAL POINT ERROR. THE ANSWER
    CSHOULD BE ",F8.3," "/" LET'S CALL IT CORRECT.")
C     ANSWER CORRECT AND WILL BRANCH TO FRAME IY
18  JX=IY
    GO TO 69
46  READ(12B)
C     READ EXPECTED ANSWER, FRAME TO BRANCH FOR CORRECT
C     STUDENT RESPONSE, FRAME TO BRANCH FOR INCORRECT
C     RESPONSE ALL FOR SECOND PASS
    READ(12B,*) FNT1,IY,INN
C     CLEAR DUAL PASS INDEX
    ISP=0
    GO TO 38
C     CHECK FOR A1
12  IF(ICODE-40461B) 48,49,48
C     CHECK FOR SECOND PASS THROUGH DUAL PASS QUESTION
48  IF(ISP-ITLK) 50,51,50
C     SET DUAL PASS INDEX
50  ISP=ITLK
C     READ EXPECTED ANSWER
49  READ(12B,24) JAN
24  FORMAT(36A2)
C     READ FRAME TO BRANCH FOR CORRECT RESPONSE AND FRAME
C     TO BRANCH FOR INCORRECT RESPONSE
    READ(12B,*) IY,INN
C     INPUT STUDENT ANSWER IA
52  CALL REED
    II=36
C     THROW AWAY TRAILING SPACES IN ANSWER
    DO 25 I=1,35
    IF(JAN(II)-20040B) 27,26,27
26  II=36-I
25  CONTINUE
27  DO 28 I=1,II
C     CHECK EXPECTED ANSWER WITH STUDENT ANSWER
    IF(JAN(I)-IA(I)) 29,28,29
28  CONTINUE

```

```
C   ANSWER IS CORRECT AND WILL BRANCH TO FRAME IY
    JX=IY
    GO TO 69
C   ANSWER INCORRECT AND WILL BRANCH TO FRAME INN
29  JX=INN
    GO TO 69
C   MOVE MAG TAPE AHEAD TWO RECORDS
51  CALL PTAPE(12B,0,2)
C   READ EXPECTED ANSWER FOR SECOND PASS
    READ(12B,24) JAN
C   READ FRAMES TO BRANCH FOR CORRECT AND INCORRECT
C   STUDENT RESPONSE ON THE SECOND PASS
    READ(12B,*) IY,INN
C   CLEAR DUAL PASS INDEX
    ISP=0
    GO TO 52
C   READ BRANCHING FRAMES FOR MULTIPLE CHOICE QUESTION
30  READ(12B,*) IB
C   INPUT STUDENT RESPONSE
    CALL REED
C   BRANCH TO THAT FRAME NUMBER WHICH IS ELEMENT IN OF
C   ARRAY IB
    JX=IB(IN)
    GO TO 69
    END
```

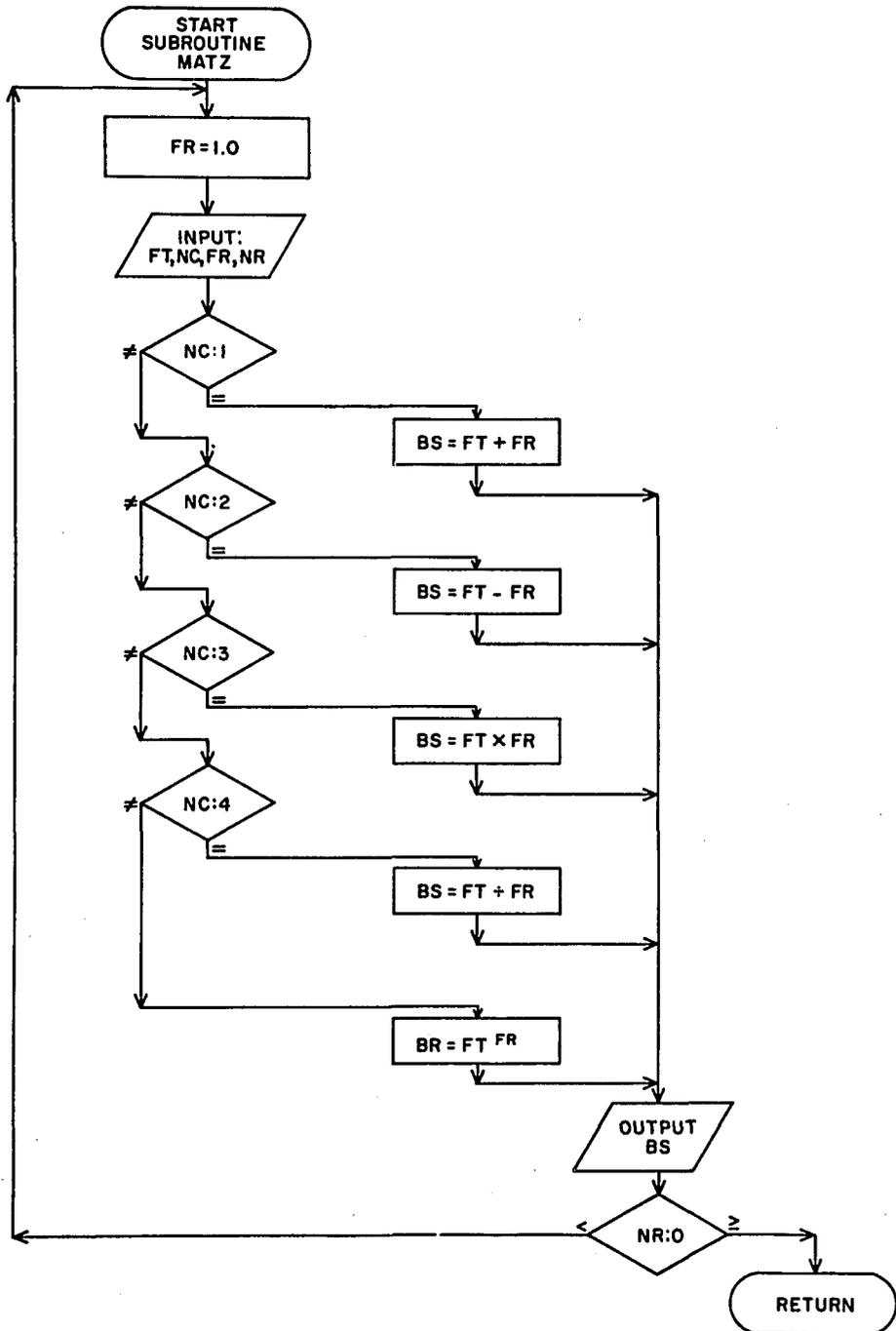




APPENDIX F

LISTING AND FLOWCHART OF SUBROUTINE MATZ

```
      SUBROUTINE MATZ
C     SUBROUTINE FOR CALCULATIONS
      8 FR=1.0
C     INPUT NUMBER 1, OPERATION CODE, NUMBER 2, DESTINATION
      READ(1,*) FT,NC,FR,NR
      GO TO (13,14,15,16,17),NC
C     ANSWER EQUALS NUMBER 1 PLUS NUMBER 2
      13 BS=FT+FR
      GO TO 19
C     ANSWER EQUALS NUMBER 1 MINUS NUMBER 2
      14 BS=FT-FR
      GO TO 19
C     ANSWER EQUALS NUMBER 1 TIMES NUMBER 2
      15 BS=FT*FR
      GO TO 19
C     ANSWER EQUALS NUMBER 1 DIVIDED BY NUMBER 2
      16 BS=FT/FR
      GO TO 19
C     ANSWER EQUALS NUMBER 1 EXPONENTIATED TO NUMBER 2
      17 BS=FT**FR
C     WRITE ANSWER BS
      19 WRITE(2,20) BS
      20 FORMAT("ANS=",F10.5)
C     CHECK DESTINATION CODE
      IF(NR) 8,21
      21 RETURN
      END
```



**APPENDIX G**

**EXAMPLES**

Example of Formatting Using ELMIC

##### .  
HERE ARE A FEW TERMS WE WILL BE USING DURING THE SESSION,

I = INTERCEPTION  
P = GROSS RAINFALL  
T = THROUGHFALL  
F = STEMFLOW

ALL TERMS ARE EXPRESSED IN INCHES.

TERMS. LET ME ASK YOU A FEW QUESTIONS TO SEE IF YOU UNDERSTAND THESE  
ANSWER WITH THE APPROPRIATE SYMBOL: I, P, T, OR F.

@@  
I0  
5  
&&

THE TOTAL RAINFALL MEASURED IN THE OPEN OR ABOVE THE CANOPY

IS  
@@  
A1  
P  
9, 8  
&&

THAT PORTION OF THE GROSS RAINFALL THAT REACHES THE GROUND  
DIRECTLY THROUGH THE CANOPY IS

@@  
A1  
T  
11, 10  
&&

THAT PORTION OF THE RAINFALL THAT REACHES THE GROUND BY RUNNING  
DOWN THE STEMS OF VEGETATION IS

@@  
A1  
F  
13, 12  
&&

WRONG, THE ANSWER IS P.

@@  
I0  
6  
&&

CORRECT, ##### .

@@  
I0  
6  
&&

WRONG, THE ANSWER IS T.

@@  
I0  
7  
&&

GOOD, ##### .

@@  
I0  
7  
&&

WRONG, THE ANSWER IS F.

@@  
I0  
14  
&&

WELL DONE, ##### .

@@  
I0  
14  
&&

INTERCEPTION IS EXPRESSED AS THE DIFFERENCE BETWEEN GROSS RAINFALL CATCH AND THE TOTAL CATCH UNDER THE CANOPY.

@@  
I0  
15  
&&

NOW, ##### , WHICH EQUATION WOULD YOU USE TO CALCULATE INTERCEPTION? ANSWER WITH A NUMBER.

- 1 I = P + F + T
- 2 I = P - F - T
- 3 I = P - F + T
- 4 I = P + F - T

@@  
I3  
16, 17, 16, 16  
&&

NO. REMEMBER, ##### , THAT INTERCEPTION IS WHAT REMAINS AFTER SUBTRACTING STEMFLOW AND THROUGHFALL FROM GROSS RAINFALL. THE CORRECT EQUATION IS  $I = P - F - T$ .

@@  
I0  
18  
&&

YES, THE CORRECT EQUATION IS  $I = P - F - T$ .

@@  
I0  
18  
&&

DURING A STORM, RAIN GAUGES UNDER A CANOPY CATCH AN AVERAGE OF 8 INCHES. GAUGES IN THE OPEN AVERAGE 10 INCHES. STEMFLOW IS .5 INCH. WHAT IS THE INTERCEPTION?

@@

I2

1.5, 19, 20

1.5, 19, 21

&&

CORRECT, ##### . INTERCEPTION IS 1.5 INCHES.

@@

I0

22

&&

WRONG, ##### , CHECK THE EQUATION AND YOUR ARITHMETIC AND TRY AGAIN.

@@

I0

18

&&

WRONG. I DON'T THINK YOU ARE TRYING. THE ANSWER IS

$10 - 8 - .5 = 1.5$ .

@@

I0

22

&&

INTERCEPTION MAY ALSO BE EXPRESSED AS A PERCENTAGE OF GROSS RAINFALL. FOR THE STORM GIVEN IN THE PREVIOUS PROBLEM, INTERCEPTION IS PERCENT.

@@

I1

15, 23, 24

&&

CORRECT, ##### , INTERCEPTION IS 15 PERCENT.

@@

I0

26

&&

WRONG. FIRST CALCULATE INTERCEPTION AND THEN EXPRESS IT AS A PERCENT OF RAINFALL IN THE OPEN AND WATCH YOUR ARITHMETIC. THE INTERCEPTION IS PERCENT.

@@

I1

15, 26, 25

&&

WRONG.  $I = 10 - 8 - .5 = 1.5$   
 $(1.5/10) (100) = 15$  PERCENT

@@

I0

26

&&

Example of Formatting in Spanish Using ELMIC

ESTOS SO ALGUNOS TERMINOS QUE VAMOS A USAR DURANTE ESTA  
SESION, ##### .

I = INTERCEPCION

P = PRECIPITACION TOTAL

T = AGUA DE TRASPASO QUE CAE AL SUELO

F = AGUA QUE SE ESCURRE POR LOS TRONCOS DE LOS ARBOLES

TODOS LOS TERMINOS SE EXPRESAN EN PULGADAS.

DEJEME HACERLE ALGUNAS PREGUNTAS PARA VER SI COMPRENDE ESTOS  
TERMINOS. FAVOR DE CONTESTAR CON EL SIMBOLO APROPIADO: I, P, T, O F.

@@

IO

5

&&

LA PRECIPITACION TOTAL QUE SE MIDE ANTES DE CAER EN LA  
VEGETACION Y LA QUE CAE EN EL LLANO ES

@@

A1

P

9, 8

&&

LA PORCION DE LA PRECIPITACION QUE TRASPASA HACIA EL SUELO

ES

@@

A1

T

11, 10

&&

LA PORCION QUE SE EXCURRE POR LOS TRONCOS DE LOS ARBOLES

ES

@@

A1

F

13, 12

&&

INCORRECTO, LA RESPUESTA ES P.

@@

IO

6

&&

CORRECTO, ##### .

@@

IO

6

&&

INCORRECTO, LA RESPUESTA ES T.

@@  
IO  
7  
&&

MUY BIEN, ##### .

@@  
IO  
7  
&&

INCORRECTO, LA RESPUESTA ES F.

@@  
IO  
14  
&&

BIEN HECHO, ##### .

@@  
IO  
14  
&&

INTERCEPCION SE DEFINA COMO LA DIREFERENCIA ENTRE LA PRECIPITACION TOTAL Y LA QUE SE MIDE BAJO DE LOS ARBOLES.

@@  
IO  
15  
&&

AHORA, ##### , CUAL FORMULA SE USA PARA CALCULAR LA INTERCEPCION. CONTESTE CON UN NUMERO.

- 1  $I = P + F + T$
- 2  $I = P - F - T$
- 3  $I = P - F + T$
- 4  $I = P + F - T$

@@  
I3  
16, 17, 16, 16  
&&

NO, ACUERDESE, ##### , QUE LA INTERCEPCION ES LO QUE QUEDA DESPUES DE SUBSTRAER EL AGUA QUE SE ESCURRE POR LOS TRONCOS DE LOS ARBOLES Y EL AGUA DE TRASPASO QUE CAE AL SUELO DE LA PRECIPITACION TOTAL. LA FORMULA CORRECTA ES  $I = P - F - T$ .

@@  
IO  
18  
&&

SI, LA FORMULA CORRECTA ES  $I = P - F - T$ .

@@  
IO  
18  
&&

DURANTE UN AGUACERO, PLUVIOMETROS BAJO LOS ARBOLES MIDEN UN PROMEDIO DE 8 PULGADAS DE AGUA. PLUVIOMETROS EN EL LLANO MIDEN UN PROMEDIO DE 10 PULGADAS. ESCURRIMIENTO DE LOS ARBOLES ES .5 PULGADAS. QUE ES LA INTERCEPCION?

@@

I2

1.5, 19, 20

1.5, 19, 21

&&

CORRECTO, ##### . LA INTERCEPCION ES 1.5 PULGADAS.

@@

I0

22

&&

INCORRECTO, ##### . REPASE LA FORMULA Y SU MATEMATICA Y ATEMPTELO DE NUEVO.

@@

I0

18

&&

INCORRECTO. NO ME PARECE QUE USTED HACE EL ESFUERZO. LA RESPUESTA ES  $10 - 8 - .5 = 1.5$ .

@@

I0

22

&&

LA INTERCEPCION TEMBIEN SE PUEDE EXPRESAR COMO UN PORCIENTO DE LA PRECIPITACION TOTAL. EN EL AGUACERO DEL PROBLEMA ANTERIOR LA INTERCEPCION ES EL PORCIENTO.

@@

I1

15, 23, 24

&&

CORRECTO, ##### , LA INTERCEPCION ES 15 PORCIENTO.

@@

I0

26

&&

INCORRECTO. PRIMERO CALCULE LA INTERCEPCION Y APUNTELO COMO PORCIENTO DE LA PRECIPITACION TOTAL EN EL LLANO. CUIDADO CON LA MATEMATICA. LA INTERCEPCION ES EL PORCIENTO.

@@

I1

15, 26, 25

&&

INCORRECTO.

$$I = 10 - 8 - .5 = 1.5$$
$$(1.5/10) (100) = 15 \text{ PORCIENTO}$$

@@  
10  
26  
66

Example of Student-Machine Interaction Using ELMIC

HERE ARE A FEW TERMS WE WILL BE USING DURING THE SESSION,  
ROBERT.

I = INTERCEPTION  
P = GROSS RAINFALL  
T = THROUGHFALL  
F = STEMFLOW

ALL TERMS ARE EXPRESSED IN INCHES.

LET ME ASK YOU A FEW QUESTIONS TO SEE IF YOU UNDERSTAND THESE  
TERMS. ANSWER WITH THE APPROPRIATE SYMBOL: I, P, T, OR F.

THE TOTAL RAINFALL MEASURED IN THE OPEN OR ABOVE THE CANOPY  
IS

P.

CORRECT, ROBERT.

THAT PORTION OF THE GROSS RAINFALL THAT REACHES THE GROUND  
DIRECTLY THROUGH THE CANOPY IS

F

WRONG, THE ANSWER IS T.

THAT PORTION OF THE RAINFALL THAT REACHES THE GROUND BY RUNNING  
DOWN THE STEMS OF VEGETATION IS

F

WELL DONE, ROBERT.

INTERCEPTION IS EXPRESSED AS THE DIFFERENCE BETWEEN GROSS  
RAINFALL CATCH AND THE TOTAL CATCH UNDER THE CANOPY.

NOW, ROBERT, WHICH EQUATION WOULD YOU USE TO CALCULATE  
INTERCEPTION? ANSWER WITH A NUMBER.

- 1      $I = P + F + T$
- 2      $I = P - F - T$
- 3      $I = P - F + T$
- 4      $I = P + F - T$

.2E1

YES, THE CORRECT EQUATION IS  $I = P - F - T$ .

DURING A STORM, RAIN GAUGES UNDER A CANOPY CATCH AN AVERAGE OF 8 INCHES. GAUGES IN THE OPEN AVERAGE 10 INCHES. STEMFLOW IS .5 INCH. WHAT IS THE INTERCEPTION?

MATH

10, 2, 8, -1

ANS = 2.00000

2, 2, .5, -1

ANS = 1.50000

2.4, 5, 3.4, 0

ANS = 19.62087

1.51

CORRECT, ROBERT. INTERCEPTION IS 1.5 INCHES.

INTERCEPTION MAY ALSO BE EXPRESSED AS A PERCENTAGE OF GROSS RAINFALL. FOR THE STORM GIVEN IN THE PREVIOUS PROBLEM, INTERCEPTION IS PERCENT.

.15

WRONG. FIRST CALCULATE INTERCEPTION AND THEN EXPRESS IT AS A PERCENT OF RAINFALL IN THE OPEN AND WATCH YOUR ARITHMETIC. THE INTERCEPTION IS PERCENT.

.015

WRONG.  $I = 10 - 8 - .5 = 1.5$   
 $(1.5/10) (100) = 15$  PERCENT

## DEFINITION OF TERMS

- Alphanumeric:** A character set or field composed of alphabetic and numeric characters. In a loose sense, other characters may also be included.
- Array:** An ordered set of data of one or more dimensions.
- ASCII:** An acronym for American Standard Code for Information Interchange. A form of coding data to make it computer readable.
- Author:** The person who writes a programmed instruction lesson.
- Author-language:** The set of operation codes used by a person writing a lesson. In this work, the codes are designed for use on a computer.
- Bit:** An abbreviation of binary digit, one of the two digits used in binary notation. The most elemental form of data storage in the computer core.
- Branching program:** A set of lesson frames arranged in such a fashion that students will read varying numbers of frames, dependent upon their responses to each frame they encounter. Some students may go through reinforcement or clarification loops, whereas others will not.
- CAI:** An acronym for Computer Assisted Instruction.
- Chain program:** A list of computer instructions to link two programs together. This is effected after the execution of the first program.
- Computer assisted instruction:** The implimentation of programmed instruction on a computer with the additional utilization of a computer's inherent capabilities.
- Computer core:** Internal portion of a computer which is capable of receiving information and storing it such that it may later be retrieved.
- Computer program:** A set of instructions composed for a computer to make it perform a specified activity.

- Computer word:** A basic unit of data in a computer memory composed of two characters or sixteen bits to be processed as an entity for the computer described in this work.
- ELMIC:** Acronym for Educational Language for Mini-Computers. This is the name of the CAI author-language described herein.
- EOF:** Acronym for end of file.
- File:** An organized collection of records. The files alluded to in this work are on magnetic tape.
- Flowchart:** A diagrammatic representation of a sequence of events, usually drawn with conventional symbols representing different types of events and their interconnection.
- Frame:** A segment of information, usually plus a question.
- Lesson:** A set of frames used to present one or more concepts to a student. A chain of frames carrying the student towards a predetermined goal.
- Linear program:** A set of lesson frames arranged in such a fashion that all students read every frame in identical sequence.
- LOGIC:** A subroutine of ELMIC used to compare the logic of a given frame in connection with the student's input.
- LOOD:** A subroutine of ELMIC used for loading a lesson from paper tape to magnetic tape.
- MATZ:** A subroutine of ELMIC which allows the student to perform mathematical calculations.
- Mini-computer:** A computer with a small core size. The size of core implied in this dissertation is approximately eight thousand words of sixteen bits each. A magnetic tape unit is also assumed.
- Operation code:** A set of alphanumeric codes used for physical and logical operations associated with a frame.
- Programmed instruction:** Logically sequenced small steps systematically moving the student to specified goals with self-pacing and immediate knowledge of progress.

- PTAPE:** A subroutine used to move the magnetic tape a given number of files and/or records.
- Record:** A unit of data representing a particular transaction or a basic element of a file consisting in turn of a number of interrelated data elements.
- REED:** A subroutine of ELMIC used for analysis of student input.
- Scratch record:** A record or portion of magnetic tape that contains information which may be overwritten or replaced.
- TALK:** A subroutine of ELMIC used to output a frame.

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