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ABSTRACT

A computer-based aid to self-directed learning, developed to meet the needs of on-the-job trainees, has been implemented on the PLATO computer system using the touch-panel capability of the PLATO-IV terminal. This document describes the training sequence for the self-directed learning system, the system task domains, task elements (the sentence generator and the essay generator), and a cognitive model for self-directed learning. Although results from a pilot experiment do not indicate that the computer-based system significantly improved learning ability, an interpretation of those results provides directions for future research. (RL)

DEPARTMENT OF PSYCHOLOGY

UNIVERSITY OF SOUTHERN CALIFORNIA

Technical Report No. 84

A FORMATIVE EVALUATION OF A COMPUTER-BASED INSTRUCTIONAL SYSTEM FOR TEACHING JOB-ORIENTED READING STRATEGIES

January 1978

Allen Munro, Joseph W. Rigney, and Donald E. Crook

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The complete training aid is quite complex, so that students are trained in its use over a number of sessions. New features of the system are introduced in alternate sessions, and students then practice with the system using a new learning task. This task in each case requires the student to troubleshoot or debug a simulated device. This device produces output, some of which is defective, and the student is required to locate the faulty component by examining the defective output and by reading an on-line "technical manual" for the device.

A pilot experiment has been completed to allow a formative evaluation of the self-directed aids system. Although the results of this experiment found no statistically significant differences between the treatment groups, they suggested directions for future research.

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SUMMARY

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I. INTRODUCTION

Learning from textbooks differs significantly from learning in real-world situations such as on-the-job training. Information in a textbook is arranged in such a way that a student is led in an idealized fashion to build on earlier knowledge. That is, the textbook writer first presents elementary information, then more complex information (based on the elementary information), then still more complex information, and so on. In the real world, however, information is not so neatly arranged. Complex concepts are frequently encountered before the more elementary concepts upon which they are based. Worse yet, there is generally far too much information available, much of it totally irrelevant to what the student wishes to learn. Since no one has pre-arranged and pre-digested the information for him, the student trying to learn in a real-world situation must take on those responsibilities himself. He must, that is, be self-directed in his learning.

Not infrequently, inexperienced technicians find themselves assigned to jobs in which they have to maintain equipment or systems they have not seen before or may have encountered only briefly in school. They have, in such conditions, a strong need to learn more about these devices, using available technical documents as a source of information. The technical manuals they consult may, in some instances, presuppose prior knowledge that is incomplete or partially forgotten. Thus, the technician on the job may have a requirement to learn information at several lower levels of complexity as well as at the technical manual level and to organize a sequence of acquisition. The information he needs may not be contained in a single place in any document, and the structure of the document--table of contents, index, and so on--may not help him locate the proper information. Under these circumstances, technicians who are not self-directed might try to read the entire technical document from cover to cover, obviously wasting valuable time. On the other hand, some technicians might ignore the information resources available and simply begin sticking test probes into the defective equipment, equally obviously wasting time. In either case, the technician would benefit from knowing some techniques of being self-directed, of determining which information is relevant to his specific task and learning only that information.

This paper describes initial steps toward the development of a training system to help people faced with this kind of complex learning task. Our research plan calls for several cycles of development and testing of the training system. In this report we discuss our first pass at the development of such a system. The training system is described and the results of a pilot experiment on the effectiveness of the system are reported. This formative evaluation will be used to revise the self-directed learning system described below. The revised system will be tested again on college students and then revised for use in technical training contexts. New data bases appropriate to such contexts will be created, and the system will be tested in this context. A summative evaluation will be performed.

Computer-based Aid to Self-directed Learning[1]

Our training program is designed to teach students how to use a computer-based aid to self-directed learning that has been developed in our laboratory. A learning task is presented to a student, and he is given considerable information--too much information, in fact--to complete his task. The aids system is designed to allow the student to break down his task into a set of more easil[illegible] objectives, to decide when a chapter of the technical manual is relevant to his objectives, and in general to keep track of his learning. This aids system can be thought of as consisting of a number of "pages," each of which presents certain types of information and provides the user with certain options. The four major components of this system are the Task page, the Objectives page, the Contents page, and the Relevant Contents page. (The term "page" in this context indicates one or more screen displays on a PLATO-IV panel). From any of these pages, the student can choose to go to any one of the others. The major components and their subcomponents are shown in Figure 1.

The Task page states the overall task or learning goal for the student. The task changes for each session that the student uses the aids system, but in each case it involves learning enough material to troubleshoot a defective device of some kind. (See Section III below). The Task page also gives the student access to the example output from the defective device. The student uses this output to help determine the source of the fault in the

[1]We thank Steve Cheney for advice in the initial stages of the design of the aids system and for help in recruiting students to test early versions of the system.

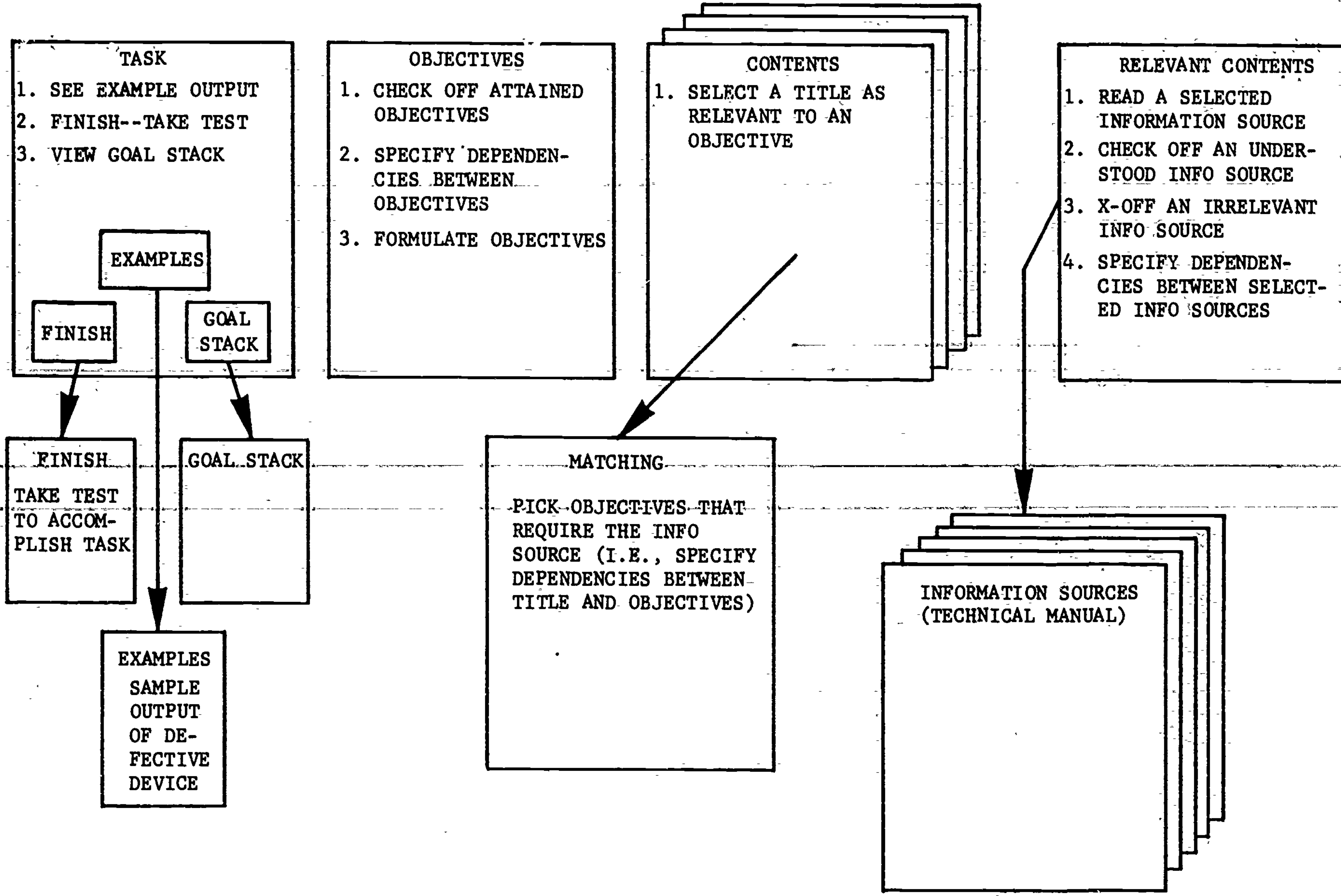

FIGURE 1. Automated Aid to Self-Directed Learning, Functions of Components Specified.

device. When the student feels he is ready to attempt the task, he can go to a test accessible from the Task page. This test requires that the student identify the faulty component of the device; if he fails this test, he is sent back to the aids system to study additional material. He can later return to the Task page to attempt the task once again. Another important function accessible from the Task page is the student's goal stack, an overt representation of dependencies which the student discovers among the various parts of the learning process, that is, task, objectives, and information sources.

The goal stack the student sees on the PLATO terminal screen looks something like the diagram in Figure 2. The arrows in the goal stack diagram show dependency relationships that hold among the student's objectives and the information resources available. For example, the curved line from objective 1 to objective 2 means that objective 2 cannot be attained until objective 1 is first attained; objective 2 is thus dependent on objective 1. Similarly, the line from information source 7 to objective 4 means that objective 4 requires the understanding of information source 7 for its attainment. The curved line from information source 3 to information source 1 means that 1 is dependent on 3; 3 should therefore be studied before 1.

The student is taught several heuristics to help him use the goal structure effectively. For example, if the node on the goal tree that represents a particular goal has an arrow head impinging on it, then that goal should not be attempted until the goal at the other end of the arrow has been attained. This is a simple restatement of the principle that it is better to attempt the prerequisites of an action before attempting the action. Since the goal structure keeps a record of goals attained by means of check marks next to completed goals, this rule is easy to heed.

The second major component of the self-directed learning aid is the Objectives page. The primary function of this page is to maintain a list of the learning objectives based on the task at hand. From the Objectives page the student can formulate new objectives that he or she believes are necessary to the accomplishment of the task. Once the student has entered an objective, it will be listed on the Objectives page whenever he returns to that page. Two other functions available on the Objectives page are checking off objectives that have been attained (by reading the relevant information) and specifying dependency relationships between objectives. When the student utilizes the latter option, the Aids system records the fact that there is a dependency between the two objectives named by the student. This dependency is shown whenever the student chooses to look at his Goal Stack (accessed from the Task page), and an arrow is drawn from the required to the dependent objective on the Goal Stack. Thus, the arrows between any two objectives on the Goal Stack page are determined by what the student has done on the Objectives page.

The Contents page simply provides a list of the titles of "chapters" or information sources of the technical manual that covers the device that the student is troubleshooting. The student can scan this list of titles and make decisions about the probable relevance to his objectives of some of the topics mentioned. When he decides that the material under a certain title is likely to be relevant to some objective, he exercises the Choose-Title option from the Contents page. Picking a title has the effect of throwing control immediately to the Matching page. On the Matching page, the student is shown the list of objectives and the title he just picked; he must specify which of those objectives requires that he learn the material named by that title. If he does not want to match any of his objectives with the chosen title, then he must cancel his choice of the title. (If he wishes, he can then go to the Objectives page, make up a new objective, and then return to the Contents page to select the title again, planning to match the title with the new objective). In this way, the student is encouraged to select only those titles he needs to solve his problem. As a result of the choices made on the Matching page, the Aids system remembers which of the chosen information sources are required by which of the objectives. This information appears whenever the student decides to look at his Goal Stack. It determines the arrows that are drawn from the numbers of the relevant information sources to their objectives. (See Figure 2).

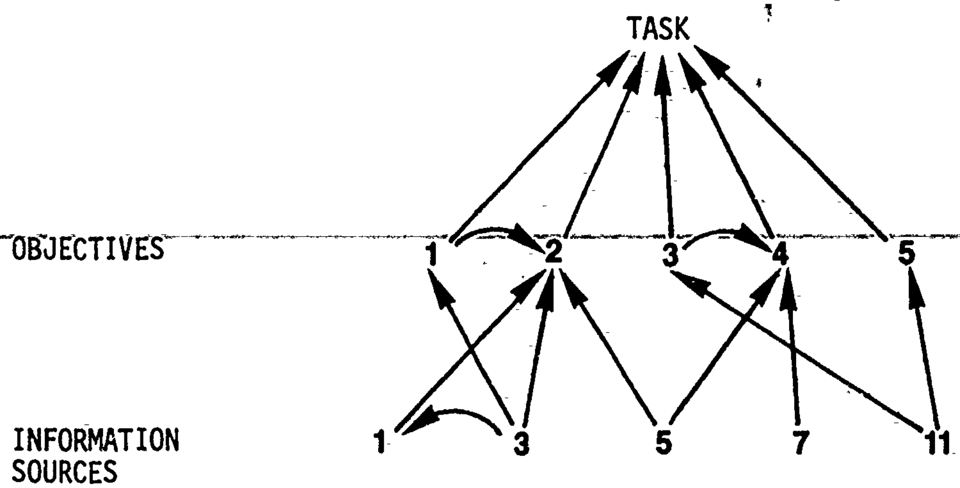

FIGURE 2. A Sample Goal Stack

Choices made on the Contents pages have one other consequence. Those titles that are chosen as relevant to some objective (and are matched with the objective) will appear on the Relevant Contents page. The Relevant Contents page is the student's personalized table of contents relevant to the troubleshooting problem he is trying to solve. Whenever the student chooses to go to the Relevant Contents page, he sees a list of all these chosen titles. A number of functions are available from this page. First, the student can decide to read any of the information sources listed there. Second, if a student has read and understood an information source, he can check off the title on the Relevant Contents page to signify that this subgoal was attained. If the student has read an information source and discovered that it was irrelevant, he can decide to remove it from the list of relevant information sources. A fourth option available is to specify dependencies between information sources. For example, if the student decides that relevant information source _1_ cannot be understood until relevant information source _3_ has been understood, then he can specify that _1_ is dependent upon _3_.

The last three choices listed above all have consequences for the Goal Stack. If the student has checked off a title, then that title's number will have a check mark below it in the Goal Stack. If a title has been removed from the list because it is irrelevant, then it will not appear in the Goal Stack at all. And if a dependency between two information sources has been specified, then an arrow will connect the numbers of their titles in the Goal Stack.

The information sources or "chapters" themselves are quite simple. Each consists of a number of pages through which the student can progress.

The student can page through the information source either forward or backward. In addition, from any page the student can elect to return to the Relevant Contents page.

II. TRAINING SEQUENCE

Students do not immediately begin with the complete self-directed learning aids system as it was discussed in the previous section. Instead, they are led to that version in a series of training sessions, each one having more of the features discussed in Section I than the previous session. The complete training sequence is shown in Figure 3.

Session	
1.	FAMILIARIZATION WITH TERMINAL INTRODUCTION TO SIMPLIFIED AIDS SYSTEM
2.	PRACTICE WITH SIMPLIFIED AIDS SYSTEM
3.	INTRODUCTION TO MORE COMPLEX AIDS SYSTEM (WITH GOAL STACK)
4.	PRACTICE WITH MORE COMPLEX AIDS SYSTEM
5.	INTRODUCTION TO FINAL AIDS SYSTEM
6.	PRACTICE WITH FINAL AIDS SYSTEM
7.	POST-TEST WITH FINAL AIDS SYSTEM (NEW TASK DOMAIN)

FIGURE 3. Training Sequence for Use of Self-Directed Aids System

The initial session familiarizes the student with the PLATO terminal and introduces him to the aids system. The student begins by playing a few games of tic-tac-toe against the computer to introduce him to the idea of touching the terminal panel. He then goes through a training lesson that teaches him to use the most rudimentary version of the aids system. (This version differs from the full system discussed in Section I in the following ways: first, the student cannot formulate his own objectives, but must make use of a set of objectives provided; second, the system does not provide a Goal Stack; third, the Objectives page does not provide the option of making explicit the dependencies among the objectives; fourth, the Relevant Contents page does not provide the option of making explicit dependencies among chosen titles.) This first session has three parts. In the first part, the student is taught about the overall structure of the Aids system and is given a quiz on his understanding of the system. Those students who score below the criterion must repeat this section of the lesson. In the second part of the lesson, the student is taught about the specific functions of each of the components of the system. This section of the training requires that the student step through each of these functions in a simulation of their actual use. In the third part of this session, the student has his first opportunity to practice with the limited aids system on a very simple task (learning to use the PLATO keyboard to type and edit answers).

In the second session students are required to solve a troubleshooting problem through the use of the simplified Aids system they learned about in the first session. The task is quite complex, and most students require from one to two hours to accomplish it.

The third session introduces students to a more complex Aids system. To the simplified system they have already learned about, the Goal Stack is added. In addition, the options to specify dependencies among objectives (on the Objectives page) and to specify dependencies among information sources (on the Relevant Contents page) are included. The lesson requires the student to make appropriate responses in a simulation of the functions of these new options.

In the fourth session, the students practice with this more complex Aids system. They are required to troubleshoot the same type of device that they have already had a troubleshooting problem on, but the problem and its symptoms are new.

The fifth session introduces the student to the writing of his own objectives on the automated Aids system. When this lesson has been completed, the student has been introduced to the complete Aids system depicted in Figure 1. This lesson is quite short and is usually combined with that of the sixth session for one long session.

In the sixth session, the student practices with the complete Aids system. The new troubleshooting task is, again, on the same type of device as were all the previous tasks.

The seventh session is a post-test session, although from the student's point of view it is simply another practice session with the full Aids system. In this session, the troubleshooting task is on a defective device of a different type from that with which the student is familiar. New information resources are, of course, provided.

III. TASK DOMAINS FOR THE TRAINING SYSTEM

Each time a student practices with some version of the Aids system, he must solve a complex learning task. In each case, the task is to troubleshoot or debug a defective device. This device produces output, some of which is incorrect; by examining this output and by reading information sources on the various components of the device, a student can determine which component is faulty (that is, causing the improper output). Each practice session with the Aids system has a different task--a different component is faulty, and, therefore, different symptoms are presented, each time.

Two such devices were selected as task areas, a sentence generator and an essay generator. (These devices are simulations, not physically embodied machines.) The sentence generator was used in sessions 3 through 6, and the essay generator was used in session 7, as a post-test of the training. These task domains were chosen to conform to a number of criteria:

(1) The topic matter permits the construction of "debugging" or troubleshooting problems. This is important because the topic matter is to be analogous to the electronics troubleshooting problems that confront Naval electronics technicians.

(2) The topic matter is sufficiently difficult that it could not be easily and completely comprehended by a single reading of a simple "technical manual" (the information sources). Again, this feature is an important part of the analogy to learning about the maintenance of electronic equipment.

(3) The topic matter is sufficiently simple that no special technical, scientific, or mathematical skills or knowledge are prerequisite to an understanding of the "technical manual." This feature is an important concern for the recruitment of subjects. Ideally, a large class of subjects should be available for whom the task topic is equally unfamiliar.

(4) The topic matter is one with which the investigators are sufficiently familiar that they can easily prepare suitable technical documents.

The Sentence Generator

The major components of the sentence-generation device are shown in Figure 4. A given component is comprised of a series of sub-components. Arrows in the diagram show the flow of control in the device. Where there are choice-points in the production of a sentence, this is represented by the use of switches in the diagram. For example, within the Noun-Phrase Generator, there is a three-way choice among three sub-components of Noun-Phrase. These are called NP1, NP2, and NP3. Only one of these serves as the activation of the Noun-Phrase Generator at one time. Within the component called NP3 there are more switches signifying other options in the production of a noun phrase with this Noun-Phrase Generator. If the NP3 unit is activated, then the DET unit must function; the Modifier-Phrase Generator either may or may not be called upon. A dashed-line box surrounding a component (such as the NP3 within NP1, or the NP within the Prepositional-Phrase Generator) signifies that control is surrendered to that component (defined elsewhere in the diagram) at that point. When that

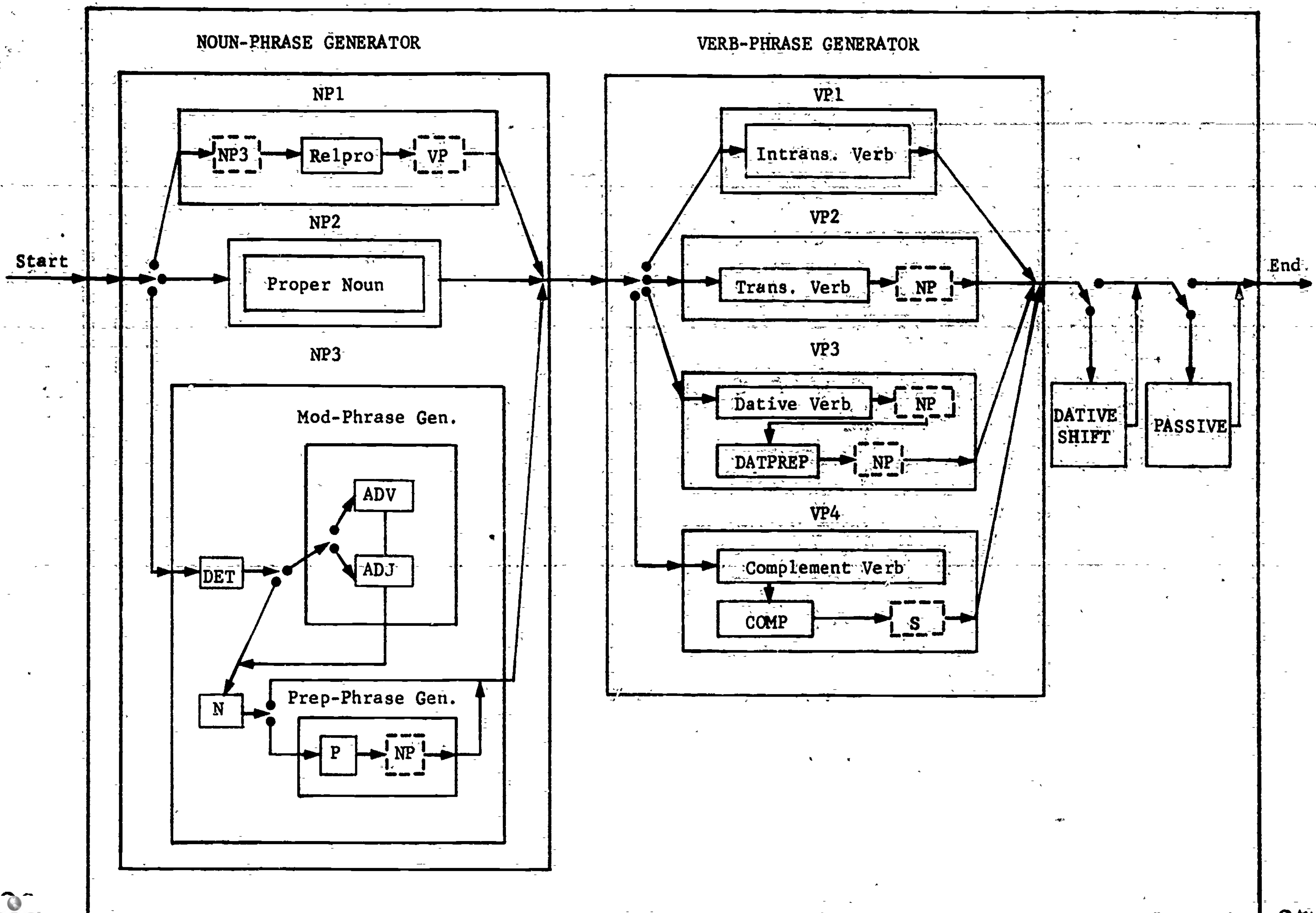

FIGURE 4. The Sentence Generator.

embedded component has finished running, control returns to the exit point of the dashed-line box. The presence of the embedded Noun-Phrase Generator components in the Noun-Phrase Generator, and that of the embedded Sentence Generator within the Verb-Phrase Generator makes the device indefinitely recursive. The two optional components after the Verb-Phrase Generator permit the application of the Dative-Shift and Passive transformations to the output of the rest of the Sentence Generator.

The diagram in Figure 4 is a functional analogue to a set of production rules which generate hierarchical structures, plus two transformational rules. The rules equivalent to the component diagram are given below (see next page). These rules describe a powerful device which produces a wide variety (although not all) of the grammatical sentence types in English. It provides a rich area for troubleshooting or debugging problems.

A student assigned to troubleshoot the Sentence Generator has access to a technical document containing 25 chapters, each several pages long; 10 of these chapters discuss various aspects of sentence grammar but are not relevant to the Sentence Generator itself. The remaining 15 chapters describe the functions and interrelationships of the components of the Sentence Generator. A list of all titles of these information resources is given below (Page 18).

Phrase-Structure Rules

1. $S \rightarrow NP + VP$
2. $NP \rightarrow \{NP_1, NP_2, NP_3\}$
3. $NP_1 \rightarrow NP_3 + Relpro + VP$
4. $NP_2 \rightarrow PN$
5. $NP_3 \rightarrow Det + (MP) + N + (PP)$
6. $MP \rightarrow (Adv) + Adj$
7. $PP \rightarrow P + NP$
8. $VP \rightarrow \{VP_1, VP_2, VP_3, VP_4\}$
9. $VP_1 \rightarrow V_i$
10. $VP_2 \rightarrow V_t + NP$
11. $VP_3 \rightarrow V_d + NP + Datprep + NP$
12. $VP_4 \rightarrow V_c + Comp + S$

Transformational Rules

1. Passive

SD: $NP - V_t - NP$

1 2 3 $\Rightarrow$

SC: 3, <u>was</u> + 2 + <u>en</u>, <u>by</u> + 1

2. Dative Shift

SD: V_d + NP + <u>to</u> + NP

1 2 3 4 $\Rightarrow$

SD: 1, 4, 2, Ø

Symbols

S = sentence, NP = noun phrase, VP = verb phrase, Relpro = relative pronoun, PN = Proper noun, Det = determiner, MP = modifier phrase, N = noun, PP = prepositional phrase, Adv = adverb, Adj = adjective, Vi = intransitive verb, Vt = transitive verb, Vd = double transitive verb, Datprep = dative preposition, Vc = complementizing verb, Comp = complementizer, <u>en</u> = perfective marker.

INFORMATION RESOURCES AVAILABLE FOR SENTENCE GENERATOR TROUBLESHOOTING

1. The Dative-Shift Component
2. Dependency Grammar
3. The EQUI-NP Transformation
4. Finite-State Grammar
5. Linear and Hierarchical Structure
6. The Mod-Phrase Generator
7. The Noun-Phrase Generator
8. The NP1 Component
9. The NP2 Component
10. The NP3 Component
11. The Particle Movement Transformation
12. The Passive Component
13. Phrase-Structure Grammar
14. The Prep-Phrase Generator
15. Rearrangement Transformations
16. The Sentence Generator
17. Syntactic Trees
18. The Transformational Component
19. Transformational Grammar
20. The Verb Deletion Transformation
21. The Verb-Phrase Generator
22. The VP1 Component
23. The VP2 Component
24. The VP3 Component
25. The VP4 Component

The technical document contains a list of grammatical sentences generated by a fully-functioning device. (In addition, the discussion of each component contains representative examples of phrases or words correctly generated by that component.) As examples of <u>sentences</u> generated by the device in Figure 4, consider the list below:

The quarterback passed the ball to the tight end.

Professor Hotchkiss is sleeping.

A very naive freshman bought the wrong book.

The teaching assistant who gave the coed an A+
was visited by the dean.

Harry thinks that Frank graduated.

A student in the back row coughed.

The instructor realized that the students were snoring.

Other chapters of the technical document, which discuss other components of the sentence generator, also present lists of sample possible outputs for those components. For example, the "Noun-Phrase Generator" chapter lists a sampling of grammatical noun phrases, such as

the tight end

a very naive freshman

Harry

the teaching assistant who gave the coed an A+

When subjects are presented with their task, they see a similar list of sentences, but some of these sentences are ungrammatical due to the failure or malfunction of a particular component of the sentence-generating device. For example, consider the following list. (An asterisk (*) before a sentence indicates that it is ungrammatical.)

*The textbook was written by.

The dean sent a letter to the department heads.

A student who failed the exam is crying.

That extremely young freshman surprised the professor.

*The secretary in the chairman's office discovered that
taught yoga.

The trophy was presented to the team by the chancellor.

(English speakers are sometimes clever enough to provide a semantic interpretation of a sentence marked as ungrammatical. The point is that the sentence is nonetheless ungrammatical according to the grammar/device given to the student.) In this case, the defective component is NP2 (alternatively, phrase-structure rule 4), which failed to output proper nouns. One way of showing the nature of the defect is presented in the diagram in Figure 5. As can be seen in this drawing, the NP2 component is "empty." It has no effect, other than to permit exit from the Noun-Phrase Generator without producing a noun-phrase, whenever the second position of the highest-level switch in the Noun-Phrase Generator is chosen. When the student correctly selects NP2 as the faulty component, he has solved his task.

The Essay Generator

The second device, an Essay Generator, is depicted in Figure 6. The Essay Generator is supposed to produce well-formed essays on a variety of topics. It accomplishes this end, in theory, by the sequential activation of a number of its components. A given component ordinarily contains a number of subcomponents. Arrows in the diagram show the flow of control in the device. Where there are choice points in the production of an

NOUN-PHRASE GENERATOR

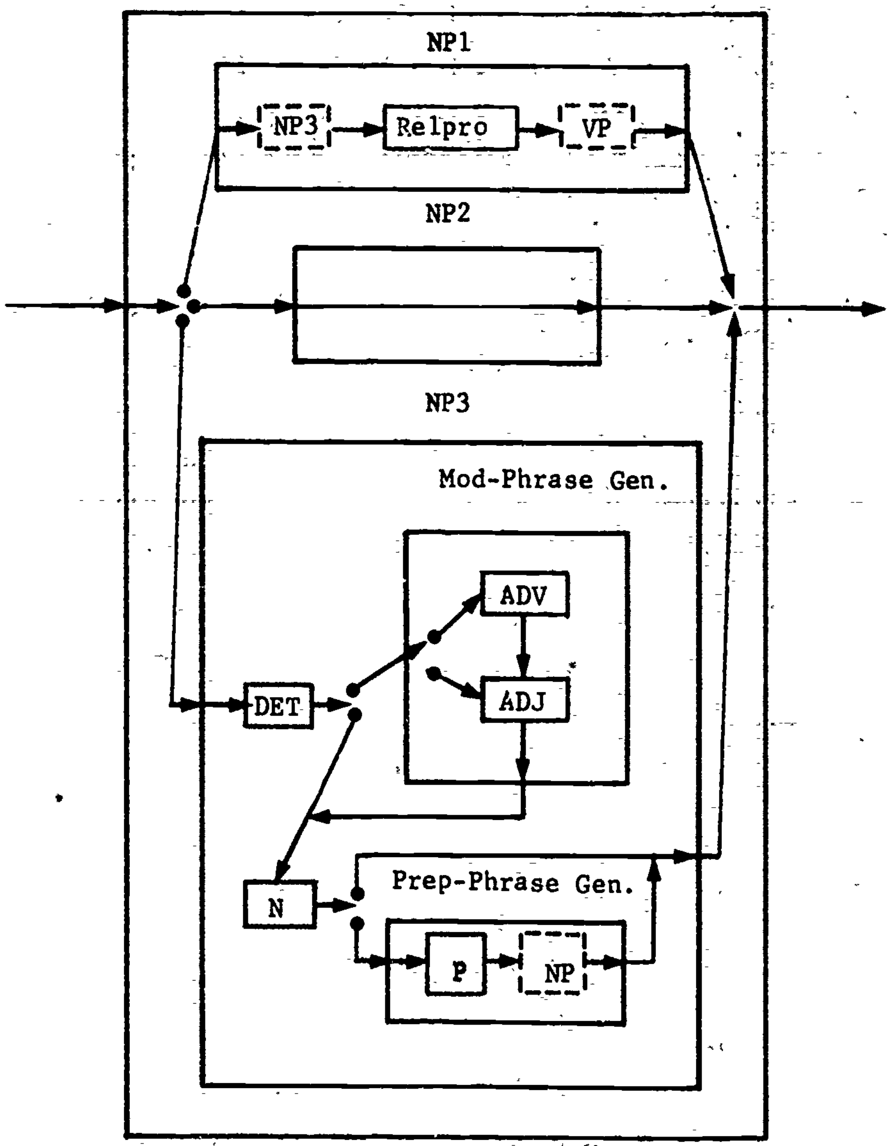

FIGURE 5. Diagram of a Faulty Noun-Phrase Generator Component of the Sentence Generator Device.

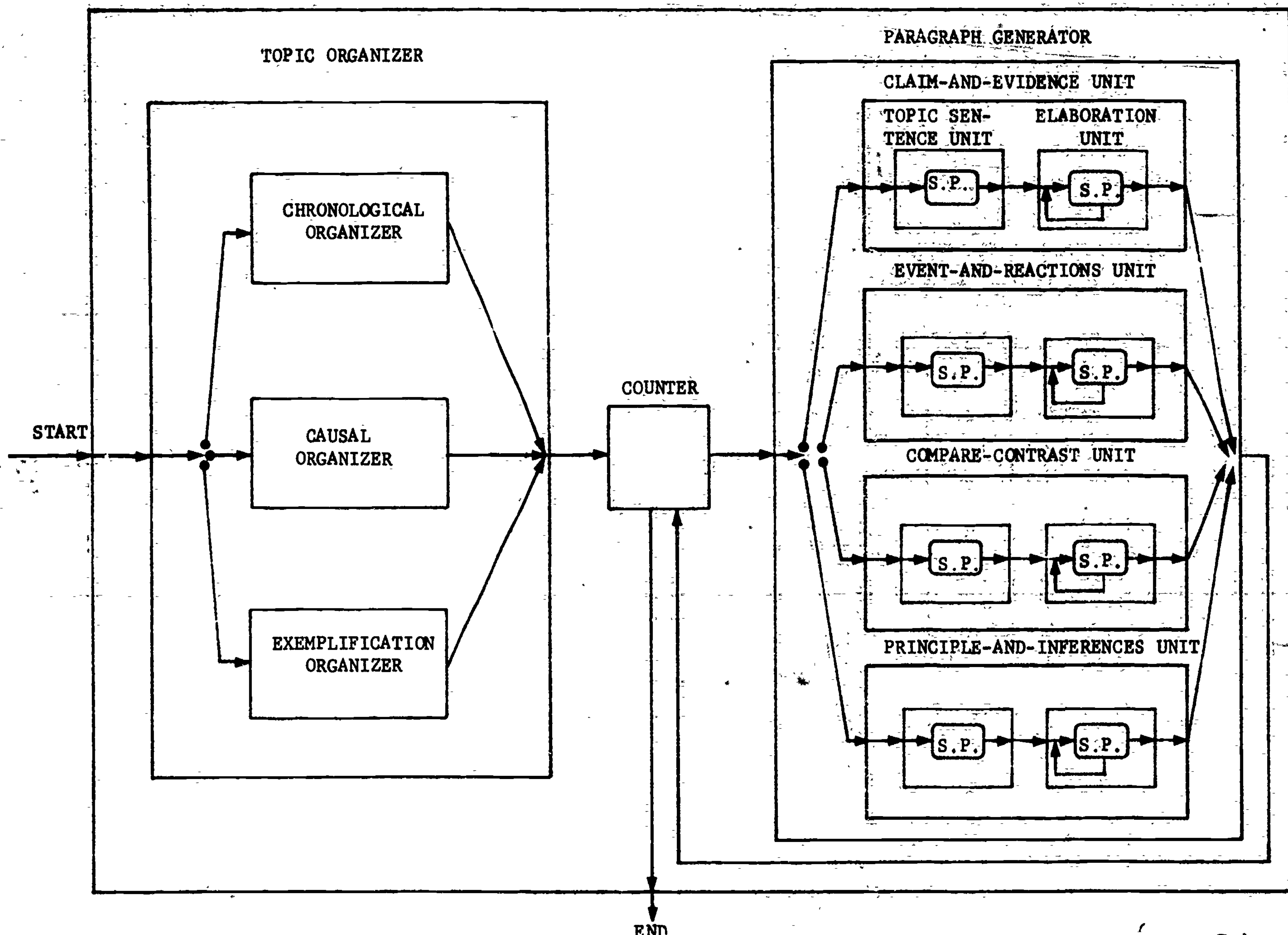

FIGURE 6. Essay Generator.

essay, this is represented by the use of switches in the diagram. For example, within the Topic Organizer, there is a three-way choice among three subcomponents of the Topic Organizer. These are called the Chronological Organizer, the Causal Organizer, and the Exemplification Organizer. There is a four-way switch within the Paragraph Generator, the setting of which determines whether a given paragraph will be produced by the Claim-and-Evidence Unit, the Event-and-Reactions Unit, the Compare-Contrast Unit, or the Principle-and-Inference Unit. Students assigned to accomplish troubleshooting tasks based on the Essay Generator have access to a technical manual of 109 pages on the PLATO system. This technical manual consists of twenty-one chapters, fourteen of which discuss the functions and interrelationships of the components of the Essay Generator and contain examples of the outputs of the various components and of the entire system when it is functioning properly. Which of these chapters are relevant depends, of course, upon the specific troubleshooting task encountered by the student. (The other seven chapters contain general information about writing but have nothing to do with troubleshooting the device; thus, these chapters are always irrelevant.) The list of all titles of the information sources is given on the next page.

An example of the output of the Essay Generator when it is functioning properly is given below.

Some of the Effects of Watergate

The Watergate scandal generally refers less to the actual break-in at Democratic headquarters than to the later attempts to cover up White House involvement in the planning of the operation. The discovery of this involvement and subsequent widespread publicity had a number of far-reaching effects.

INFORMATION RESOURCES AVAILABLE FOR
ESSAY GENERATOR TROUBLESHOOTING

1. Causal Organizer
2. Chronological Organizer
3. Claim-and-Evidence Unit
4. Compare-Contrast Unit
5. Counter
6. Elaboration Unit
7. Essay Generator
8. Event-and-Reactions Unit
9. Exemplification Organizer
10. Figures, Graphs, and Illustrations
11. Footnotes
12. Headings
13. Paragraph Generator
14. Parts of Speech
15. Principle-and-Inference Unit
16. Reference Citations in Essays
17. Sentence Characteristics
18. Sentence Producer
19. Sentence Types
20. Topic Organizer
21. Topic Sentence Unit

One result was the eventual resignation of the President of the United States while under threat of impeachment. This, in turn, meant a new administration with a largely new cabinet.

Another effect of Watergate is that the public has become very suspicious of its elected officials. In the last election, being an incumbent or having political experience often seemed to be more of a liability than an advantage to a candidate. Citizens are suddenly quick to demand explanations for any improprieties.

A third effect has been a change in the relative strengths of the Republican and Democratic parties. The Republicans have lost membership, while the Democrats have gained. The Republican party treasury, which had had a surplus, is now in the red. The Democratic treasury, by contrast, had been deeply in the red but has since almost fully recovered.

When subjects are presented with the task of debugging the Essay Generator, they see several such essays, but some of them are defective due to the failure or malfunction of a particular component in the Essay Generator. The nature of the defect depends upon the type of component that is defective. For example, if some component within the Topic Organizer is faulty, then the paragraphs within an essay might appear in a random order rather than the orders specified by those components. If the defect lies in a component of the Paragraph Generator, then the sentences within a paragraph might appear in the wrong order. For example, consider the following essay.

Questionable "Scientific" Theories

Recently a number of questionable theories have been proposed by scientists working outside their areas of specialty. In many cases these theories have been avidly adopted by large segments of the public. Yet scientists in the fields that deal with these theories are often skeptical of the claims made.

The public, however, has responded favorably to Professor Bandersnatch's numerous appearances on television talk shows and has purchased over 1.5 million copies of his book, Pyramid People. Archaeologists and Egyptologists in particular have greeted his claim with hoots of derision. One example of this phenomenon was the reaction to Professor Arnold Bandersnatch's announcement that the ancient Egyptian pyramids are actually the remnants of ancient spaceships to Earth.

However, since the appearance of Talmay's book, Hair Oil, in September of last year, sales of Vitamin E in this country have increased 150%. Doctors and biologists have almost universally scoffed at this idea. Another example is the claim made by the physicist Elmer Talmay that Vitamin E, taken in large doses, will prevent hair loss.

In this case, the defective component is the Event-and-Reactions Unit. All paragraphs of this type have scrambled sentence order, with reactions to some event appearing before the statement of that event. All other paragraph types are correct, however.

IV. COGNITIVE MODEL FOR SELF-DIRECTED LEARNING

One way of viewing the goals of this research is to say that we intend to find the means to teach people how to do effective web-learning (described in Norman, 1973, 1974, in press). What is it that they will know when they have graduated from our training procedures? How will what they know guide their learning of complex materials in the future?

Our answers to these questions are couched in terms of schema-theory (Norman, Rumelhart, & LNR, 1975; Rumelhart & Ortony, in press; Munro & Rigney, 1977). The central tenet of schema-theory is that knowledge guides thought. Stated baldly, this seems to be a truism. In schema-theory, however, explicit claims are made about the means by which knowledge guides thought. Computer simulations of schema-theory models provide rigorous tests of the adequacy of the proposed mechanisms for the relation of concepts in memory (of knowledge). Knowledge, in turn, to a large extent, consists of "frozen" or fossilized activations--copies of other concepts in memory, with specific details determined by the particular contexts within which those concepts were activated (see Munro & Rigney, 1977, for further explanation).

In schema-theory terms, the knowledge that subjects acquire as a result of the training described elsewhere in this report is best represented in terms of a prescriptive schema. A prescriptive schema is a conceptual structure, which, when activated, gives people the impression that they are giving themselves instructions. Prescriptive schemata are responsible for the effects that we attribute to "self-direction strategies." The set of schemata that students acquire from our training program is an abstract conceptual structure with considerable scope. (The uses of the terms "abstractness" and "scope" with respect to schemata are discussed in Munro & Rigney, 1977). Here are the hypothesized schemata that we believe students acquire as a result of their training.

(1) SELF-DIRECTED-LEARNING (TASK)

is when

BUILD-GOAL-STRUCTURE (TASK)

TASK-PURSUE (TASK)

end.

(2) BUILD-GOAL-STRUCTURE (TASK)

is when

ANALYZE (TASK, for OBJECTIVES (TASK))[2]

PREREQUISITE-SEARCH (for EACH (OBJECTIVE), in OBJECTIVES)

PREREQUISITE-SEARCH (for EACH (OBJECTIVE), in CONTENTS)

end.

(3) TASK-PURSUE (TASK)

is when

EXAMINE (GOAL-STRUCTURE)

UNTIL (CHECKED (EVERY (OBJECTIVE)), PURSUE (OBJECTIVE))

TASK-ATTEMPT (TASK)

end.

(4) TASK-ATTEMPT (TASK)

is when

IF (DO (TASK), then QUIT, else SELF-DIRECTED-LEARNING (TASK))

end.

---

[2] The ANALYZE sub-schema has not yet been represented. How people are able to discover the prerequisites or component actions of a task is not well understood.

```
(5) PREREQUISITE-SEARCH (for GOALS, in SUBGOAL-SET)
          is when
     FOR-EACH (MEMBER, of SUBGOAL-SET,
          IF (PREREQUISITE (MEMBER, for GOAL),
          then (SPECIFY-DEPENDENCY (MEMBER, to OBJECTIVES-LIST))))
          end.
(6) PURSUE (GOAL)3
          is when
     FOR-EACH (SUBGOAL (NECESSARY (SUBGOAL, to GOAL)), in GOAL-STRUCTURE,
          WHILE (ANY (UNSATISFIED (SUBGOAL' (NECESSARY (SUBGOAL', to
          SUBGOAL)))),
               PURSUE (SUBGOAL'))
          TRIAL (SUBGOAL))
               end.
(7) UNSATISFIED (GOAL)
          is when
     NOT (CHECKED (GOAL))
     NOT (ELIMINATED (GOAL))
          end.
(8) TRIAL (GOAL)
          is when
     ATTEMPT (GOAL) to ATTEMPT (ACTION, of GOAL)
     EVALUATE (GOAL)
          end.
```

[3] This structure is a variant of Rumelhart & Ortony's (in press) schema for TRYing, a subschema of their PROBLEM-SOLVING schema.

(9) EVALUATE (GOAL)

is when

IF (NECESSARY (GOAL, to HIGHER-GOAL),

then IF (SATISFIED (GOAL), then CHECK (GOAL),

else TASK-PURSUE (TASK)),

else ELIMINATE (GOAL, from GOAL-STRUCTURE))

end.

(10) ATTEMPT (GOAL)

is when

IF (BELIEVE (CAUSE (ACTION, SATISFIED (GOAL))),

then DO (ACTION),

else when SUCCEED (PREREQUISITE-SEARCH (for GOAL)),

ATTEMPT (PREREQUISITE (GOAL)))

end.

According to the first of these schemata, the student believes that the way to achieve a task through self-directed learning is first to build a goal structure and second to pursue the task, using that goal structure. The second schema listed above describes what is involved in building a goal structure. One analyzes a task for objectives (subgoals necessary for the performance of the task), then one searches for prerequisite relationships among these objectives, between the available information resources and the objectives, and among the relevant available information resources. However, the schema does not contain explicit reference to the process of adding these relationships to the goal structure, because the goal structure is constructed for the student by the program that aids him or her in self-directed learning. The fifth schema listed above is an essential part of the goal-structure-building schema, since it specifies how the search for prerequisites is conducted.

The second major part of self-directed learning, after building a goal structure, according to the above schemata, is to pursue the task. The third schema above gives the top-level structure for task pursuit. One examines the newly constructed goal structure first; then one pursues the objectives included in that goal structure until every one of them has been checked. (Checking is the process by which a student marks the attainment of a subgoal, using the aids program on PLATO). When all the necessary objectives have been checked, the student attempts the task. If the attempt fails (see schema #4), then he begins the self-directed learning process again, reconstructing or modifying the goal structure.

The pursuit of objectives is governed by the sixth schema given above. This is a recursive procedure that traces down dependency relationships in the goal structure. When a goal is found that has no prerequisites, that goal is subjected to a trial. This means (see #8, 9, & 10) that the student does an action to bring about the goal and then evaluates the results of that action. If the goal is satisfied, he checks the goal and then pops back to the appropriate point in the procedure that is pursuing an objective. If it is not satisfied, he looks for a new way to pursue his overall task. If the attempt reveals that the goal was unnecessary to the attainment of its higher goal, then it is dropped from the goal structure.

The above schemata constitute working hypotheses about the nature of the conceptual changes brought about by training in the self-directed learning aids program discussed above.

The prose explanations of these schemata, above, emphasize the way in which these schemata call each other in a top-down, conceptually-driven processing mode. Naturally, there is also a bottom-up, data-driven aspect to the activation of these schemata in normal circumstances. For example, when a student finds that he has satisfied a goal (say, as a result of reading one of the relevant information resources), this activates the subschemata in the fourth line of the ninth schema presented above. The activation of these subschemata (IF (SATISFIED (GOAL), then CHECK (GOAL,...) activates, in a data-driven fashion, its "parent" schema, EVALUATE. The activation of EVALUATE, in turn, can activate the schema that calls _it_, and so on, so that activation spreads in an upward as well as a downward direction.

V. EXPERIMENT

An experiment was conducted to test the effects of the self-directed learning aids system. A control condition was established, containing only the Task and Contents pages of the system described in Section II. A student in the control condition has the same learning task and the same information to read, but he has none of the Aids system available to a student in the experimental condition. (Information sources in the control condition are accessed directly from the Table of Contents. As soon as the student touches a title, he is shown the corresponding information source).

Control Training Sequence

The training sequence for control subjects is similar to that for experimental subjects, except that the basic system is never modified for them, so that there is no need for teaching sessions other than the initial one. Consequently, all sessions are practice sessions using the control system. The complete sequence is shown in Figure 7.

1	FAMILIARIZATION WITH TERMINAL INTRODUCTION TO CONTROL AIDS SYSTEM
2	PRACTICE WITH CONTROL AIDS SYSTEM
3	PRACTICE WITH CONTROL AIDS SYSTEM
4	PRACTICE WITH CONTROL AIDS SYSTEM
5	POST-TEST WITH CONTROL AIDS SYSTEM (NEW TASK DOMAIN)

FIGURE 7. Training Sequence for Control Subjects

The initial session begins in the same way as in the experimental condition, with a session in which the student is first given some practice using the touch panel of the PLATO terminal by playing tic-tac-toe. This is followed by a two part PLATO lesson on the functions of the control "Aids" system. As with the experimental group students, each part of this lesson is followed by a quiz which the student must pass in order to progress. This introduction is followed by a short practice session using a very simple learning task.

In the second, third, and fourth sessions, the student solves complex troubleshooting problems (one for each session) using the control "Aids" system. Each of these tasks involves a different problem with the same type of device, the Sentence-Generator. These sessions provide practice for the student in the use of the control "Aids" system and in troubleshooting problems on devices of the sort used for these exercises. In the post-test (Session 5), students are to use whatever learning skills they acquired during their training to perform a troubleshooting task in the new domain of the essay generator. Several types of data are collected during this session, on both control and experimental subjects.

Data Collection

The data collected during the post-test were designed to measure both effective learning and self-directed learning. Effective learning is defined in terms of the time required to perform the task and the number of errors made in performing it. For each student data is collected on the number of erroneous attempts made to solve the problem and the total time taken to solve the problem after being presented with it. Self-directed learning is much more difficult to measure. It was decided that self-directed learning is typified by two phenomena: planning and selectivity in the use of information sources. The data collected reflect operational definitions of these phenomena.

Planning

It is not an easy matter to discover whether a student is engaged in effective planning. One type of data saved by our PLATO program is the sequence in which the student accessed the information resources available to him. Our analysis of the troubleshooting task presented to the students in the post-test session has resulted in the formulation of a set of rules for scoring deviations from the order in which the information sources should be accessed. These rules, which we call anti-precedence rules, take the form of prohibitions of certain sequences. The extent to which a student has departed from sequences permitted by an ideal task analysis can be expressed in terms of the number of times the student's study sequence violates the anti-precedence rules.

Here is the set of anti-precedence rules based on our analysis of the task used in the post-test:

1. No information source should precede 7
2. 1, 2, 9 should not precede 20
3. 3, 4, 6, 8, 15, 21 should not precede 13
4. 6, 21 should not precede 3

   6, 21 should not precede 4

   6, 21 should not precede 8

   6, 21 should not precede 15

   (Note: If the student violates more than one of the rules of #4, only one violation is counted.)
5. 18 should not precede 6, 21

Here is an example of how the scoring was done. Consider the following hypothetical sequence of accesses to information sources:

2, 7, 21, 20, 4, 15, 13, 7, 8

Rule 1 is violated once, because information source 2 precedes 7. Rule 2 is also violated once, because information source 2 precedes source 20. Rule 3 is violated twice; information sources 21 and 15 both precede 13. Rule 4 is violated; 21 precedes both information sources 15 and 8. As the note above explains, this is counted as only one violation. There are therefore a total of five violations of our anti-precedence rules in the example sequence shown.

Selectivity in the use of information resources

Selectivity has to do with the ratio of the use of relevant information sources to the use of all information sources. A student for whom this ratio is high has read primarily only relevant sources. Three different ratios are computed by our program. The first is the ratio of number of relevant information sources read to total information sources read. The second is the ratio of the number of readings of relevant information sources to the number of readings of all information sources. The third is the ratio of time spent reading relevant information sources to the time spent reading all information sources.

Results

Mean scores on two measures for the effectiveness of the two groups of learners are presented in Table 1. In the final test session, in which students were required to troubleshoot a faulty essay generator, those students who had not been exposed to the training in self-directed learning were slightly slower than those who had received the training. The experimental group subjects, on the average, solved the problem 9 minutes before the control subjects. The number of erroneous choices made by the two groups of subjects before identifying the appropriate component as defective was about the same.

In Table 2 the evidence concerning the selectivity displayed by students trained under the two conditions is presented. The measures of selectivity that are ratios of the use of relevant information sources to total information sources show little or no difference between the two groups. Control subjects chose more than twice as many titles to read than did the experimental subjects, suggesting that students in the control condition were not as selective; however, this difference was not statistically significant.

Table 3 summarizes the measure used to detect planning. Planning, as described above, is evidenced by few violations of principles of efficient sequencing in reading the available materials. The means suggest that the experimental subjects were better planners than the control subjects, since they made only 72% as many planning violations. Again, this was not confirmed statistically.

A one-way analysis of variance between performance of the two groups

Table 1

Effectiveness of Learning in Post-test Session

	Means: Time to complete (minutes)	Means: Errors
Experimental (n = 7)	65 (31.90)	2.9 (3.13)
Control (n = 4)	74 (25.15)	3.0* (0.00)

* n = 2

Standard deviations are in parentheses.

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Table 2

Selectivity in Post-test Session

	Means			
	Titles Chosen	R_1	R_2	R_3
Experimental (n = 7)	9 (3.79)	0.73 (0.11)	0.75 (0.09)	0.73 (0.12)
Control (n = 4)	20 (13.89)	0.83 (0.15)	0.72 (0.12)	0.72 (0.08)

R_1 = Ratio of number of relevant information sources read to number of total information sources read

R_2 = Ratio of number of readings of relevant information sources to number of readings of all information sources

R_3 = Ratio of time spent reading relevant information sources to time spent reading all information sources

Standard deviations are in parentheses.

Table 3

Planning in Post-test Session

	Means Violations of efficient sequencing
Experimental (n = 7)	1.8 (3.08)
Control (n = 4)	2.5 (5.00)

Standard deviations are in parentheses.

indicated that the groups do not differ significantly on the basis of time to perform the task, errors made, selection of relevant titles, and efficient sequencing. The difference in the number of titles chosen (Table 2) approaches signigicance, $p < 0.1$.

Discussion

Interpretation of these results is problematic. A cursory inspection of the results leads one to suspect that the special training received by the experimental group did not have any important effects, and is therefore not a useful approach to take. Although the students in the experimental group seem to be slightly more efficient planners in the post-test session and slightly more selective readers, they don't seem to be significantly more efficient learners. They made about as many errors as did the students in the control group and they solved the troubleshooting problem in only slightly less time.

A closer examination of the students' behaviors in the post-test session, however, reveals that the nominal experimental treatment may not have been operational. The results cannot be interpreted as evidence that the use of the self-directed aids system is not helpful, because the experimental subjects were not really using the aids system. Only three of the seven experimental treatment students ever specified dependencies among information sources that they had chosen as relevant. Only two of them ever looked at their goal stacks. None on these students ever specified a dependency between objectives. A majority of these subjects (four of the seven) failed to formulate more than one objective. (Those who formulated only one objective simply restated their task in the form of an objective; e.g., "Identify the defective part of the Essay Generator.") Thus, the two groups did not really differ in functional treatment.

In retrospect, we are impressed that the students in the experimental group were able to do as well as those in the control group. The control group students had a much easier assignment. They simply had to make use of an automated table of contents to read information sources they thought might help them to solve the problem. What they had to concentrate on was learning new information relevant to their task at hand, and all their intellectual resources could be devoted to this task. The students in the experimental group, on the other hand, had a much more difficult assignment. Not only were they required to solve the same complex learning problems that the control subjects had to solve, they were also required to learn and use the many details of the very complex system that was supposed to aid them. Under these circumstances, it is surprising that the experimental subjects were able to complete the task in slightly shorter times than the control subjects, since the experimentals had so much additional apparatus to manipulate. Many subjects made it clear to the experimenters, both in verbal comments at the conclusion of the post-test and in the written critiques that were solicited from them that they had not fully internalized a set of rules for the use of the aids system and that they were very confused about the functions of its basic components. In fact, some students, after muddling through a number of information sources, simply began to make wild guesses about which component might be defective. In some cases, students chose as the defective component devices for which they had not even read the information sources.

Not all students who were given the aids system found it to be useless or even a handicap, however. The subject JR, for example, made very effective use of it. She showed good planning by formulating useful objectives and then selecting information resources that could help her attain those objectives. By the measure of planning discussed in the results, her planning was perfect; she had no violations of our rules for efficient sequencing. She was also a selective user of information resources. She chose only nine titles for study, and her selectivity ratios (explained in Table 2) were very high ($R_1 = 0.89$, $R_2 = .90$, $R_3 = 0.88$). She was also an efficient learner. She took about an average amount of time to solve the problem; however, unlike many other students, she made no errors. She correctly identified the defective component on the first attempt.

The fact that this student was better able than others to exploit the functions of the automated aids system dramatically highlights the variation found in student performance. An examination of the standard deviations given in Tables 1, 2, and 3 confirms this variation. The large variation and the small sample size cause any differences between the group means to be non-significant.

Perhaps, then, the fault lies not with the automated aids system itself, but rather with the training program that was designed to teach the experimental subjects how to use the aids system. A regression of scores on the Nelson-Denny test of reading ability on time taken to complete the task reveals an interesting difference between the experimental subjects and the control subjects. This difference is shown graphically in Figure 8. Note that the control subjects display the relationship that would be expected *a priori*: students who score lower on the reading test take longer to complete the task. Experimental subjects, on the other hand, show considerably less effect of reading ability. However, experimental subjects scoring in the low range on the Nelson-Denny test require much less time to complete the task than control subjects scoring in this same range. Perhaps the automated aids system benefits poor readers to a greater extent than it benefits good readers.

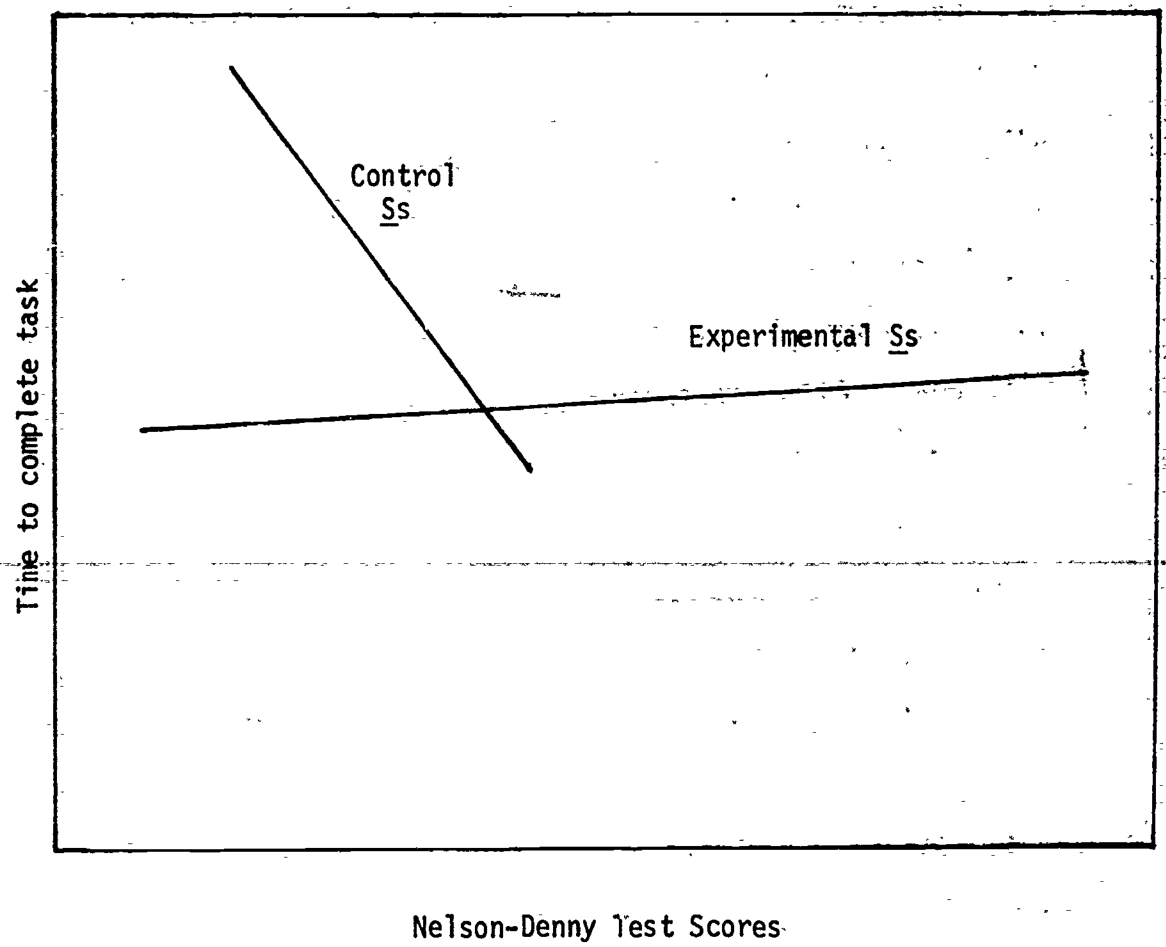

Figure 8. Regression of Reading Scores on Time for Each Group

VI. DIRECTIONS FOR FUTURE RESEARCH

A more thorough training program is certainly called for. Students in the experimental group were exposed to a very large number of aids-system functions, but were given little opportunity to practice using most of these functions. Each function was demonstrated once in training, and the student was then required to mimic its use once. For many functions, this was the only time that the student had to use that function. In our revised training system for the use of the automated aids system, students will be required to practice with each of the available functions until the use of each is well-understood and easily executed by the subject.

A second major problem in our experiment, in addition to the lack of adequate practice for those in the experimental group, was the burden of learning about two complicated systems--the automated aids system and the sentence generator--at the same time. It is very important that subjects should receive training drill on the use of the functions of the aids system in a context in which they are not burdened with the simultaneous need to puzzle out the workings of another complex system at the same time. To this end, students in future experiments will be drilled on system functions in the context of simple learning problems first. Only after the functions seem to be well understood will students be required to use the system to solve the more complex kinds of problems for which the system was designed to be used. Because the system is really designed to aid in the solution of complex problems, its use for simple practice problems may seem superfluous to students. Our training will therefore contain explanations that the simple problems are used for illustration and practice. The student will be reminded that the system is most useful for the solution of complex problems in which large amounts of information are available, and that the simple problems are included only for pedagogical reasons.

A third major problem in the training our experimental subjects received was that it did not adequately motivate them to make use of the system functions. Three measures will be taken to increase this kind of motivation in subsequent experiments. First, the reasons for the inclusion of particular functions will be explained more fully to the subjects. They will be shown how each function can contribute to the solution of a problem and under what conditions the students will have extra difficulty if he fails to make use of a function. Second, the students will be induced to improve their troubleshooting performances. In real world on-the-job contexts, professional troubleshooters understand that errors in diagnosis are expensive. The replacement of properly functioning components is wasteful of both time and materials. Our subjects must be induced not to employ a random guessing strategy to identify the defective component in a troubleshooting problem. Some costs to the subjects, possibly monetary, will be instituted in order to prevent the adoption of such a strategy. On the other hand, it is very important that subjects not be encouraged to be too conservative in their approach. A troubleshooter's time has value, and we do not want to drive subjects to a cautious study of all the information resources available to them before they make a judgement. Indeed, an important part of our conception of self-directed learning is that such learning is selective. We may, therefore, find it necessary to make use of monetary disincentives for reading too many information sources. The third measure we will take to increase the students' motivation will be to institute some kind of reward system for the use of certain functions of the aids system. In particular, we would like to reward the use of those functions that help the student to monitor his progress toward the accomplishment of his task, such as the check-off and X-off functions of the Relevant Contents and Objectives pages. Moreover, students would be rewarded for accessing the goal stack in order to plan a course of study. Ideally, the administration of rewards for the use of such functions should be under the control of the subject himself. By following the principles of behavioral self-control set forth in Kanfer & Goldstein (1975), Mahoney (1974), Mahoney & Thoresen (1974), Thoresen & Mahoney (1974), and Watson & Tharp (1972), we should be able to help students instill learning habits that they can apply outside of the experimental environment as well as within it.

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