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DESIGN AND USE OF INFORMATION SYSTEMS FOR AUTOMATED ON-THE-JOB TRAINING

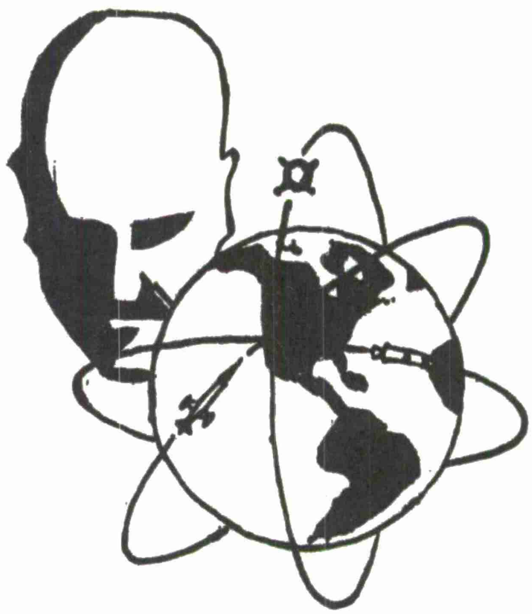
I: CONCEPTUAL AND EXPERIMENTAL APPROACHES

TECHNICAL DOCUMENTARY REPORT NO. ESD-TDR-64-234

DECEMBER 1963

Thomas B. Sheridan
Sylvia R. Mayer

DECISION SCIENCES LABORATORY
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts



Project 7682, Task 768204

(Prepared under Contract No. AF 19 (628)-455 by Bio-Dynamics Incorporated, Cambridge, Mass.)

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FOREWORD

One of the research goals of the Decision Sciences Laboratory is the development of design principles for automated training subsystems which could be built-into future Information Systems. Such subsystems would provide Information Systems with the capability of training automatically their own operators. The need for such on-the-job training has already become apparent. To be able to design such a capability requires first the solution of many conceptual and experimental problems.

Task 768204, Automated Training for Information Systems, under Project 7682, Man-Computer Information Processing, was established to formulate and answer some of these problems.

This report is one in a planned series supporting Task 768204. It was prepared as a joint effort of the staff of Bio-Dynamics, Inc., working under terms of Contract AF 19(628)-455, and Decision Sciences Laboratory, Electronic Systems Division. The authors are Dr. Thomas B. Sheridan, Principal Investigator and Dr. Sylvia R. Mayer, Contract Monitor.

Several Bio-Dynamics staff members are contributing directly in the accomplishment of different parts of this study: Ms. S. Molnar, R. Rosenberg and J. Mickunas on the work described in Chapter III, Dr. B. Duggar: Chapter IV, Dr. A. Johnson: Chapter V.

DESIGN AND USE OF INFORMATION SYSTEMS FOR AUTOMATED ON-THE-JOB TRAINING

I. Conceptual and Experimental Approaches

Abstract

This report describes exploratory developments on laboratory models of automated training subsystems for Information Systems. Such subsystems could provide future Information Systems with the capability to train their users on-the-job.

The report outlines on-going studies concerned with (1) the unique training requirements in advanced Information Systems; (2) new training concepts and techniques to meet these requirements; and (3) an analytic tool to describe functional and structural overlap of equipment required for both operations and training.

REVIEW AND APPROVAL

This Technical Documentary Report has been reviewed and is approved.

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Decision Sciences Laboratory

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KEY WORD LIST

1. COMMAND & CONTROL SYSTEMS
2. TRAINING DEVICES
3. DESIGN
4. MODELS (SIMULATION)
5. AUTOMATION
6. EXPERIMENTAL DATA
7. ANALYSES
8. BEHAVIOR
9. DECISION MAKING
10. COMPUTERS
11. DISPLAY SYSTEMS

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I. Introduction

Air Force Information Systems perform many complex "intellectual" functions which, until recently, have been regarded as the exclusive province of man. The research reported herein is based on the premise that, with a modicum of new design principles and human engineering, these Information Systems could do much more: they could also train their human components to use and maintain them. This report describes initial research efforts aimed at developing these automated[1] training subsystems for Information Systems.

A. Automated Training Research in the Air Force: Past and Present

Air Force research and development in automated training has been in progress for more than a decade. Techniques, devices and theory for automated training have evolved gradually. At the present time research on various aspects of automated training is being carried on by Air Force Systems Command (2, 14, 15, 17), and Air Training Command is conducting an intensive program of experimental applications of these techniques (16). Completed studies have left little doubt as to the potential value of this approach for the Air Force (6, 8, 9, 11, 12, 27). Questions of feasibility and suitability are no longer posed. Rather the current problem is one of improving and refining primitive methods and concepts for more efficient implementation in a variety of Air Force training operations.

B. Automated Training Research in the Air Force: Future

The majority of studies have been concerned with part-task training in classroom settings. This emphasis has been proportioned to the past

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[1] As used here this term includes the methods and concepts of programed instruction plus machine control and direction of that instruction.

and current practice of conducting the major part of Air Force training in formal classroom settings prior to on-site assignment. Automated training for on-the-job use has received somewhat less research emphasis. However, many characteristics of future Air Force operations point to an inevitable future shift in training location. The recent Path Finder Study (3) initiated by Lt Gen James E. Briggs of Air Training Command, predicted that a large portion of future training must occur on-the-job, on-the-operational equipment. This change will stem from the complex and costly nature of many of the future Air Force systems - particularly Information Systems. Classroom simulators of the traditional type will be economically unfeasible. Factors of cost in dollars and/or cost in floor space may preclude the traditional approach.

Complex simulators will probably not be feasible except where danger to man, machine or mission prohibits the novices' interaction with operational equipment. The main advantage of conducting training at the job location will be the availability of operational equipment and operational problems for "use" in training. Exactly what form this "use" should take or how it should be accomplished is now a question for research.

A study program - its early phases are described herein - is researching this question specifically for future Air Force Information Systems.

C. Automated Training by Information Systems

This approach is based on evidence[1] that the operational equipment of existing and future Information Systems could provide the physical requirements for an automated training and skill maintenance function

[1] Past studies in the SAGE System and current research in System 473L support this view.

without interfering with the primary mission function. Furthermore, several applications of automated training in Information Systems have already demonstrated the potential of this method for the training tasks in these systems (8, 9, 10, 11, 18, 27).

The long-range objective of this research is to provide basic principles upon which to design into an otherwise conventional Information System this automated training function.[1] The immediate objective is to analyze and demonstrate with laboratory models how the logical functions and mechanisms of Information System tasks and associated equipment overlap with the functions and mechanisms required for training of these tasks.

The immediate objective is being accomplished in a three-part plan:

Phase I. This phase involves modeling of artificial, representative Information System tasks first in graphical symbology and then in hardware. This phase has required the development of a new symbolic language which can describe both man and machine response in terms easily translatable into electrical circuitry. Completed exploratory studies are described in this report, Chapter III.

Phase 2. This phase is addressed to development of automated training programs tailored to Information System tasks. These automated training programs will use Phase 1 equipments for input-output and storage functions. This phase is still in its formative stages. Completed work, experimental and theoretical, is described in Chapters IV and V.

Phase 3. In this phase equipment which models the operational tasks (Phase 1) is to be integrated with equipment which provides the

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[1] This interim report attempts only to summarize problem formulations and associated exploratory design studies. Individual reports will be issued on later formal studies with scope and results meriting more complete documentation.

automated training functions (Phase 2). From this process principles will be inferred by which to design the built-in training function. This work will be presented in a later volume in this report series.

II. Summary

The long range objective of this work is to provide principles upon which to design into conventional Information Systems the capacity to train automatically their own users. Development of these design principles will depend on research findings relative to:

1) what can and should be taught to enable operators to utilize most efficiently Information System capabilities,

2) automated training procedures for Information System tasks,

3) degree of overlap between the functions and structures of the normal operating task and equipment and the functions and structures of the training task and equipment.

This report outlines necessary research, describes the design of studies underway, and outlines some results and conclusions derived from completed work. Specific recommendations to implement findings will appear in later reports in this series.

The experimental and theoretical approaches have proceeded along the following three distinct but related avenues:

1) a "representative" Air Force Information System task was modeled in a new symbolic language, and experiments undertaken to explore methods of teaching the logic flow of the task,

2) two "logic" games involving querying-reasoning behavior are being used as the framework for the study of such behavior, and evaluation of methods of teaching optimum strategy,

3) a novel concept for programed learning of the functions of systems composed of interrelated, multiple subsystems has been developed and experimental validation is underway. This concept involves the "method of discovery" and the "phylogenic" ordering of functions.

Progress along each of these avenues is described in separate sections of this report.

III. Studies on a Method for Self-Instruction in Task Logic

A. Introduction

A sub-objective of the overall program was to determine and demonstrate, through use of experimental task or model, how the functions and mechanisms of a normal operating task and associated equipment may overlap with the functions and mechanisms of a training program and equipment. A three step program directed towards achieving this sub-objective was defined as follows:

1. Development of a narrative and hardware model of a representative Air Force Command and Control System Task.
2. Development of a program to teach this task to a novice operator using the task simulator for input-output and storage function.
3. Integration of equipment which models the operational task with equipment which serves to teach the task operation. From this, presumably, principles could be inferred to design operational equipment having the programed operator training function "built-in".

The first step has been completed, the second and third have been completed for several alternative teaching configurations, and additional experimental evaluations are underway.

The "representative" task was based upon the activity of the SAGE Intercept Director whose job it is to follow and assist an aircraft(s) through an entire mission. This SAGE operation was taken as exemplary of an Air Force Command and Control function, and the Intercept Director task was considered a workable compromise between command, or decision, functions and rote functions.

The job of the SAGE Intercept Director (and his relationship to the SAGE Intercept Technician) requires a decision process, leads to a definite outcome, and can be subjected to a procedural analysis. The tasks of the Intercept Director and the Intercept Technician were considered as one task since it appeared that the Director would have to know the Technician's task in order to perform his own mission.

Familiarization with the task was gained through available reports (19 -24) as well as a cardboard mock-up and a prototype instruction program designed by the American Institute of Research.[1] The entire task consists of "minor" and "major" sequential elements. Minor sequences are the smallest independent actions or elements of the overall task. A minor task element might consist of contact with the pilot, whereas a major task might involve following an aircraft throughout its mission. Thus, the major sequences consist of blocks of minor sequences. The order of major sequences depends upon the activities of the aircraft and the priorities of the situation. There is no fixed number of minor sequences in a major sequence. The Intercept Director may follow an assigned aircraft throughout its mission, or he may terminate his assignment if the conditions warrant. (This is in contrast to a minor sequence where once the sequence is initiated it has to be followed through until the correct solution is obtained.) However, once a specific stimulus appears, a corresponding set of responses are required to arrive at a correct solution.

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1 This work, conducted under contract AF 19(604)-5951, provided the first exploratory development on automated, on-the-job training for Information Systems.

B. Graphical Model of the Task

A task analysis and graphical description of the logical relationships between stimuli and correct responses, including specification of all stimulus-response contingencies leading to correct outcomes, was performed. For simplification of the procedural analysis of the Intercept Director's task, and facilitation of its modeling, only the correct actions were included in the analysis and graphical representation. In addition, steps which were overly redundant insofar as they did not characterize any "new" logical relationship or situation, the initial phase of operation during which the Intercept Director and his Technician check out their equipment, and much of the symbology which appears on the Digital Display screen have not been incorporated in the present model. However, a short sequence of the tracking mission illustrates the possibilities of representing the logic and sequencing of SAGE type tasks in symbolic form.

A limited review of the literature in analytic symbology suggested no generally accepted symbols, so special graphical symbology was devised here to represent individual stimulus responses and elements of the task in their temporal and logical relationships. It is hoped that these symbols will be of use to other research of a similar nature. The graphical symbology was devised with general objectives in mind:

1) That it specify unambiguously and without redundancy the essential logical relationships in the tasks under consideration (e. g., the SAGE Intercept Director Task)

2) That it be capable of specifying unambiguously and without redundancy the logical relationships in programed training

3) That the format of presentation have the time or sequential continuum intuitively apparent

4) That the symbols and their format be able to be drawn freehand as the task analysis proceeds, without need to erase or redraw (assuming a modicum of planning had gone into choosing a large enough piece of paper or scale of drawing)

5) That the symbolic representation be easily translatable into electrical circuitry.

The basic symbols used to describe a minor element are:

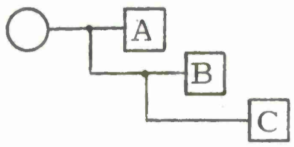
The direction of causality is invariably:

man ⟶ control, control ⟶ display, display ⟶ man.

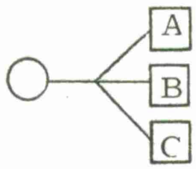
Logical relationships are indicated by straight lines interconnecting the elements in the manner of a signal-flow graph. Causation is always from left right, i. e. an input is on the left side of an element, an output on the right. For example, an action element depicted by the following picture

can be described narratively as: display 1 prompts the man to actuate control A. This response causes display 2 to appear, signifying the correct response and the beginning of a new task. A complete catalog of the symbols used to specify task elements and the relationships between these elements appears in Appendix I.

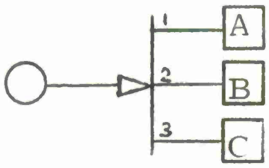
A variety of branchings may be required to indicate the logical relationships of elements in a complex task. Those used in the graphical description of the Intercept Director's task are described below.



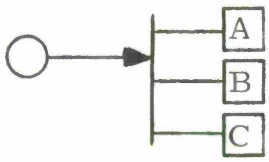
1) A side branch indicates that the straight path (action A) is taken first, then the closest back track on the side path (B), then the next closest back track (C), and so on. This is a logical "and", with ordered sequence.



2) An unordered "and"branch indicates that A, B, and C must all be accomplished, but in any order.

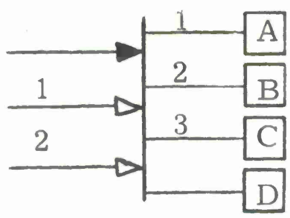


3) A decision branch indicates that the action to be selected is contingent upon a previous branch decision or display, as indicated. In the example at the left A is selected if display 1; B if display 2; C if display 3 led to this action.



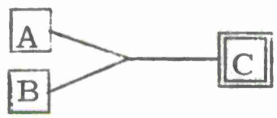
4) A "whimsical" branch is indicated by a closed arrow. In the example A, or B, or C are equally satisfactory alternatives.

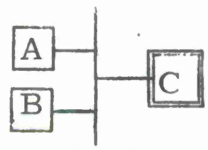
The decision and whimsical branching may be combined in several ways. For example,



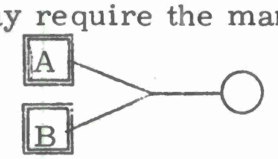
indicates that if the upper path has been taken a whimsical choice may be made among A, B, C and D; however, if display 1 appears then A is chosen; if display 2, then B; if 3, then C (note that prior to this step either 2 or 3 called for the same response). Various other versions should be clear from the context.

All of the forms of branching described above are divergent and indicate actions initiated by the man. Branching may also be convergent, between control and display or between display and man. Thus, the diagram on the left indicates display C is operated by control actions A and

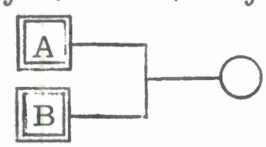




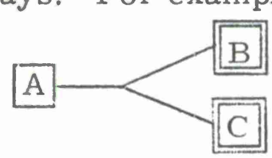
B, whereas the diagram on the right indicates display C is operated by control actions A or B. Similarly, two or more displays (A and B) operating concurrently may require the man to perform a certain function,



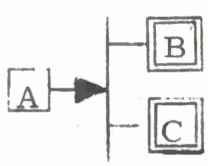
or either of several displays (A or B) may require a certain action of him.

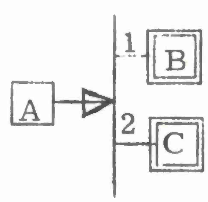


However, only divergent branchings were used in the model of the Intercept Director's task. The forms of branching used to indicate actions initiated by the man were also used to show the relationships between actions and displays. For example, control action A may lead



to several displays (B and C), or

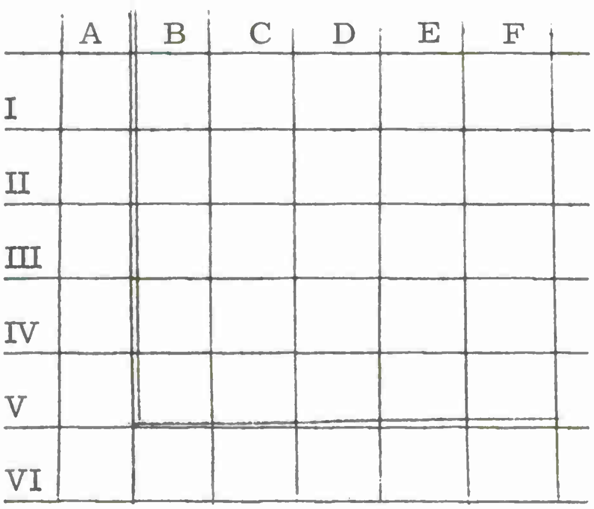




control action A leads to either display B or display C whimsically on the left, contingent upon previous conditions 1 or 2 on the right. A complete logical description of the stimulus-response sequence appears on drawing C-201-2(all drawings appear in Appendix II).

With the developed symbology it is possible to represent a variety of complex command and control type tasks. By teaching the logic symbology to a user, teaching of the actual task can be reduced to a "follow-the-diagram" level.

In modeling the selected task a special symbolism for description of the complex visual display was needed. A matrix of 6 x 6 lights was chosen to present the stimuli and the end results of each minor sequence. The diagram on the left shows the arrangement of the lights in the matrix of the present model. The diagram to the right shows the arrangement of blocks of the SAGE SID display.



	A_1	A_2	A_3	A_4
E	D_1	D_2	A_5	A_6
	C_1	C_2	C_3	C_4

Attention Displays

SAGE SID DISPLAY
(This set of symbols represents a single aircraft and its mission as it appears on the radar screen. The information conveyed by each position is contained in the following text.)

Abstraction, or model, of the SAGE SID display.

In the model display, the lights in column A and row VI later will serve as the "prompting" stimuli for teaching purposes. They are not used in the present model of the operational task. The remaining lights in the matrix correspond to the SAGE positions of the symbols. Because the lights are in two states - on or off - the versatility of the conveyed information is reduced as compared to the real SAGE displays.

The SAGE symbology appearing in blocks $A_1A_2A_3$ and A_4 is represented in the model by the lights IC, ID, IE and IF, respectively.

The letter symbols appearing in blocks A_1 and A_2 of the SAGE displays are represented by the lights IC and ID off. The numeral symbols appearing in blocks A_3 and A_4 of the SAGE displays are represented by the lights IE and IF on. During the early stages of the tracking mission, blocks $A_1A_2A_3$ and A_4 of the SAGE symbology convey information about the track identity of the target. Similarity is maintained in the model through the display of lights IC, ID, IE, and IF. In the later stages of the SAGE tracking mission symbols in block A_1 indicate the airbase as does the model light IC. If the airbase is open, the light IC is on; if the base is closed, the light IC is off. Blocks A_5 and A_6 of the SAGE system correspond to lights IIE and IIF in the matrix. In the early stages of the mission, when lights IIE and IIF are turned on, they represent the number of the Weapon Director and of the Intercept Director, respectively. When the light IIE is off, it represents an unidentified aircraft.

When the light IIF is off, it represents an aircraft which is flying low. In later stages of the mission light IIF being on represents an aircraft which is flying high.

The Block E of the SAGE displays is represented by the light IIB. If the light IIB is on, the aircraft which is being tracked is "on-command" tracking. Otherwise, the aircraft is "off-command" tracking.

The blocks D_1 and D_2 of the SAGE symbology are represented by lights IIC and IID. The enemy or target aircraft is represented by having light IIC off. When the light IIC is on, it represents a friendly or an interceptor aircraft. The scramble condition of SAGE procedure is represented by turning off light IID. When the aircraft is airborne, the light IID is turned on.

The blocks $C_1C_2C_3C_4$ of the SAGE symbology are represented by the lights IIIC, IIID, IIIE, and IIIF, respectively. These lights represent the track number of the interceptor. The letters appearing in the track number are represented by the lights, which are turned off; the numerals, by lights on.

The four "attention" symbols of the SAGE symbology are represented by lights IVC, IVD, IVE, and IVD. The first attention display - ASGN, assignment of the task - is represented by illumination of all four lights.

The lights VB, VC, VD, BE, and VF are used to indicate the voice exchanges between the Intercept Director and the pilot. The first complete radio contact is indicated by having all five lights turned on. The second step in the exchange of radio messages is indicated by lights VD, VE, and VF.

The logic flow charts, instrumented with appropriate pushbuttons, and the lights display matrix represent a simplified model of the SAGE Intercept Director's task. The operator, who manipulates the present equipment, is presented with a series of displays. Drawing C-201-1 shows the sequence of displays given to the trainee by the hardware display. This sequence follows the SAGE mission through 18 displays. The branching paths in the sequence cover events which actually appear during the tracking mission of the SAGE task. In addition, these paths can be selected on a probabilistic basis thus introducing a realistic element of uncertainty about the future developments in the tracking mission.

Drawing C-201-2 shows all of the minor sequences for correct responses to each of the displays. To solve a given display, the operator goes through the appropriate minor sequence of responses. When he completes the series of correct responses to a given displayed problem, the display is advanced by one step to the next minor sequence, according to the major sequence. This changed display then becomes a new problem, which in turn has to be solved by the operator in a similar fashion. In the present model, no provision has been made to change the configuration of the display when only partial responses in the minor sequence have been correctly used. (An error detection capability is to be incorporated into the model later).

Thus, drawing C-201-2 is a flow diagram of the SAGE task. This flow with branching contingent upon the display or state of the major sequence diagram shows the logical symbology which was devised to analyze and describe the SAGE task in terms of both temporal and spatial sequences. Drawings A-201-1 through A-201-16 show examples of correct minor sequences which are needed to complete given problems.

C. Reduction of the Model Task to an Operating Machine

In setting out to construct a working device which would embody the model task and which could be manipulated to elicit the displays in their proper order, several decisions on its construction were made before the detailed design was begun.

It was decided to construct the equipment, insofar as possible, of modular components. Modular construction would allow great versatility since any control or display element could be positioned anywhere within a large area. Further, this mode of construction did not require as precise a layout of the machine face as a fixed array would have.

Modular design (with the exception of elements common to many functions such as power supply, stepping switch, and timer) was also applied to the portion of the device hidden from the operator. In this case, the ease of maintenance (by replacement of a faulty element) was a major factor in the decision. In addition to the decision to fabricate this hardware with modular design, a console was chosen to present the displays and controls. This console simulated the general configuration anticipated at operator stations of future Information Systems.

Several attributes of the model task had bearing upon the components and circuits to be used:

-The major sequence of eighteen steps

-The minor sequences, the length of which is from two to eleven steps

-The requirement for conditional displays depending upon a pseudo-random factor with known probability

-The ambiguity of displays (in that their significance depends upon the point at which they are encountered in the major sequence)

-The implicit understanding that the device might later require error detection and identification

-The fact that the operator's controls are not assignable to specific steps of the minor sequence. Of the 30 controls in the task, eight are used in different minor sequence steps depending upon the major sequence status; the remainder are unique to particular minor sequence steps.

It seemed advisable also to use a severely limited number of different circuits to accomplish the design; it was hoped that this would facilitate trouble-shooting and perhaps make easier the revision of the task, if that should prove desirable.

Generically, the circuits used in the machine fall into three categories:

1) latching circuits, used for memory and for counting

2) selection circuits, used primarily for control of the display

3) a probabilistic circuit.

The latching circuits used are shown on drawings B-201-2 and B-201-3. The self-latching relay can be energized by pushbutton P_1, for example, and will remain energized by virtue of the ground path through its own contact and that of relay X. Deenergizing of relay 1 is accomplished either by energizing relay X, thereby opening the ground path or by pushbutton P_2 which places a short circuit across the coil of relay 1. It should be noted, with reference to this circuit, that P_1 remains affected so long as the relay is energized; no further use of the pushbutton can be made until relay 1 is released.

The second form of latching circuit used is the prime pair. In this case, operating P_1 will energize relay 2 (via the normally closed contact on relay 1) but will not affect relay 1 until the button is released, at which time relays 1 and 2 are placed in series. Deenergizing of the entire circuit can be accomplished by activating relay X, thus removing the ground. The prime pair has the distinguishing feature of disconnecting the pushbutton from the active portion of the circuit; after both relays have been energized, P_1 can be used, via line 1-1-0, for other purposes. This feature makes possible counters which register the number of times P_1 is used. Such counters, one of which is used to keep account of the minor sequence, require a minimum of one relay per count plus three relays for the routing of signals. The prime pair circuit also has use as a "pulse-stretcher", yielding a contact closure which starts with an operator's action and ends only after some particular relay fully operates. This is the use of the prime pair shown at the bottom of Drawing B-201-3.

The major sequence control, shown partially in drawing B-201-3 is simply a 25-position stepping switch with its associated circuits. Since the "last" pushbutton to be used in a minor sequence can be AB, XB, XE, XG or LG, it is necessary that the stepping switch be allowed to choose the appropriate one, and the major sequence control circuit is arranged to do just that. The parts of this circuit which are not shown in the drawing have to do only with the means of recycling the machine to an arbitrary point in the major cycle. Relays, R, S, T, U and V represent one way in which change in the major sequence state can be inhibited to take account of operator error; another, but less selective way is to have a normally closed contact in series with the normally open contact of pole 1-2.

The selection circuit shown in drawing B-201-1 corresponds to the truth table at the top of the drawing. (Lamp 10 is really two lamps in series; while lamp 11 is a single bulb). Relays designated "5, 7, 15, 16, 17" are numbered in accordance with five distinct displays in which either lamp 10 or lamp 11 or both are used. As can be seen from the drawing, both lamps have zero potential across them when none of the five relays is operated. When any one relay is energized, one or both lamps has the full potential applied, corresponding to the requirements shown in the truth table. The relays which constitute the display control are in turn activated by being connected to a deck of the major sequence control stepping switch.

No drawing is given in this report for the circuit used to yield probabilistic effects. The circuit consists only of a 10 rpm synchronous motor, two adjustable cams and two single-pole-double-throw cam-operated switches. Well in advance of the need for a random choice, the motor is started. The varying time interval between the starting of the motor and the adjustment of the cams combine to render the outcome unpredictable. Yet the ratio of "switch closed" to "switch-open" occurrences is set only by the cam adjustment and is therefore known. If the occasion should arise that the time interval between motor starting and switch output usage becomes short or regular, then inclusion of two thermal time-delay relays in the motor drive circuit will restore the pseudo-random nature of the circuit.

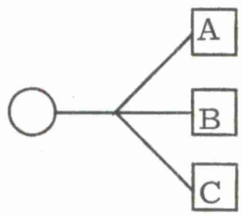
D. Design of "Operational" Console to Support Training and Performance

1. The problem and its conceptual framework.

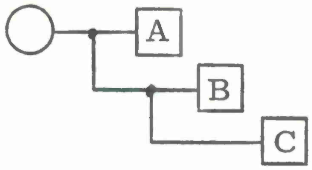
The foregoing sections describe developments of the diagram form and the hardware form of the laboratory model which simulates the logical structure of a typical complex man-computer task in a Command and Control System. This highly simplified model exemplifies the essential logical decisions. Stimuli are reduced to light patterns and responses to push buttons. Like typical Information System consoles, this one also lacks performance aids and cues to the logical structure of the operational task.

The logic required to express the complete task is made up entirely of the following conditions:

a. The "and" conditions

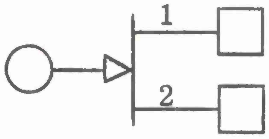


(1) Unordered "and" conditions of responses - the man manipulates components of the machine in any order.

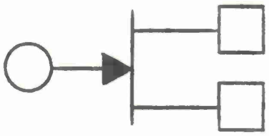


(2) Sequential "and" conditions of responses - the man manipulates components of the machine in a given sequence.

b. The "or" conditions



(1) Single choice "or" conditions of responses - the man selects a response which is required by a previous condition.



(2) The "whim" condition of responses - the man selects one of several equally satisfactory strategies of responding.

Various combinations of the above conditions, including the use of related symbols to show similar contingencies between actions and displays were used to construct a logic diagram. Symbolized in this form, the task appears to be extremely simple. However, earlier studies (26) on the SAGE operational task upon which this model was based, indicated that this task was difficult to learn and perform (1) when taught by conventional on-the-job training methods and expressed in natural language, and (2) when no performance aids or cues to the operational task were available at the interface.

In another early study of this same SAGE task (24), trainees responded well to the new verbal programed instruction techniques for learning display symbology, concepts, terms, etc. But they had difficulty understanding those frames which taught the over-all task logic. It was hypothesized that this difficulty might be related to some undefined inadequacy of the natural language to express unambiguously and in a compact form the logical structure of these man-computer tasks.

In still another early study, on a similar SAGE task (10) it was shown that trainees learned the task logic more easily and efficiently when they studied from conventional text-book verbal descriptions. These "operator-programs" are compact diagrammatic representations of the man's required "program" within the man-machine task. They are similar to the logic diagrams in this study in that relationships are represented graphically rather than verbally. However, these operator programs use blocks of verbal description in place of the graphical symbols which form the nodes in the logic diagrams of this study

Out of these early studies grew the conviction that (1) natural language and its sentence-paragraph format is not an efficient medium for presenting the logic of complex physical systems, (2) a graphical language and diagrammatic format might be more effective.

Although there is not yet any clear-cut experimental evidence in the psychology of learning to support this conviction, engineering tradition clearly supports it. To describe physical systems, engineers and physical scientists have developed many graphical meta-languages such as mechanical drawing, electronic circuitry drawing, computer-program flow diagrams, energy-bond diagrams, etc. The utility of these graphical languages and diagrammatic forms in the training and work of engineers and physical scientists is time-tested. However, graphical languages have not been widely used in the training and work of the usual non-engineer, non-physical scientist operators of complex physical systems. Nor has the possible utility of this approach been studied heretofore even superficially.

A grim commentary is frequently made on the difficulty of learning to operate today's complex Information Systems: - "the only ones who can operate the system effectively are the engineers who designed it." Undoubtedly, many skills in the engineer's repertoire, as well as his depth of knowledge about the system, contribute to the above tribute. Yet it seems useful for the present study at least to entertain the assumption that part of his special skill stems from his ability to study and conceptualize the system dynamics in terms of graphical meta-languages and concise diagrammatic formats. It should be relatively simple to equip the operator who is not an engineer with this special skill. Development of methods for doing just this constitute the first studies in this series.

The studies summarized below describe initial efforts in the development of a technique for using a graphical language and flow diagraming to mediate learning and support performance in the operation of the laboratory model. The task logic symbology and diagraming method developed in the first phase was used in these studies.

2. Console Design Features.

The next step was to embody the notions described above in the console design.

The response (or "working") panel of the console mock-up was subjected to a major human engineering design effort. This panel layout is entirely different from that found in typical operator consoles in current Information Systems. Figure 1 and 2 show several versions of this approach. The essential new features are as follows:

(a) The task-logic diagram is an integral part of the response panel. Color-coding is used throughout this diagram.

(b) The response switches are positioned within the logic diagram where required. This is in direct contrast to the conventional, symmetrical arrangement of switches wherein little regard is given to their working relations.

(c) Part of the response panel is given over to an additional "training" response panel. Its function is explained in the next section.

(d) "Reinforcement" lights are added. Their training function is explained in the next section.

This design results in a console configuration which differs from the conventional in that it incorporates training features plus performance supports.

Introduction of the performance supports greatly reduces the complexity of the training by eliminating much of the information which the trainee formerly had to learn and remember. On the other hand, use of the symbology and diagraming technique adds a new training requirement: learning to interpret the graphical system. However, the latter is a minor training task. Furthermore, once the trainee has learned the system, he could perform any task similarly diagramed.

E. Pilot Studies

After minimum verbal instruction and several minutes of practice naive subjects could trace through a major sequence on the graphical flow diagram (Appendix II, C-201-2) without error, provided they received immediate reinforcement after each operation during the practice period. The minimum verbal instructions consisted of the following elements:

1) task description; the diagram illustrates logical sequence of actions, you must trace through the proper series.

2) starting point orientation; follow the diagram from left to right, beginning with the series labeled I.

3) reinforcement orientation; you will be told when any action you take is incorrect (improper sequence or improper series).

Experiments with the hardware model were designed to study training procedures using the same symbolic and graphical task description techniques. Color-coding was used to eliminate the semantic content and the numbering of displays and contingencies. In addition, preliminary observations of naive subjects' performance with the flow diagram suggested the following specifications for the console:

1) ordered sequence "and" buttons were placed directly along the color-coded stripes, rather than on side branches.

2) unordered "and" buttons were enclosed in color-coded boxes rather than at the end of diverging branches.

3) whimsical branches were color-coded black to represent all connecting paths.

4) a red light was fastened above the working panel (see Figure 1) to provide negative reinforcement after incorrect actions.

The first display presented to the subject on the display panel was also symbolically displayed, together with its color code, on the working panel (see Figure 1). The subject's task consisted of the following elements: identify the color code represented by the display, follow the console diagram from left to right and activate all buttons in that particular minor sequence, identify the color code for the next minor sequence, etc. The complete major sequence used in these experiments consisted of 12 minor sequences. As each minor sequence was successfully completed the display was advanced to the next minor sequence.

Early emphasis was directed towards developing a self-teaching program requiring no written or verbal instruction, but such an approach proved impractical to implement. The logic symbology used in the working panel of the console was then presented in a simplified form on a "training panel", but a small amount of instruction was required even to use this instructional aid. An early form of the console layout appears in Figure 1.

A small group of subjects was run with and without error reinforcement and/or the training panel. Observations from these tests were then used to develop an improved console layout (see Figure 2) and accompanying instructions. The early training panel required following color-coded paths from left to right, proceeding from the top path to the bottom. Some subjects would then attempt to work from the top path to the bottom path when using the working panel, although such a progression ignored the relationships between display and color-codes. The improved training panel was organized differently and this type of error eliminated. Although the early working panel presented succinctly the logical aspects of the task (a trivial task to those who understood the logic symbology), naive subjects did not approach it in a logical manner. Subjects tended to search for spatial correspondence between lights and buttons, would repeatedly

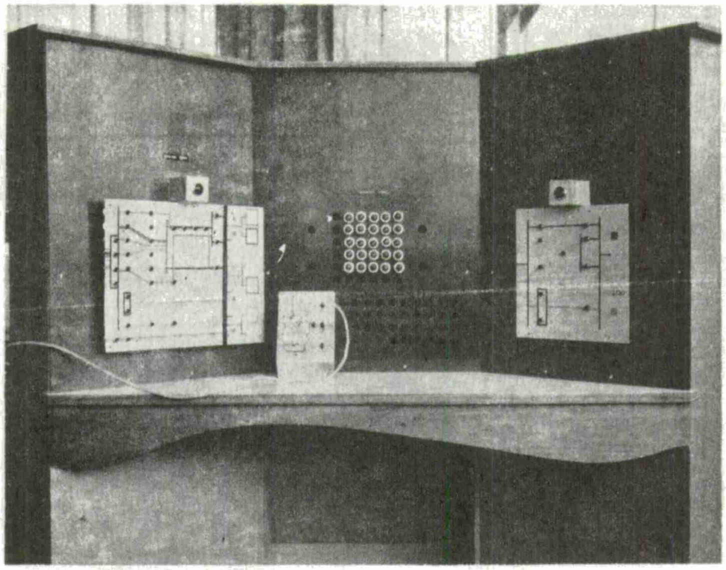


Figure 1. An early console layout showing working panel on the left, display in the center, training panel on the right, and the remote control box at the lower center. Red lights for error reinforcement are located over the two side panels.

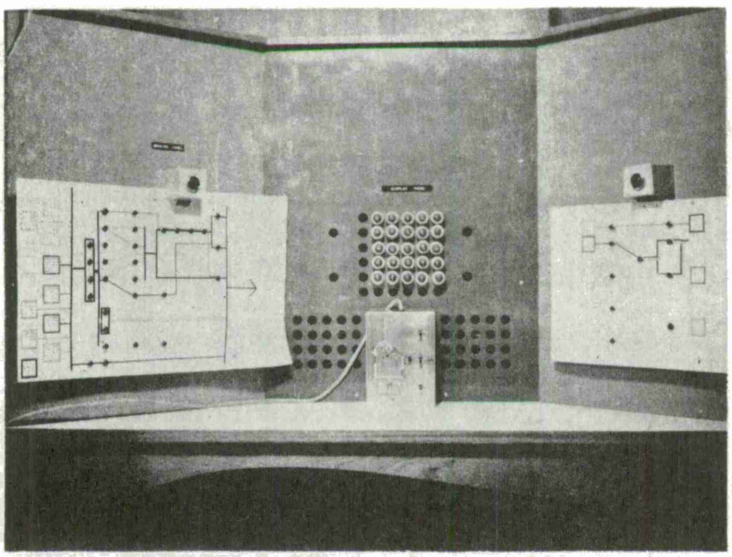


Figure 2. Final console layout. Note the simplifications in the first four unordered "and" buttons symbol, and in the catalog of display color-codes.

ignore the first four unordered "and" buttons, or would become confused and skip to the next minor sequence when they encountered a whimsical branch. The improved console layout reduced these tendencies, as demonstrated by reduced time and errors during training (completion of a major sequence without errors was the criterion for completion of training). The first set of instructions appear in Table 1.

Although initial experiments (three subjects) with the improved console demonstrated that the task could be learned with the aid of the training panel and immediate error reinforcement, the necessity for these aids had not been established. Consequently a two by two matrix experimental design (performance after use of the training panel versus no such pretraining, and immediate reinforcement after each action versus reinforcement only after completion of minor sequences) was devised to evaluate these variables. Only two subjects were used for each of the four conditions. Subjects were Boston University students who responded to a request placed with the Student Employment Office.

Experimental procedure was as follows:

1) the subject was given a printed set of instructions (Table 1) and asked to read them.

2) the experimenter then directed the subjects' attention to the training panel or display panel as required.

3) if the subject used the training panel he was required to practice until he could complete the panel sequence without error (subjects generally reached this criterion on the second try, and were ready for the main task after a total of about two minutes of practice).

Table I

Instructions used in Console Experiments

A. First set of instructions (immediate reinforcement)

1. Display Panel. Many different patterns of lights can appear on the display panel. Your job is to make the first pattern of lights change into another pattern. After a certain number of changes the display panel lights will go off. Then your job is finished.

2. Job Aids. On the left are small colored pictures of the displays you will see. Around each picture is a color strip. Following this color will help you to push the correct series of buttons, which will change the display. If you push a wrong button the red light will go on, to help you find the button.

B. Modified instructions (immediate reinforcement)

1. Display Panel. (same as original instructions above)

2. Job Aids. On your left is another panel containing many buttons. On the left of this panel are small pictures of the displays you will see on the display panel. Around each picture is a color strip. The strips in black color represent all colors on this panel. Following a particular color or a black color from left to right will help you to punch the correct sequence of buttons. Then, the display will change. If you punch a wrong button, the red light above the panel will go on. Then go back to the last correct button and decide why you made an error.

   The buttons on this panel do not correspond in location to the lights on the display panel.

(if the reinforcement was delayed until the completion of the minor sequence, the statement regarding the red light was changed as follows: "If you punch the wrong buttons anywhere in the left to right sequence, the red light above the the working panel will go on at the end of the sequence. The display will not change. Then, you will have to return to the beginning (left side of the working panel) and try again).

4) if the subject began immediately on the main task he was required to continue on a minor sequence until he completed it without error, then on to the next minor sequence throughout the major sequence. The major sequences were repeated until the subject performed one without error in any of the 12 minor sequences. The subject then performed a further major sequence consisting of 6 minor sequences.

Time to completion and sequence of buttons activated were recorded, these data being sufficient to define the performance. Results appear in Table 2.

The results substantiate the hypothesis that the logic symbology can be taught on the training panel and then transferred, to a moderate degree, to the working panel. Use of immediate error reinforcement was found to be an effective substitute for pre-training. That the task requires some form of instruction assistance was clearly demonstrated by the failure of subjects to complete a single minor sequence without the learning aids.

The implications of these experimental results for inclusion of self-instructional features in Air Force Command and Control Systems equipment are presently under study. These findings, together with those from the experiments described in other sections of this report will be used to develop general engineering principles useful in the design of future Command and Control Systems.

Table 2

Time and Error Scores for Major Sequence Trials (12 minor sequences) with and without learning Panel, and Immediate or Delayed Feedback.

I Immediate Reinforcement

Learning Panel

Subject	Trial*	Time	Errors
A	1	7:15	5
	2	5:36	8
	3	3:33	0
B	1	5:45	25
	2	3:24	6
	3	2:30	0

No Learning Panel

Subject	Trial*	Time	Errors
C	1	13:30	15
	2	2:57	4
	3	2:03	4
	4	1:39	0
D	1	6:15	6
	2	2:57	0

II Delayed Reinforcement

Learning Panel

Subject	Trial*	Time	Errors
E	1	6:36	14
	2	1:24	0
F	1	18:03	213
	2	2:51	0

No Learning Panel

Subject	Trial	Time	Errors
G	No major or minor sequences successfully completed in the alloted time**.		
H			

*Trials were repeated until the subject performed a major sequence without error.

**If the subject could not successfully complete any of the first four minor sequences in 20 minutes, the experiment was terminated.

IV Studies on Information-Solicitation and Problem-Solving Training

A. Introduction

Some Air Force Command and Control tasks are at least partially characterized by the soliciting of information concerning the environment, and the use of this information to form hypotheses or to test the validity of previously formed hypotheses. It is therefore of interest to determine whether the user of a complex information system can be taught by the system equipment how to solicit information efficiently from it. To describe the capabilities which the system must have in order to provide this tutorial function, we must know:

1) How to describe the "manner" in which people query their environment in the process of "solving problems",

2) what portion of this manner of solicitation and utilization of environmental information can be deliberately beneficially modified,

3) how to teach this (i. e., modify the natural behavior),

4) how to teach particular application of this querying-reasoning process to particular people (in particular, command and control tasks to Air Force personnel), and

5) how to translate this tutorial task into system engineering terms (displays, controls, computer programs, etc).

The obtaining of experimental information concerning the above areas constitutes a major portion of the present and planned programs.

Initial experiments have been directed towards the first three of these five areas using abstract "logic games". Examination of actual Air Force personnel performing Air Force command and control jobs was rejected for the initial effort due to difficulties in intelligently observing such tasks, generalizing from them to future tasks which do not exist today, and the small number of individuals that could be observed (and therefore difficulty in discriminating between individual "style" and characteristics invariant among successful performers).

The following were the principal criteria used in selecting the games to be administered:

1) Subject's cognitive behavior to be manifest as much as possible.

2) His problem (i. e. his objective in the game) to be capable of close specification.

3) The classical trichotomy of logical processes - induction, deduction, and analogy would be represented in the games chosen (although analogical querying-reasoning would be included in inductive or deductive games rather than being separately examined).

B. The Maze Game

The maze game is a problem solving task in which the subject takes sequential steps according to certain rules, uncovering clues enroute, and attempts to arrive at the "end" of possible sequences by the shortest route. The maze consists of a series of 39 color-coded tags, on the front of which are entered one or two nonsense syllables. Through manipulation of the clues necessary to lead to a particular solution it is possible to vary the complexity of the task. Finding the logical trace through the pattern of nonsense syllables is an inductive problem.

The following written instructions were given to each of 3 subjects: "This is like a treasure hunt. The clue that leads to each tag is given on the front of the tag. On the back of each tag is often, but not always, a clue that leads to some other tag. The three red tags are "free" clues that you may use at any time. Any of the other 36 tags can be used only when you already have the clue or clues that lead to them. Find the tag which hides the treasure."

There are five equivalent routes through the maze which involve the use of only eight tags. One of these routes is outlined below:

Number	Front of tag	Clue on back of tag	Comments
1	FIFI	BIP	"free" red tag
2	GOKO	DAK	"free" red tag
3	ZADA	CUG	"free" red tag
4	BIP & DAK	QOM, TAH	
5	QOM & TAH	LYN	
6	CUG	RIV	
7	LYN & RIV	FER	
8	FER	JACKPOT	end of maze

Use of other tags lead to longer routes or lead to blind alleys. The syllables, with several exceptions, were chosen from a list of nonsense syllables reported to have low association value (reference 25, page 540).

Results of 6 trials are listed in Table 3. Rapid learning was most evident in the reduction of the number of "blank" tags which were turned over. Although the subjects demonstrated the ability to memorize successful clues or to discover the rules (or logic), it was difficult to analyze from the data how the subject learned them. Performance indicated that as new information was gained it was "correlated" with data obtained earlier, with the next choice partially predicated upon all the information on hand. Long periods of study followed by long periods of direct attempts at solution were not observed during these limited experiments. However, it is speculated that different instructions or rewards for minimizing the number of tags used could alter these observations.

A modified form of the game has been programmed on the PDP-1 computer.[1] Through the use of automated data processing it may be feasible to study the effects of procedural variables on performance of the maze game by large numbers of subjects.

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[1] This work is in progress at Decision Sciences Laboratory, Air Force Electronic Systems Division.

TABLE 3

Preliminary Experiments Using the Maze Game

Total Number of Tags	Trials					
Subject	I	II	III	IV	V	VI
A	30	20	27	12	19	11
B	17	17	23	16	13	-
C	21	26	18	13	9	10
Number of "Blank" Tags						
A	8	5	7	1	4	1
B	8	8	7	5	4	-
C	7	8	4	1	0	0

C. The Numbers Game

The numbers game was selected for study since it met all of the requirements criteria and since analysis of the subject's reasoning can also be performed. The operator's task in the numbers game is to determine a four digit number which has been selected by the experimenter. The operator solicits information by selecting a four digit test number from a list of 30 such numbers and requesting a "score" for the test number. The score is zero if the operator's number does not contain any of the experimenter's digits in the corresponding positions; one for one digit correct, etc. As the game progresses the queries that the operator makes can be evaluated as to their pertinence to the decisions which he must make and whether or not successive queries contain redundancies. In addition, for efficient performance the operator must sequentially make plausible hypotheses and then obtain confirmation or denial of them. Efficient use of both positive and negative information in the formulation and testing of hypotheses leads to a rapid solution. The use of sequential hypotheses is in contrast to the situation in which an operator requests "all" the information on a broad subject at once. The editing problem and likelihood of overloading the operator's information handling capacity are high in the latter case, particularly during the learning phase.

The experiments with the numbers games were conducted in two phases:

1) observation of 15 untrained subjects performing a long series of trials after reading a brief set of instructions. Eight of the subjects received a lecture demonstration after five games (at which time the rules were changed to permit the operators to construct their own four digit test numbers).

2) observation of three groups of four subjects performing 5 games after receiving selected forms of training assistance.

Time, identity, and score of each request were recorded. From these data it was possible to reconstruct each trial for analysis at a later time. Instructional techniques used during the second phase experiments were:

1) lecture demonstration of the first game using an optimal strategy,

2) feedback of guiding comments after each query during the first two games, ("Socratic" comments)

3) feedback of results during the first two games in terms of an optimum logic bookkeeping function.

The guiding comments used in method 2 were developed after an analysis of common reasoning errors observed during performance by the control group. The ten comments, listed in Table 4, were printed on 3 x 5 cards which were then selectively displayed to the subject according to the nature of his queries. It was anticipated that these comments would guide the subject in learning an optimal strategy. The automated bookkeeping function was accomplished by updating after each query a display of all information obtained from previous queries. Since all of the logical deductions were made for the subject, he only had to make shrewd choices of queries to reach a solution with a minimum effort. It was anticipated that after the first two games the subject would then adopt a similar form of logical bookkeeping for the remaining games.

Subjects were college students who responded to a request for paid subjects to participate in a psychological experiment. The first group of 15 subjects were Boston University female and male students. Other groups were summer school students (no attempt was made to match groups on the basis of age, sex, or education).

Results of the experiments are summarized in Table 5. After five games there were only minor differences between groups in time and number of queries to completion. However, the large number of incomplete trials observed when using the "Socratic" comments would, if included greatly increase the magnitude of the time and number of queries, observed with this method. Using automated bookkeeping, the subjects' performance on their first trials were as good as those after five games with any of

Table 4

<u>Guiding Comments Used as an Instructional Technique</u>

1. Good, one of the four digits is correct. Ask questions which will help to find which is <u>correct</u>. As you find which are incorrect you will also learn more.

2. Good, Now what numbers in which positions have been ruled out?

3. That was a good choice. What digits now remain as pc ssibilities?

4. Good, you ruled out another possible digit and now have more refined information on the previously scored numbers.

5. Although this is good information, don't forget to follow up on the scored numbers previously asked.

6. Good, now you have sufficient information to specify the ______ digit(s). You can also re-evaluate the previous questions that had a score due to this digit. What can you rule out?

7. Good, now you have sufficient information to specify the complete number. Do you see why? If not, ask more test numbers from the list, but don't guess wildly. Test hypotheses!

8. Poor choice! Some of the digits have already been ruled out. At this stage it would have been more efficient to select a number which will provide new information on <u>each</u> of the unknown digits.

9. Bad choice! Previously asked questions have already given you the answer to that question. Do you see why?

10. Spatial correspondence as well as numerical correspondence is necessary. You have missed this important point.

Table 5

Summary Data from the Numbers Game Experiments

Time to completion (minutes & seconds) for each game

Group			I	II	III	IV	V	Total
1.	Control (n=15)	mean	19:11 *	14:53	19:26	18:48	9:57	16:27*
		median	18:15*	13:55	15:50	9:30	9:00	
2.	First game worked through (n=4)	mean	-	21:17	15:42	13:06	13:11	15:49**
		median	-	17:17	15:30	12:45	15:00	
3.	Comments on games 1 &2 (n=4)	mean	11:18*	12:09*	15:49*	7:41*	10:35*	11:30*
		median	11:18*	12:22*	10:22*	7:57*	9:05*	
4.	Automated bookkeeping (n=4)	mean	12:10	12:10	21:30	9:55	9:55	13:08
		median	12:20	8:47	17:50	8:55	7:57	

Number of queries to completion

			I	II	III	IV	V	Total
1.	Control	mean	19.0*	16.9	18.4	17.4	15.6	17.4*
		median	18.0*	15.0	16.0	14.0	15.0	
2.	First worked	mean	-	17.2	17.0	16.7	16.2	16.8*
		median	-	16.5	15.5	16.0	15.5	
3.	Comments	mean	13.0*	15.7*	18.5*	13.5*	16.5*	15.4*
		median	13.0*	14.0*	17.5*	13.5*	16.5*	
4.	Bookkeeping	mean	14.5	14.2	21.7	14.2	16.0	16.1
		median	13.5	13.5	22.0	15.5	16.0	

*Four of the 15 control subjects failed to complete the first test and are not included in the averages for that test. Four of six subjects receiving the guiding comments failed to complete the first test, and two of these also failed on the subsequent tests. Therefore the reported figures represent a biased population (the "good" subjects) and understate expected figures.
**Time and questions for the first test were determined by the demonstration program and are not reported in the averages.

the teaching methods. Those subjects who received the automated bookkeeping did not immediately learn to perform this function for themselves, as evidenced by the sharp increase in time and number of queries on the third game. It is noteworthy that those subjects who observed a demonstration of optimum strategy on the first trial did not perform better than the control group on subsequent trials.

After four games most subjects were able to perform the game with only occasional deviations from an optimal strategy. However, deductive errors which led to poor overall performance were occasionally observed after many trials for subjects who had previously demonstrated good performance. Since instructions to the subjects were permissive (neither speed nor minimum numbers of queries were mentioned), the experimental results may not apply in situations for which the task statement differs. After about five queries the selection of an optimum test number required a careful search of the list of test numbers. Consequently, the subjects had to trade off time against query effectiveness.

First and fifth trials by a control and by a bookkeeping subject are outlined in Tables 6 and 7. These subjects were not representative of their respective groups, the control being much better than average for that group, and the bookkeeping subject being slightly better than average for his group. However, performance by these subjects illustrate the major types of errors observed with other subjects.

Referring to Table 6, first game by the control subject, the first three queries suggest that this subject had already grasped the fundamentals of the game. The subject selected trial numbers to attempt to pin down which digit was correct in the first number. However, on the fourth query the subject could have been more efficient had he selected a number which was either four new digits, or which would test which of the last three digits in the second query was correct. In the fifth query the subject is back on the track following-up the second query. The relatively long time intervals after the second and eighth queries appear to have been used in evaluating past information and determining which test number(s) would complete the information required for a specific digit. After the ninth query the subject moved hastily and failed to fully evaluate the information obtained from the next test number. Consequently a completely useless query was made. After 13 queries sufficient information had been obtained to specify the complete four digit number, but the subject used two more test numbers to confirm the third digit. On the fifth game the subject did not make any completely useless queries, but in his haste he did use four test numbers which were inefficient. The consistent short intervals between queries indicates that the subject had a good workable system of evaluating information content. The chance selection of nine consecutive test numbers with zero scores is also partly responsible for the small time intervals since the required logical deductions were simple.

Table 6

Examples of Numbers Game Trials by Control Subject (AW)

	Test Number	Score	Time Interval	Comments *
1.	3102	1		First game.
2.	3251	2	:35	Good, follow-up of first query.
3.	3779	1	1:50	" , first digit established as "3".
4.	7123	0	1:10	Fair, second digit has already been ruled out.
5.	1971	1	:35	Good, follow-up of second query.
6.	8228	0	:50	Fair, third digit has already been ruled out.
7.	4681	1	3:45	Good, last digit established as "1".
8.	2050	0	:35	Fair, third digit has already been ruled out.
9.	1564	1	1:05	Good.
10.	4595	1	:35	Good, establishes second digit as "5".
11.	5576	1	:40	Poor, no new information.
12.	4219	0	:50	Good
13.	9342	1	:40	Good, complete number can be deduced.
14.	5346	1	:30	Poor, no new information.
15.	9443	1	:20	Poor, no new information.
16.	3541	4	:15	Success in 14 minutes and 15 seconds.
1.	8610	0		Fifth game.
2.	2788	0	:25	Good, all new information.
3.	0965	0	:25	Good, all new information.
4.	3102	0	:20	Good, all new information.
5.	5967	0	:25	Fair, 2nd & 3rd digits already ruled out.
6.	1034	0	:40	Good.
7.	4219	0	:25	Fair, 3rd digit already ruled out.
8.	6486	0	:25	Fair, 3rd digit already ruled out.
9.	7892	0	:30	Good, first digit established as "9".
10.	9342	1	:25	Good, second digit established as "5".
11.	8228	0	:30	Fair, last digit already ruled out.
12.	3251	2	:25	Good, complete number can be deduced.
13.	9551	4	:30	Success in 6 minutes and 25 seconds.

* The comments represent an evaluation of performance and were not given to the subject.

Table 7

Examples of Numbers Game Trials by Subject (KU)
Who Received Instruction Through Automated Bookkeeping

Test Number		Score	Time Interval	Comments *
1.	5967	0		First game (with bookkeeping).
2.	3102	1	:35	Good, all new information.
3.	1564	1	:30	Fair, 3rd digit already ruled out.
4.	3251	2	:50	Good, follow-up of second query.
5.	3779	1	1:20	Good, 1st digit established as "3".
6.	5576	1	1:05	Good, 2nd digit established as "5".
7.	3551	Wrong	1:05	Poor, fourth query ruled out this guess.
8.	2050	0	1:00	Good, 4th digit established as "1".
9.	4219	0	1:00	Good.
10.	8228	0	:45	Good.
11.	7137	0	:30	Good.
12.	5346	1	:25	Good, complete number can be deduced.
13.	3541	4	:15	Success in nine minutes and twenty seconds.
1.	2788	0		Fifth game.
2.	9007	1	:20	Good, all new information.
3,	9443	1	:35	Good, follow-up of second query.
4.	8610	0	:50	Good, all new information.
5.	5967	0	:35	Good, follow-up of second query.
6.	3102	0	:25	Good, follow-up of second query.
7.	4219	0	:25	Fair, 3rd digit already ruled out.
8.	6850	1	:40	Fair, 4th digit already ruled out.
9.	7892	0	:25	Good, follow-up of previous query.
10.	3251	2	:30	Good, 1st, 3rd, & 4th digits established (9-51).
11.	1971	1	:50	Poor, fifth query answered this.
12.	5346	0	:35	Good.
13.	1564	1	:25	Good, complete number can be deduced.
14.	9551	4	:15	Success in six minutes and 50 seconds.

* The comments represent an evaluation of performance and were not given to the subject.

Referring to Table 7, first game by the bookkeeping subject, the first three queries do not suggest any keen insight into the game strategy. However, the automated bookkeeping display or other undetermined factor guided the subject back to following-up the second and third queries. After six queries the subject demonstrated a lack of understanding by guessing--- an impossible guess since query number four would have had to be scored "3" for the guess to be correct! However, with all logical deductions made automatically it was a simple task to complete the trial efficiently. On the fifth game this subject made one completely ineffective query (number eleven) and only two that were less than optimal. Poor luck in those randomly selected test numbers made the task difficult, but the subject demonstrated a good understanding of the optimal strategy.

An evaluation of the trials by other subjects who received the automated bookkeeping indicated that all subjects learned to use the zero scores effectively, but several had considerable difficulty in making logical deductions which would allow them to evaluate the scored test numbers effectively.

V. The Phylogenic Concept of Program Order

A. Background of the Problem

One of the major ambiguities in the current state-of-the-art of programed instruction and automated training is the question of how to organize and order content in the teaching program. The only available answer now is "use a logical order." This rule of thumb leaves much to be defined - even for the highly verbal, academic subject-matter programs from which it originated. However, as in the present case where the programed instruction is concerned with teaching utilization of complex physical systems, the "logical order" rule is of little help.

This chapter considers the special problem of content order where the program is concerned with teaching utilization of a complex physical system made up of multiple subsystems. It explores one possible conceptual approach and examines the implications of the proposed sequencing rule. Implementation of this concept would be reflected in the "availability" to the trainee of different system controls at various stages of training. Problems would lead to the discovery of system functions. Within each level of the program the problems would be graded with respect to allowable error tolerances in the use of each function. This method would shape precise skills for utilizing each function.

The proposed phylogenic concept leads to training by a "method of discovery." It would be implemented in the form of a combination of training program, problems and equipment features which would lead the trainee automatically along the paths of such discovery. This teaching method is similar to the "discovery method" being proposed as part of a dramatic reform in the school mathematics curriculum (28). Like the latter, this phylogenic concept for systems training aims to produce analytic power and knowledge of capacities and limitations, rather than reliance on "formula" solutions.

This phylogenic concept seems particularly promising for the type of training required in those future Information Systems which will be implicitly programed.

B. Introduction

It is desired that techniques be developed whereby existing and future systems which require operators may be instrumented or altered in such a way that they may teach the operator his role without preliminary or con- concurrent outside instruction. The systems to which the techniques are to be applied may range in complexity from those demanding the simplest mechanical operations to those that exist only on an abstract or administrative level such as the decisions attendant to the choice of tactics in a strategic situation. The approach discussed in this portion of the report relates an attempt to generalize upon the abstract problems to be encountered in the implementation of self-teaching processes. A suggested approach to a constructible analogue or prototype is described at the end.

It is necessary at the outset that certain observations be made regarding the nature of the operator, his role in the system, the system itself, and its role in a larger environment upon which it is to make measurements and produce alterations. First: we shall assume that since an operator is required, his role is one which cannot be automated, at least at present. That is, we are considering systems to which the utmost in computer technology has already been applied in the processing of inputs and the conditioning of outputs. Somewhere in the loop there is necessitated a filtering function which only a human operator can subsume. Therefore, second: the information presented to the operator has a semantic content and the controls available to him must have an effect which ultimately alters the sources of that kind of information. There may also be available to the operator various means of weighting or reassembling the incoming information as an aid to decision or memory and he must be taught the proper use of these tools also. Third: the intrinsic nature of the learning process is bound to be different from the ultimate operating process so that it may be necessary both to alter initially the system functions being taught and to train the subject in the learning process itself at the outset.

C. The Operator, the System, and the Environment

A useful way to visualize schematically the operator, the system, and the environment is in the form of three respectively linked structures or networks between which one is trying to achieve an impedance match. The system, which holds the central position between the other two, has been designed to provide the proper match and to allow each to communicate with the other as efficiently as possible. However, fortunately or unfortunately for the problem at hand, the system and the environment both exist already, and the naive, untrained subject may be considered initially to present a total mismatch. It is the purpose of the training program to adjust his output impedance to match the input impedance of that end of the system which is available to him. The usual training process consists of making many preliminary coarse adjustments in the operator before he is placed "on-line", allowing the fine match to be achieved in the latter condition. However, if a system is to be made self-teaching, considerable alteration of the system or of the apparent environment or both may be necessary in order for learning to commence. Once the process has started, the structures may gradually revert to their "normal" state as the self-adapting property of the human operator allows him to follow and adjust his impedance appropriately. The questions that must be addressed here concern the proper starting point and the proper management of the ensuing development.

D. Function vs. Structure

In considering any given system one might ask oneself who it is that knows that system best both functionally and mechanically. The best answer, it would seem, is that it is he who originally designed the system. Why? Because each subcomponent of the system was designed to fulfill a specific functional need and for the designer it was at the height of his apprehension of that functional need that he invented that subcomponent. If, then, we can elicit the same sort of inventive process from the trainee, and can present to him a display or control only after he has apprehended its necessity, there should result an operator who has a firm grasp of the use of the system. Note that we are not asking him to design the system mechanically, only functionally, for once he has realized his need for a specific kind of information or control, we may then present him with the actual system component which exists for the purpose and with a little experimenting on his part he will find that his wish has been granted. The means by which the inventive process may be stimulated and the manner in which the subject verbalizes his requests are problems which will be taken up presently.

It should be pointed out here that we are not advocating a manhunt for the actual designer himself, because in fact there probably was no one such person. We are saying, rather, that it is the creator's role and attitude that we are trying to elicit from the subject. We may therefore visualize our own reconstruction of the evolution of the system and it may take any number of equally useful logical forms.

It is apparent that any such teaching process in which the operation being taught is allowed to develop, piece by piece, at the command of the trainee, is inherently self-adapting to the individual. The training program will eventually have led him to the development of the entire system but along the way his requests for new subcomponent displays and controls will have been conditioned to some extent by his current understanding of the problems before him and of the components already at hand. However, inasmuch as the training process differs from the final operating process, one must not expect that the geometry of the system environment will be a real one. That is, the elemental and incremental problems presented to the trainee may be considerably distorted in their time and space dimensions from problems of a similar nature which might occur during actual operation of the system. For example, an "emergency" situation would not result in disastrous consequences if coped with slowly: its semantic content of emergency must be taught before urgency may be expected.

E. Phylogenesis

In coming now to the consideration of how best to proceed in the presentation of the system functions to the subject, we return to the proposition stated above that it is the "original designer" of the system who knows it best. If we are seeking a logical order of development, what better one might there be than the process of evolution through which the system itself has passed in arriving at its present form? Hopefully it is reasonable to assume that each new modification applied to the system in the past was in fact an improvement which broadened the scope of display or control available to the operator, and was the result of a desire to solve a problem for which the previously unmodified system was inadequate. One would turn, then, to the "phylogeny" of the system for the teaching program. Addition or deletion of steps may occasionally be necessary because, on the one hand, systems are often updated in many ways at once, and on the other, functions which were formerly included may have atrophied and been discontinued later. However, in most cases the phylogenic history of the system will be an excellent basis for the program and it is available in the technical archives of the developer. We repeat, however, that the actual phylogeny is not really necessary. It is only proposed that it may have been a most reasonable sequence of steps on which to base the training program.

F. Example No. 1

It would perhaps be most instructive at this point to indicate by example the application of the phylogenic teaching method to two systems that are relatively familiar: first, the driving of an automobile. It will be assumed for the purposes of exposition that the problem of man-machine communication has been solved sufficiently for the subject to verbalize his requests for functions in an appropriate machine language. The assumption is not a trivial one but for the moment we might allow the existence of an instructor as an interpreter with the understanding that he is to be eliminated eventually.

Training commences with the subject being placed in an automobile devoid of any controls or dashboard displays and situated at the top of a long hill. He is told only that his goal is to transport himself to a visable point "over there", and the automobile is given a nudge to start it rolling down hill. Depending upon the geometry of the road, the subject's first request might be for a steering function or it might be for something which allows him to slow or stop himself at will. Let us assume the latter, but notice the illustration that the order of requests may be influenced by our choice of environmental geometry. The subject will now ask for a control which will allow him to slow the automobile whenever he wishes but he need only verbalize his demand for a slowing function; he is not required to invent the structure of a foot pedal or a hand brake. In response to his request a foot pedal appears and since it is obviously to be used by the foot, he tries it and soon is satisfied that his request has been granted. Next a curve appears in the road and the subject realizes that a turning function is necessary. Again, he does not need to specify form: steering wheel, joystick, or rudder pedals; he has only to verbalize the function. A steering wheel is revealed to him and with a little experimenting he finds that it will produce the desired effect.

Presently the automobile arrives at the bottom of the hill and the means of self-propulsion must be sought. The order in which the discovery or invention of accelerator, clutch, gear-shift, ignition key, et cetera are elicited by the teaching program depends upon the proper manipulation of the environment and the latter contains problems which had best remain hidden at this stage. However, the example has been carried far enough to demonstrate a rudimentary application of the method. Note that the possibility of considerable time and space distortion has already arisen depending upon the individual subject. If he is an adventurous type, he may not have requested a slowing function until he has reached a high speed or even until a stone wall has been placed in front of him to create an emergency. Thereupon the stone wall will have to be held at bay long enough for him to verbalize his request and experiment with the foot pedal presented. In the extreme case one might have to let him crash into the wall and then start him over again at the top of the hill in order to convey the meaning of speed to him. The term "semantic content", as used in this discussion, implies that a control, a display, or an environmental situation must have meaning to the subject, and the lengths to which the program must go to impress that meaning upon the subject may vary greatly with the individual.

G. Example No. 2

As a second illustration of the phylogenic method let us consider the teaching of standard business practice. Certainly any naive trainee starts with some crude notion of the operation of a company; he will be asked to describe or diagram that notion and will be told that his goal is the development of the detailed structure of a large corporation. Starting with the individual's simple diagram, problems in bookkeeping, inventory management, capital flow, salary schedules, and so forth will be thrown at him in such a way that each new problem requires a logical addition to his diagram. In order for him to grasp fully the meaning and uses of each addition, its invention must be elicited from him with little or no prompting. This, then, is postulated as one of the major advantages of the phylogenic method: that necessity is the mother of invention and that the creative process of invention produces the strongest and most meaningful impression of the purpose of a system component.

In neither of the two examples was it necessary actually to trace the evolution of the giv en system. For the purposes of driver training the details of engine, tire, chassis, or body design were irrelevant; and in the teaching of business practice we did not research the history of mercantilism. In both cases it was necessary, rather, to put ourselves in the place of the subject and to imagine how he would view his environment and how he should verbalize solutions to the "modern" problems we will present to him.

H. Discussion

Let us now examine some of the properties of the special problems involved in the application of the phylogenic teaching method. A means of communications must be set up between the subject and the system whereby he may make requests for functions not yet available; the semantic content of environmental situations must be conveyed and be made interpetable by the system displays; and the invention of the function of every control on the final system must be elicited before training is complete.

In the cases where a subcomponent has multiple functions, they must be separated during training to allow them to be discovered at the appropriate time. More important, however, is the requirement that the trainee be taught at the outset how to abstract the simplest possible verbalization of the function he desires. If he himself is unsure of exactly what it is he wants, his understanding of what has been given him will be incomplete. To some extent the form of the request made will depend upon the manner of problem persentation, but the simplification of requests may well have to be taught by preliminary instruction in the application of the method. Consideration will be given to the necessity for a generalized, aboriginal teaching device for this purpose later.

The development of the first example, driving an automobile, was terminated before it had dealt with the uses of the gear shift or the ignition key, which operations differ from those of brake or steering wheel in that the former involve discrete functions while the latter produce a continuous effect upon the system in its environment. The postulation that a subject is to determine by experiment whether a requested control has been granted to him makes it clear why such "continuous-effect" devices are easier to deal with in a teaching program. They allow the subject to apply perturbations with a magnitude and direction of his own choosing. That is, his use of them is neither right nor wrong but their functions become obvious immediately. In teaching the use of controls whose operations are of a discrete nature, one must, as before, arrange to elicit from the subject the desire for such controlling functions but it should be made clear to him either before he makes his request or after the control has been presented that its operation is binary or multivalued rather than continuous. The kind of perturbations he can produce with this control will perhaps be less descriptive of its purpose, so one must be careful to provide only the function specifically requested.

There may often arise situations in which the subject requests functions which are either unavailable or irrelevant. For instance, having been told when he is placed in the automobile that his goal is to arrive eventually "over there", he might ask for a means by which to raise himself off the ground and fly. This request would not be irrelevant if he were being taught to fly an airplane but it is certainly not allowed for automobiles. In such cases it would seem perfectly logical either to ignore or refuse the request provided that it is not one which would be honored at a later time. Some indication of irrelevancy or forehandedness may have to be included in a self-teaching device.

Before concluding the discussion of the examples, some attempt should be made to describe a useful automation of the man-machine communication problem. In the case of the automobile one might provide the subject with a miniature model of his vehicle and the environment. By grasping the model automobile he would cause it to execute the kind of maneuvers for which he desires an effective control on his own car and would thereby communicate the function wanted to the system. He would, of course, be constrained from performing multiple maneuvers simultaneously or from attempting impossible ones.

I. The Aboriginal Machine or Primer

It was pointed out in the initial arguments above that the naive trainee may be considered at first to present a total impedance mismatch to the system whose operation he is to learn. If he is to take even the first step toward "inventing" the system for himself he must already have a grasp of the rudiments of the man-machine language with which he is to verbalize his requests. It would seem necessary, then, that the trainee be given preliminary instruction in the language and in the general rules of application of the phylogenic method of system development. But inasmuch as it is a learning process that must be taught -- a process which does not differ much between systems to which it will be applied -- the development of an aboriginal machine or primer is proposed to accomplish this end. All trainees, for whatever operating roles they may be destined, would commence their training on the primer; and it would continue to be available to them later for occasional review of the method as needed. The actual form of the primer has not yet been conceived but it is visualized tentatively as an electronic and mechanical device offering knob and switch controls and meter and scope displays. The "environment" would be a two-or three-dimensional model to which the subject would have direct access, both for observation and for manual perturbations.

J. Updating of Systems

A final note on the advantages of the phylogenic method regards the application of the technique to the retraining of operators on updated systems. Since one may logically assume that any updating of a system involves improvements of necessary additions to displays or controls, all that is required of the phylogenetically trained operator is that he carry his training one or more steps further in a process which he has already learned. If there has been a considerable time lapse since his original training, a review of the method on the primer and perhaps a quick re-invention of the system he has been operating will suffice to prepare him for learning the uses of the new improvements.

K. Prototype Model for Demonstration of Phylogenic Teaching

A hardware model has been constructed for demonstration and research in phylogenic teaching (see Figure 3). Using this device the subject is taught to control the characteristics of a Lissajou figure on an oscilloscope. The console contains all of the controls and figure generation circuits, including power supply.

The console, as it is first presented, is a flat surface with holes in it showing the ends of shafts or toggles just out of reach. Each hole is color coded. The desired Lissajou figure is displayed on a transparent overlay in front of the oscilloscope. The subject's task is to manipulate the scope figure so that it coincides with the figure on the overlay. Starting with an ellipse for both figures, but with the scope figure off to the right, the subject requests a control which will allow him to shift the figure to the left. Similarly, other figures are presented which introduce the subject to vertical, gain, "limiting" (flattened area), "roundness", and axis reversal controls as they are requested. As the figures increase in difficulty a complete understanding of the functions of previously used controls is necessary for rapid progress. Provision has been made for display of two separate figures on the oscilloscope through use of a time sharing circuit and a second set of controls. All controls act independently of each other.

Additional details on this method are provided in Appendix III and IV.

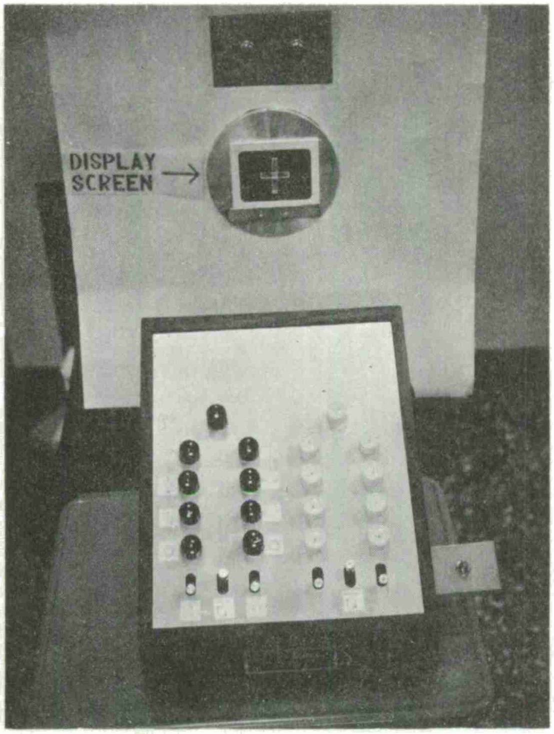

Figure 3. Console and oscilloscope display for demonstration of the phylogenic teaching concept.

VI. Conclusions

The first year's effort on this project has produced the following conclusions in the three study areas:

A. Method for Self-Instruction in Task Logic

1. The essential features of a representative command and control task can be modeled with the new analytic symbology devised for this study.

2. This graphical symbology provides a concise language which is an efficient medium for teaching the task logic.

3. The logic flow diagrams constructed with this symbology can be used as self-teaching programs. Exploratory studies indicate use of this symbolic language reduces some of the disadvantages of a natural language (English) found in earlier programs designed to teach task logic.

4. Design, layout and labeling of console response panels in a topological relation to the task logic flow diagram appear to hold promise of facilitating the self-teaching function.

B. Information-Solicitation and Problem-Solving Training

1. An experimental task - the "Numbers Game" - has been shown to be a useful tool for studying querying-reasoning behavior and developing methods of self-instruction in this behavior.

2. Querying-reasoning behavior, as represented by the experimental task, can be beneficially modified with practice and training.

C. The Phylogenic Concept of Program Order

1. A conceptual approach to ordering content in programed instruction has been developed. This involves a "method of discovery."

2. An experimental model for studying this approach has been designed and developed.

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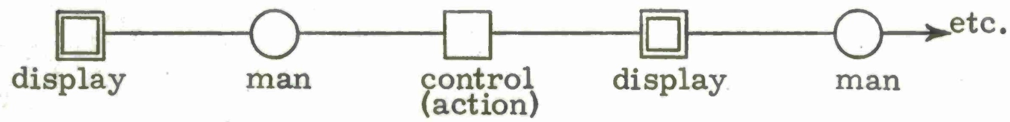
Appendix I

Symbology for Representing Logical Relationships Between Task Components

Causation or sequence proceeds from left to right, generally in the following sequence:

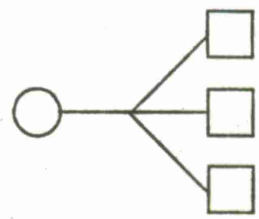


If only one man performs the entire task, the man symbol may be eliminated. In many tasks a variety of control actions will be accomplished between display changes, or several displays may be used to specify our action. In such cases the straight lines which indicate the logical relationships will have to branch accordingly. The following tabulation of branchings are suggested for use with the present set of symbols.

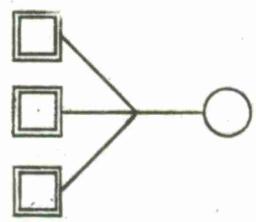
A. The "and" branches:

1. Unordered

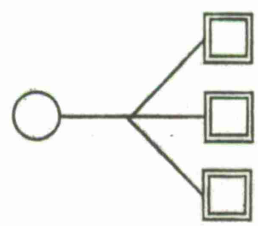
do all in any order



observe all in any order

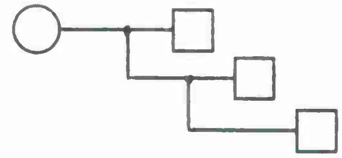


action leads to several displays

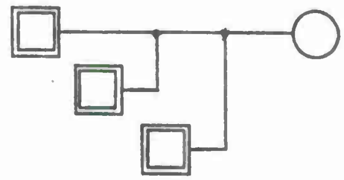


2. Sequential (ordered)

do direct line, then next branch

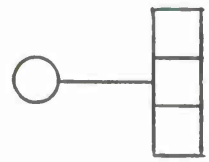


observe direct line, then next branch

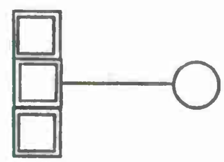


3. Simultaneous (ordered)

do coordinated action



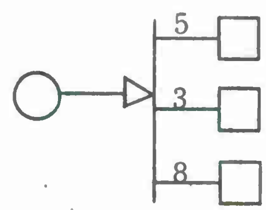
observe in a coordinated fashion



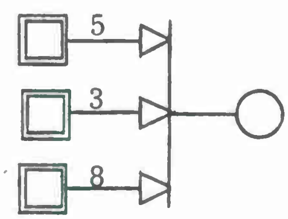
B. The "or" branches:

1. Contingent (indicated by an open arrow)

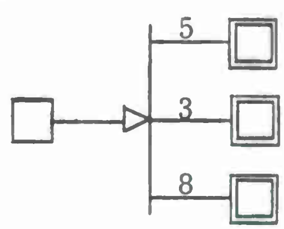
do the action specified by the previous display or decision path



observe the display specified by the previous decision path or display

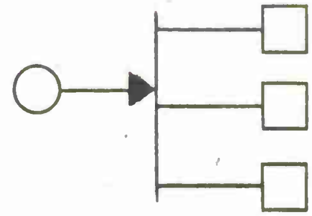


action leads to display according to previous decision path or display

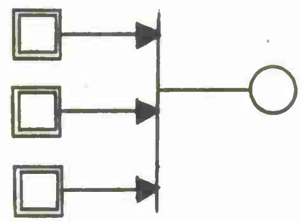


2. Whims (indicated by closed arrow)

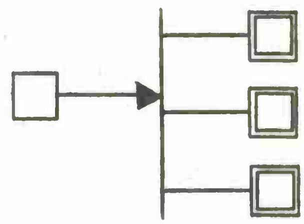
do any one



observe any one

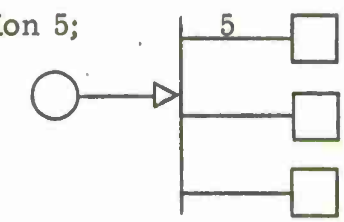


action randomly leads
to any one

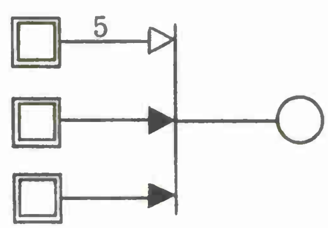


3. Combination contingent and whim

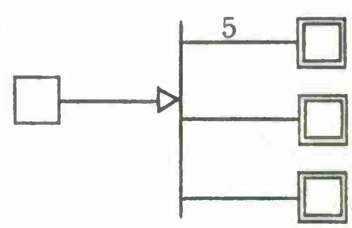
do top branch if condition 5;
otherwise select any
action



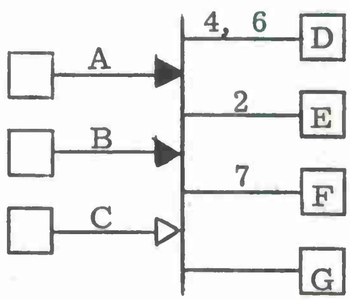
observe top one if
condition 5; other-
wise observe
any display



action leads to top display
if condition 5; other-
wise randomly leads
to any one



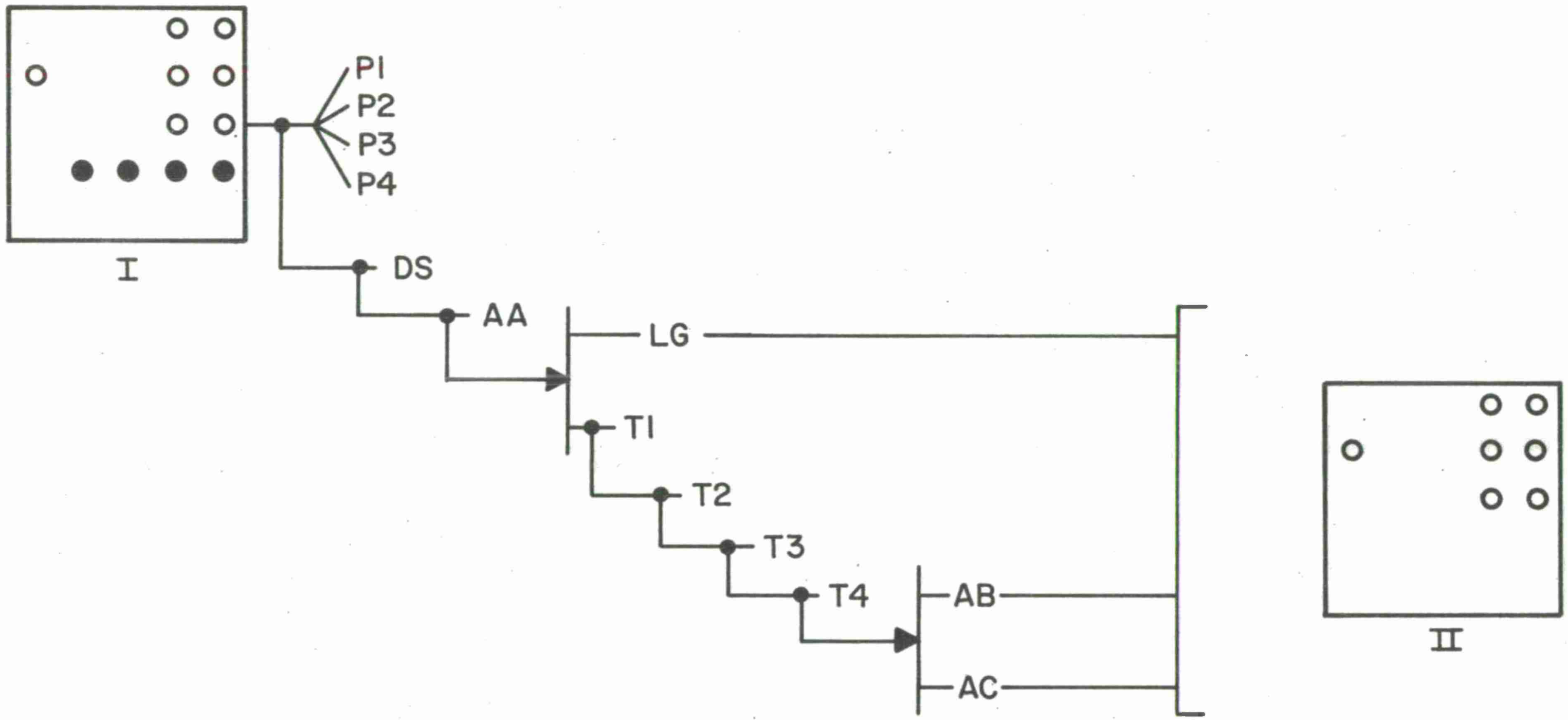
Various combinations of the above branchings are permissible. For example, several response paths may converge at the same decision point. In the example below any of the four actions at the right represent equally acceptable strategies when the decision point is reached by paths A or B. However, if path C is followed, do D if condition 4 or 6, do E if condition 2, do F if condition 7.



Appendix II

Logic Diagrams

Drawing	Title
A-201-1	Minor Sequence 1
A-201-2	Minor Sequence 2
A-201-3	Minor Sequence 3
A-201-4	Minor Sequence 4
A-201-5	Minor Sequence 5
A-201-6	Minor Sequence 6
A-201-7	Minor Sequence 7
A-201-8	Minor Sequence 8
A-201-9	Minor Sequence 9
A-201-10	Minor Sequence 10
A-201-11	Minor Sequence 11
A-201-12	Minor Sequence 12
A-201-13	Minor Sequence 13
A-201-14	Minor Sequence 14
A-201-15	Minor Sequence 15
A-201-16	Minor Sequence 16
B-201-1	Typical Display Circuit
B-201-2	Self Latching Relay and Prime Pair
B-201-3	Major Sequence Control
C-201-1	Major Sequence
C-201-2	Sequence Summary



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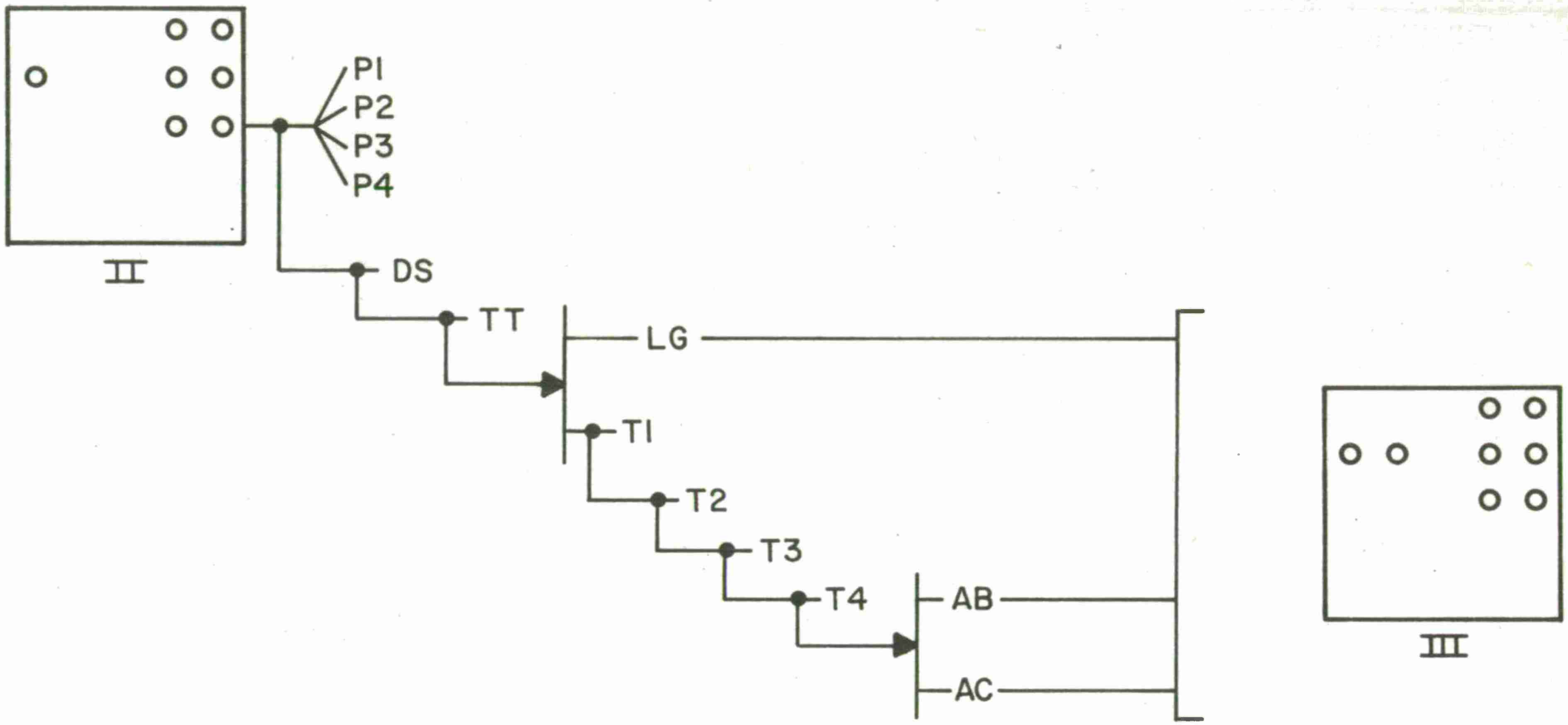

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BIO-DYNAMICS, INC.

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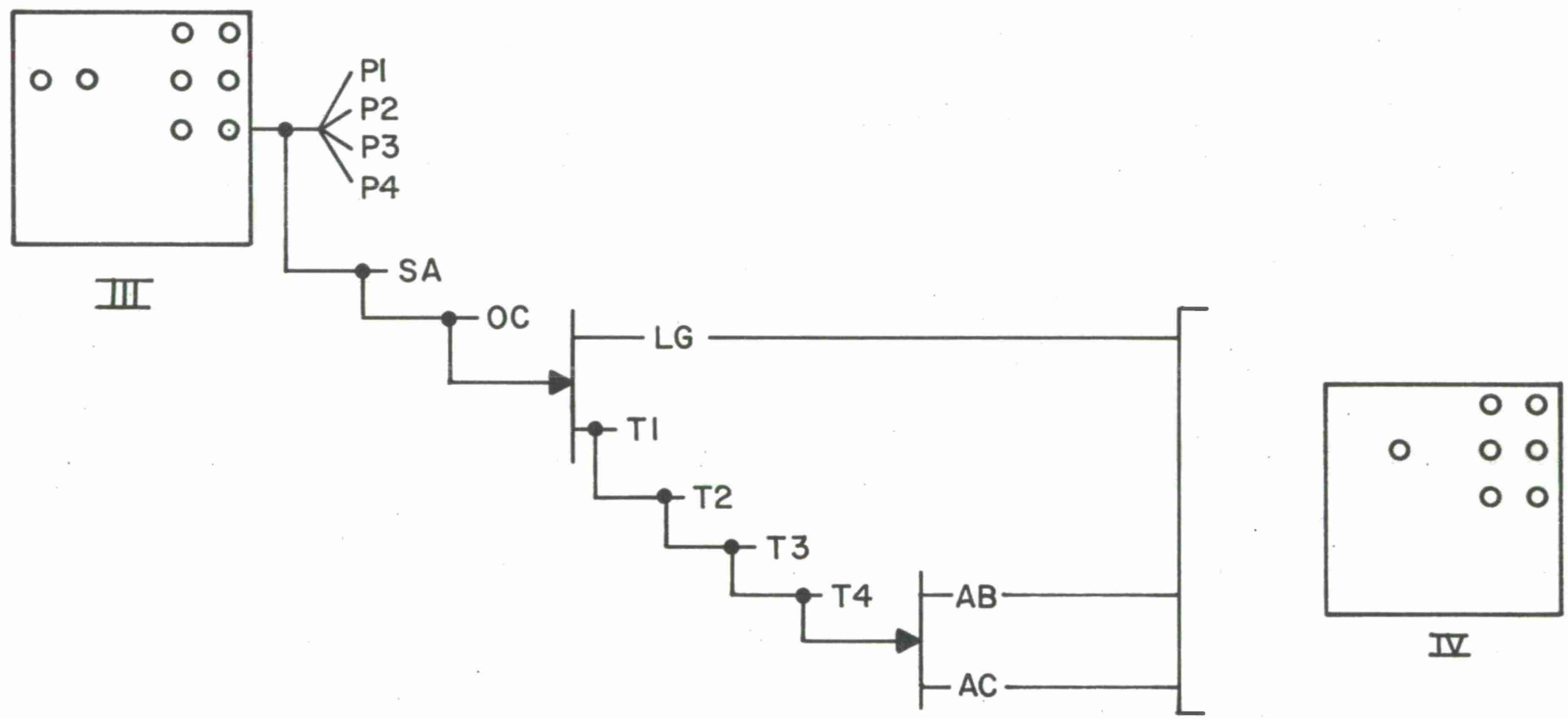

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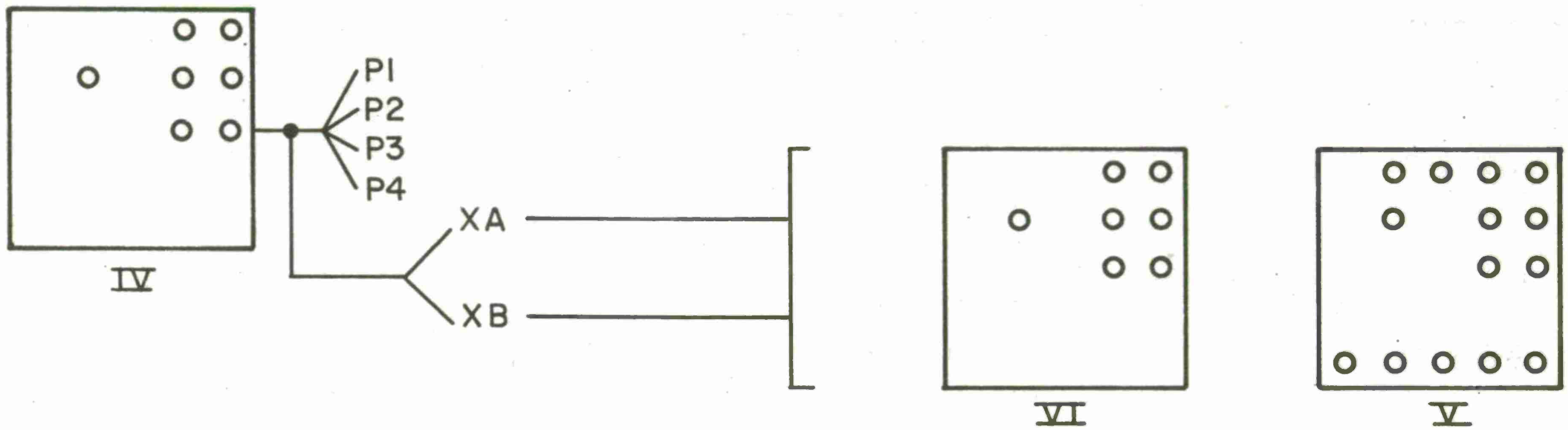

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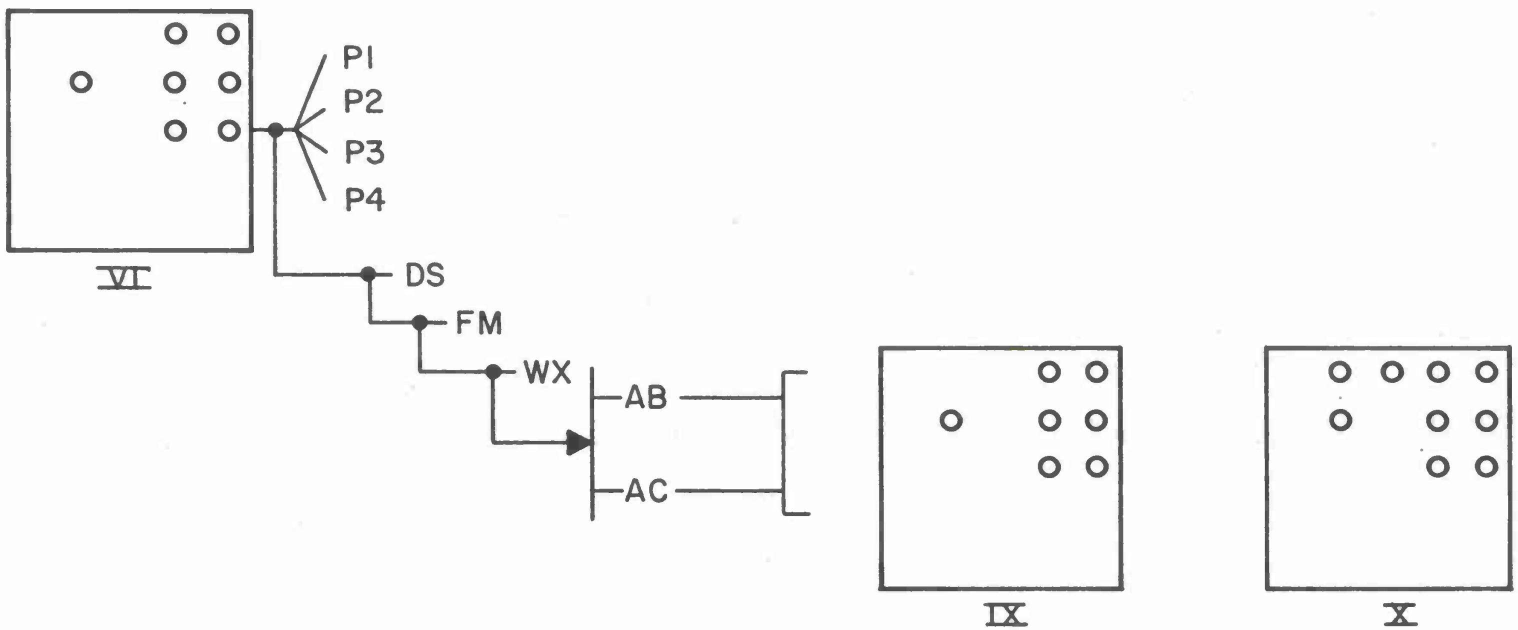

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MODEL TASK
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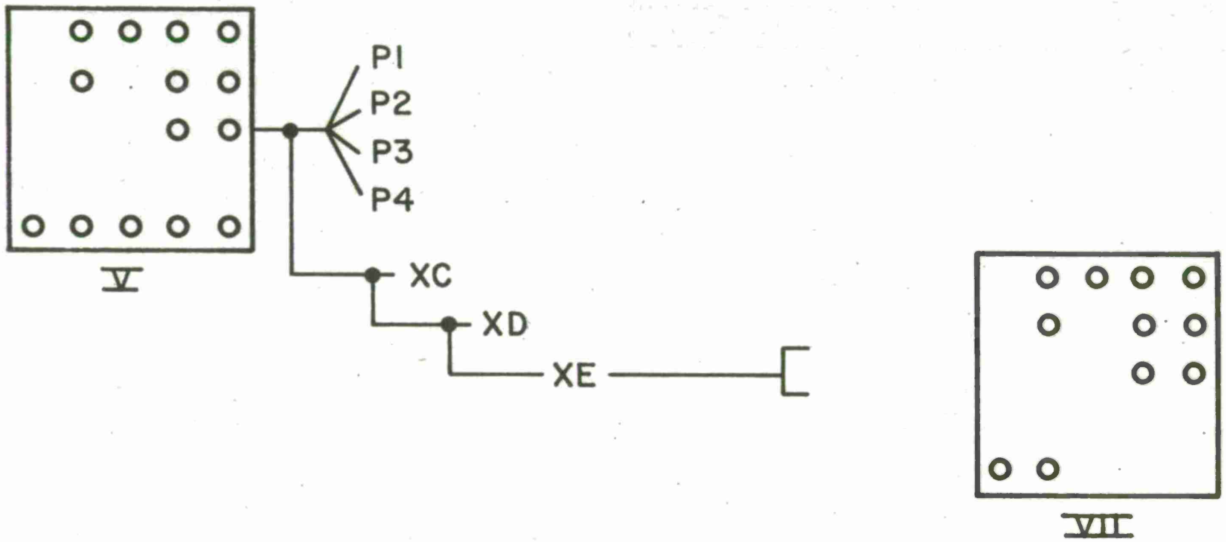

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BIO-DYNAMICS, INC.

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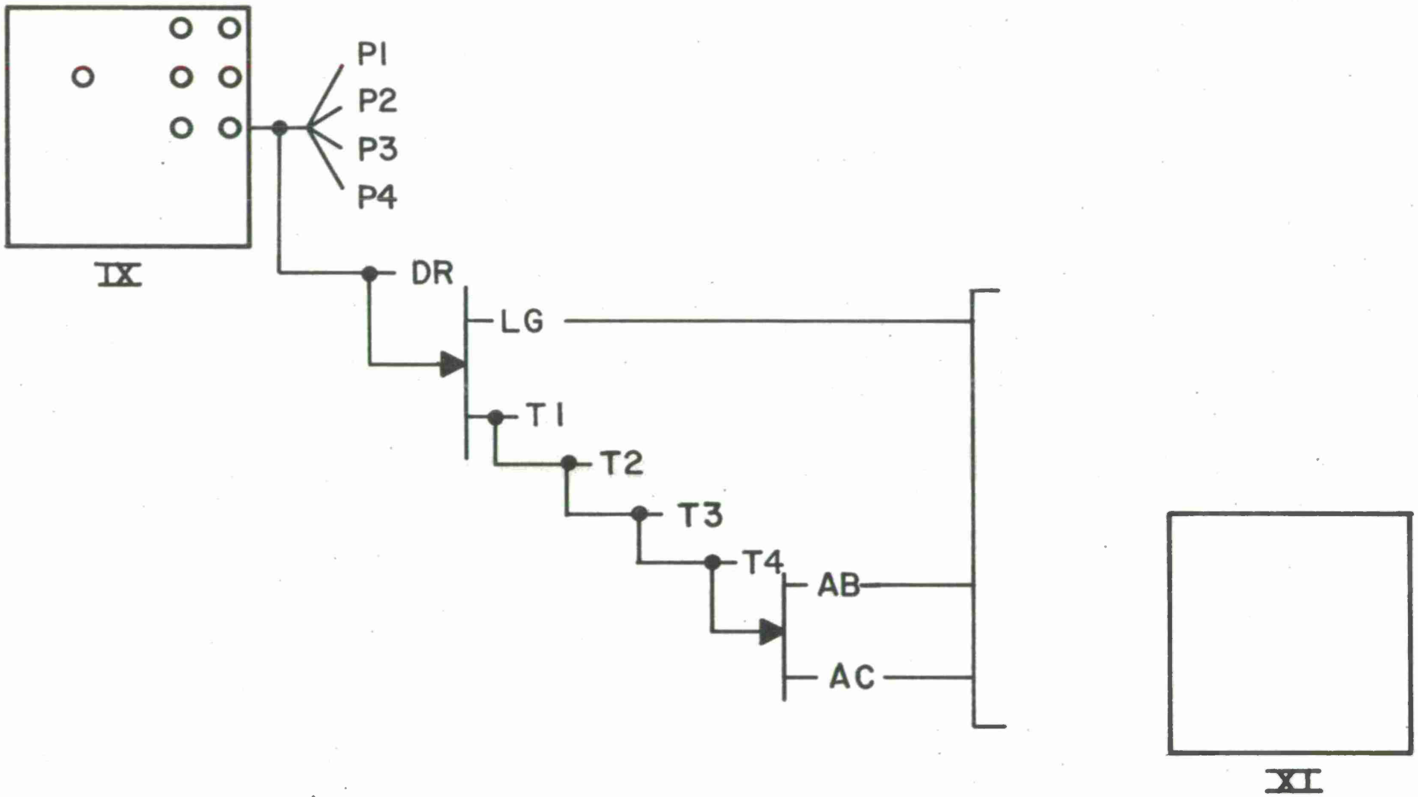

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MODEL TASK
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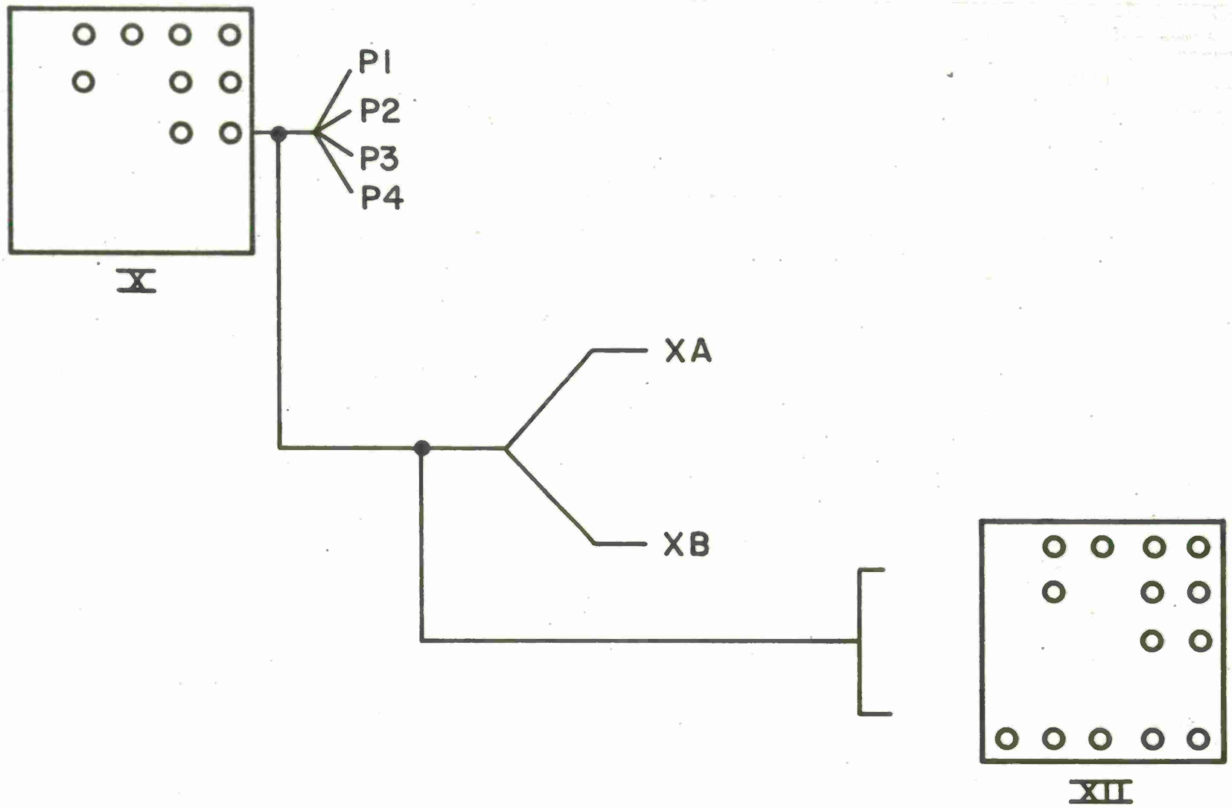

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BIO-DYNAMICS, INC.

MODEL TASK
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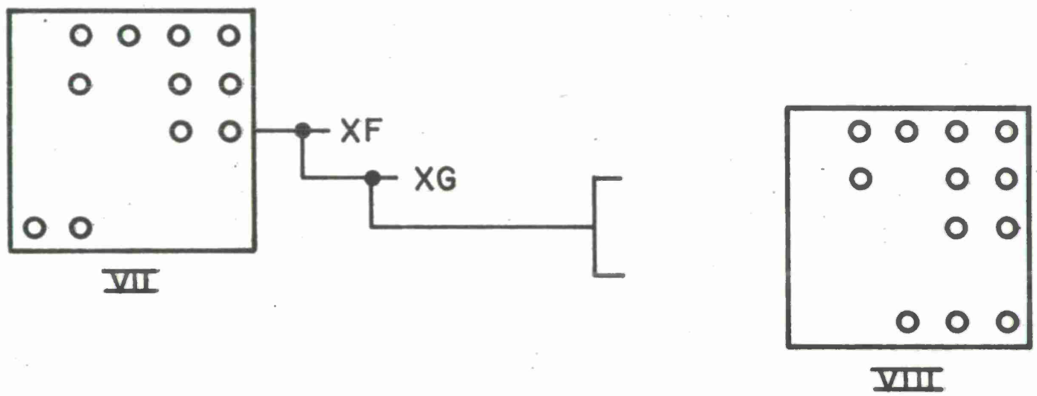
TRACED	APP'D	



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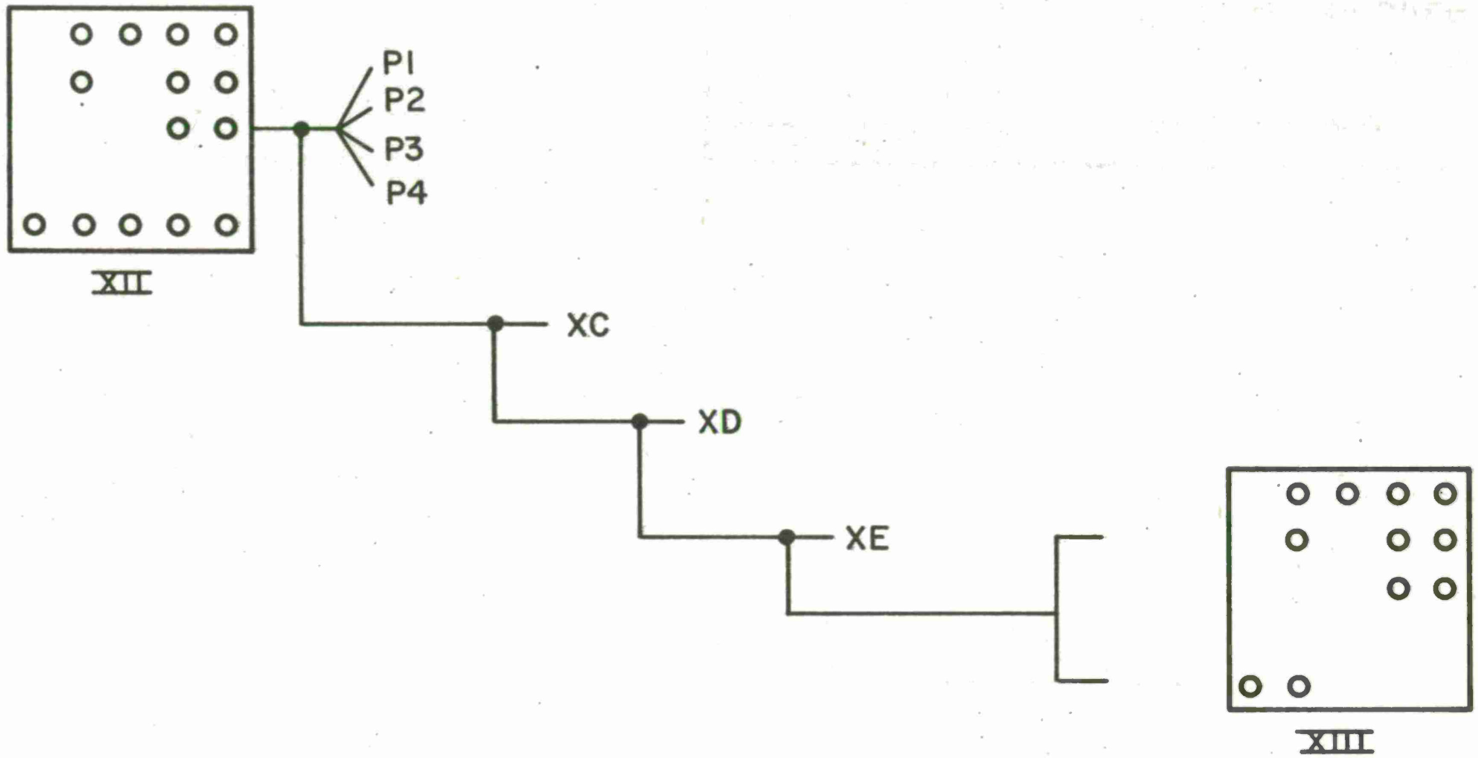

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MODEL TASK
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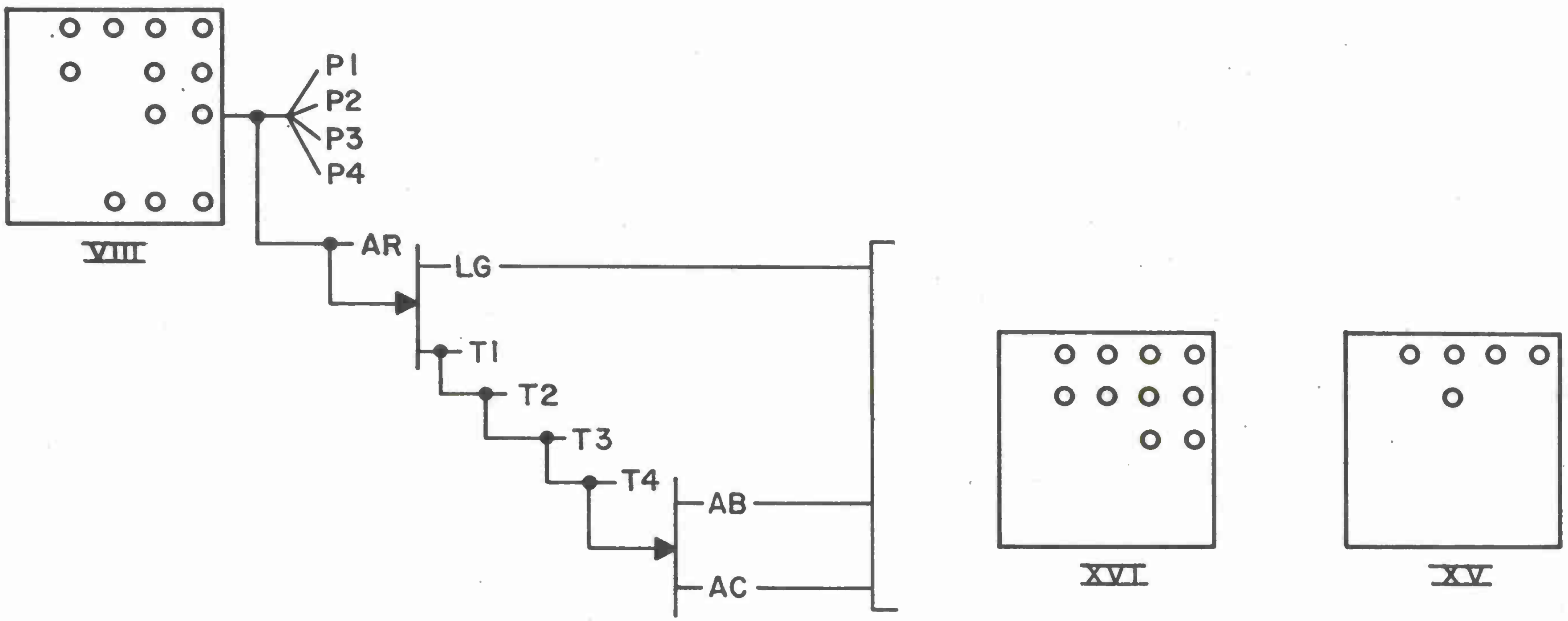

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MODEL TASK
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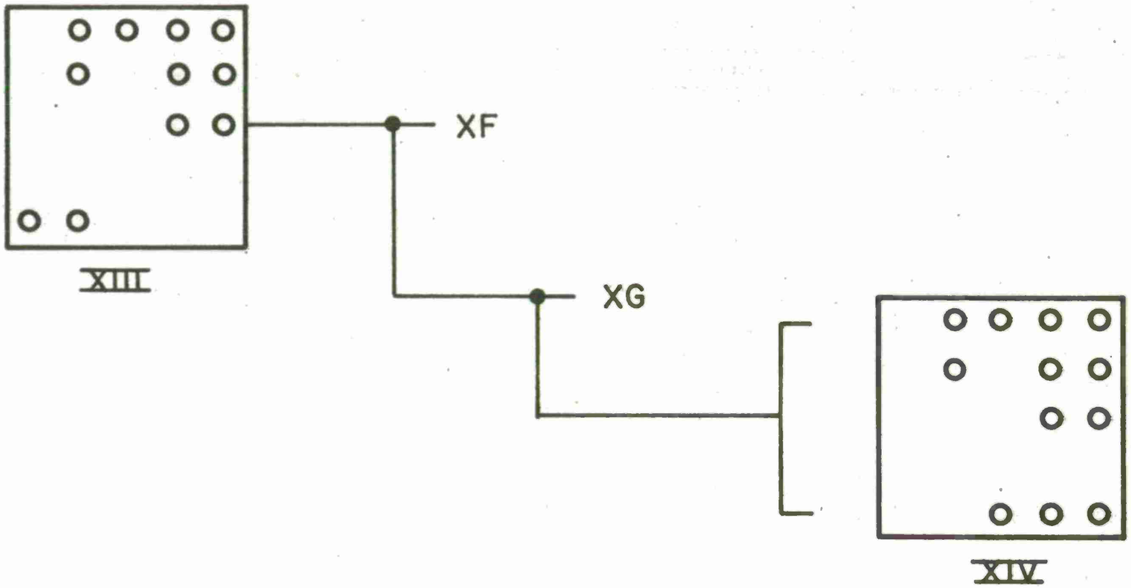

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BIO-DYNAMICS, INC

MODEL TASK
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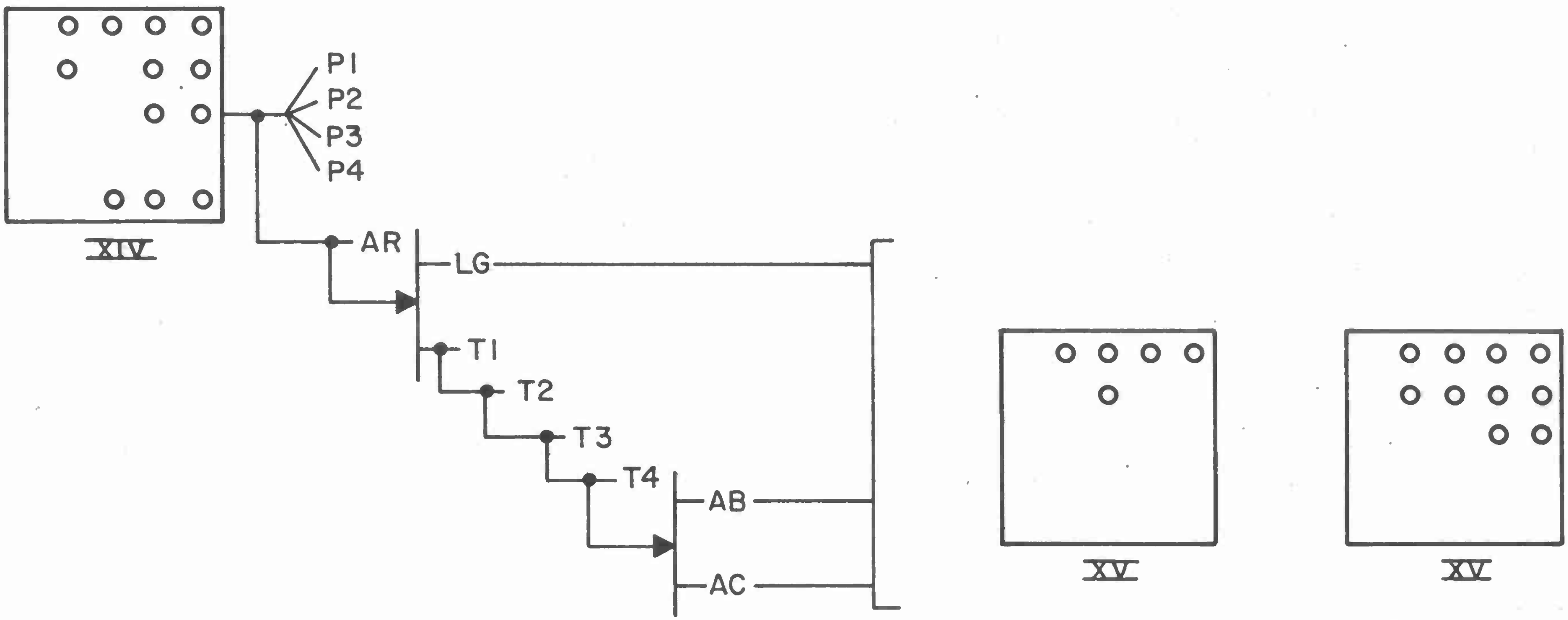

BIO-DYNAMICS, INC.

MODEL TASK
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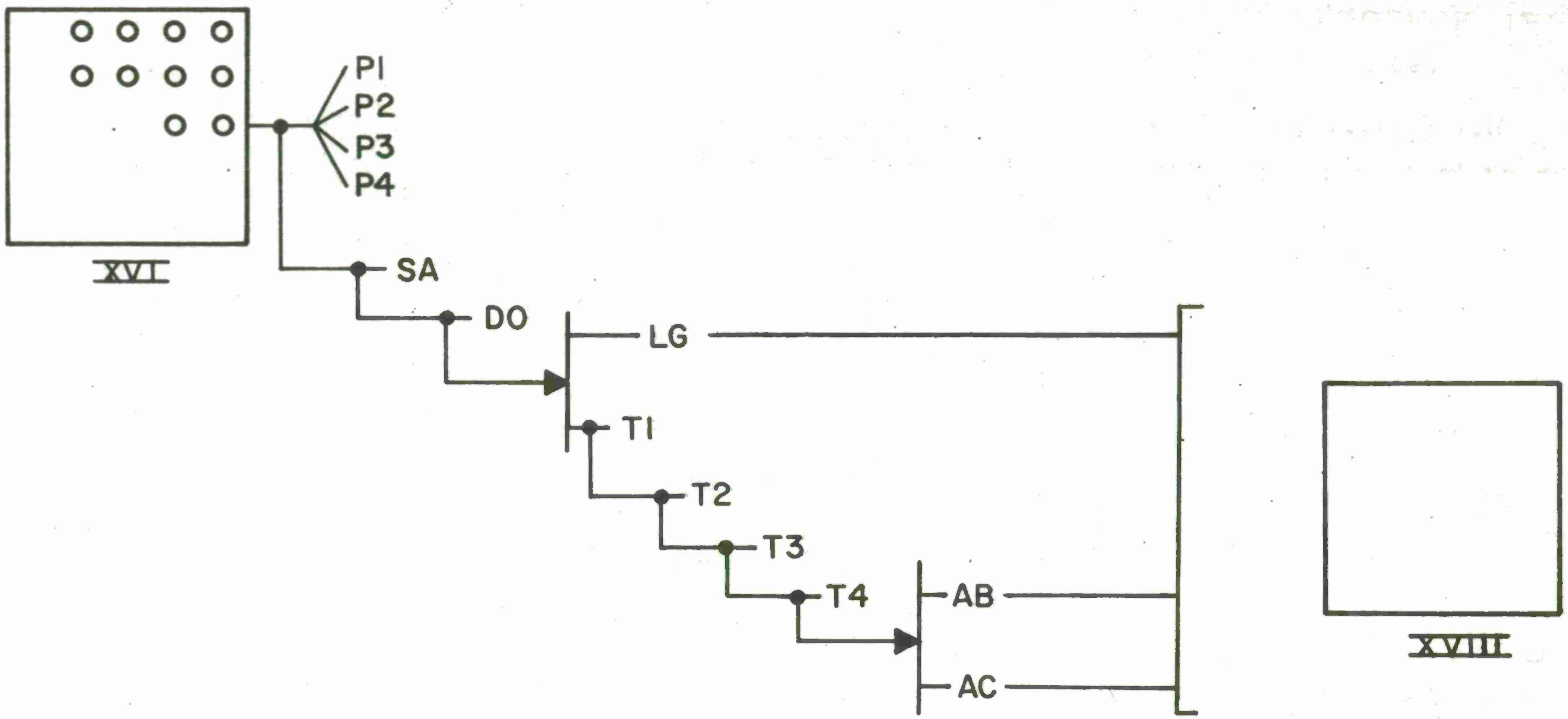

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BIO—DYNAMICS, INC.

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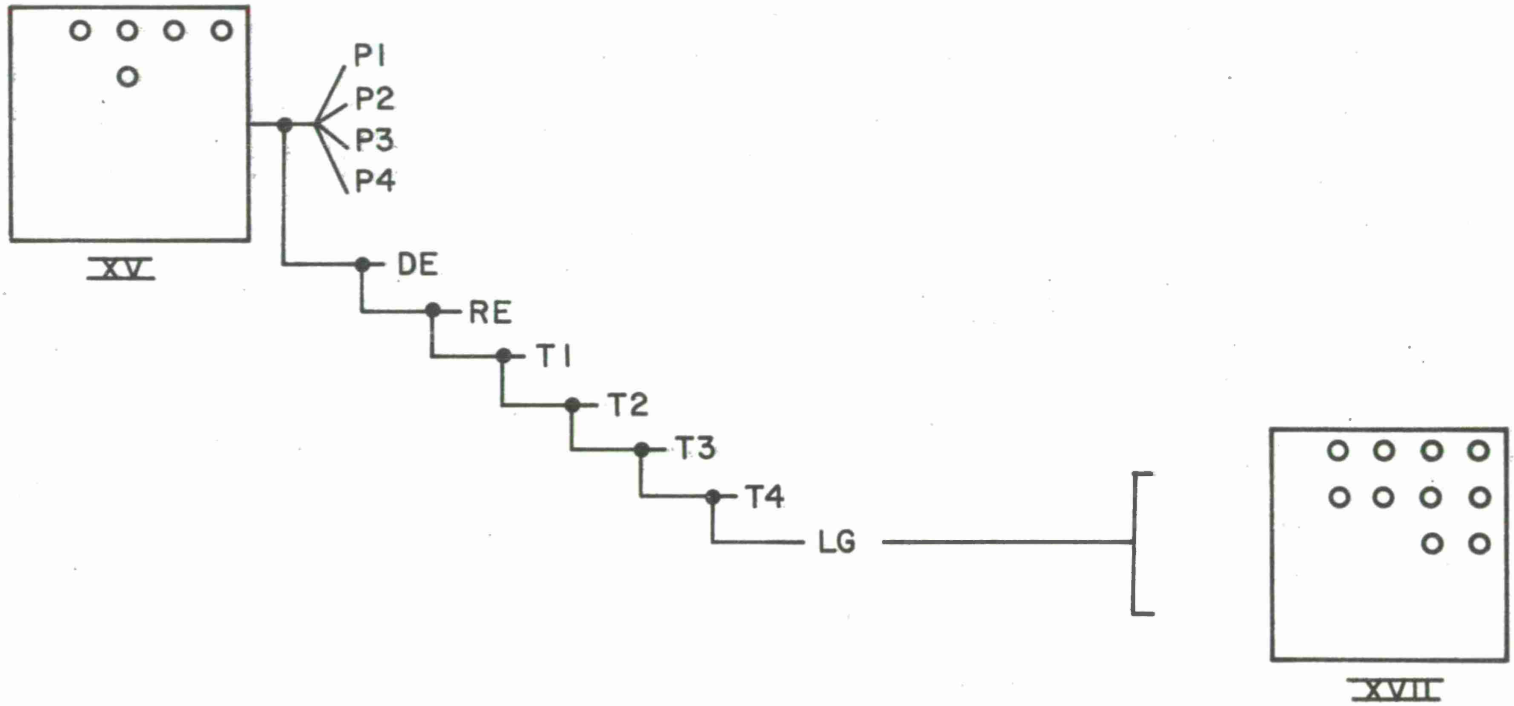

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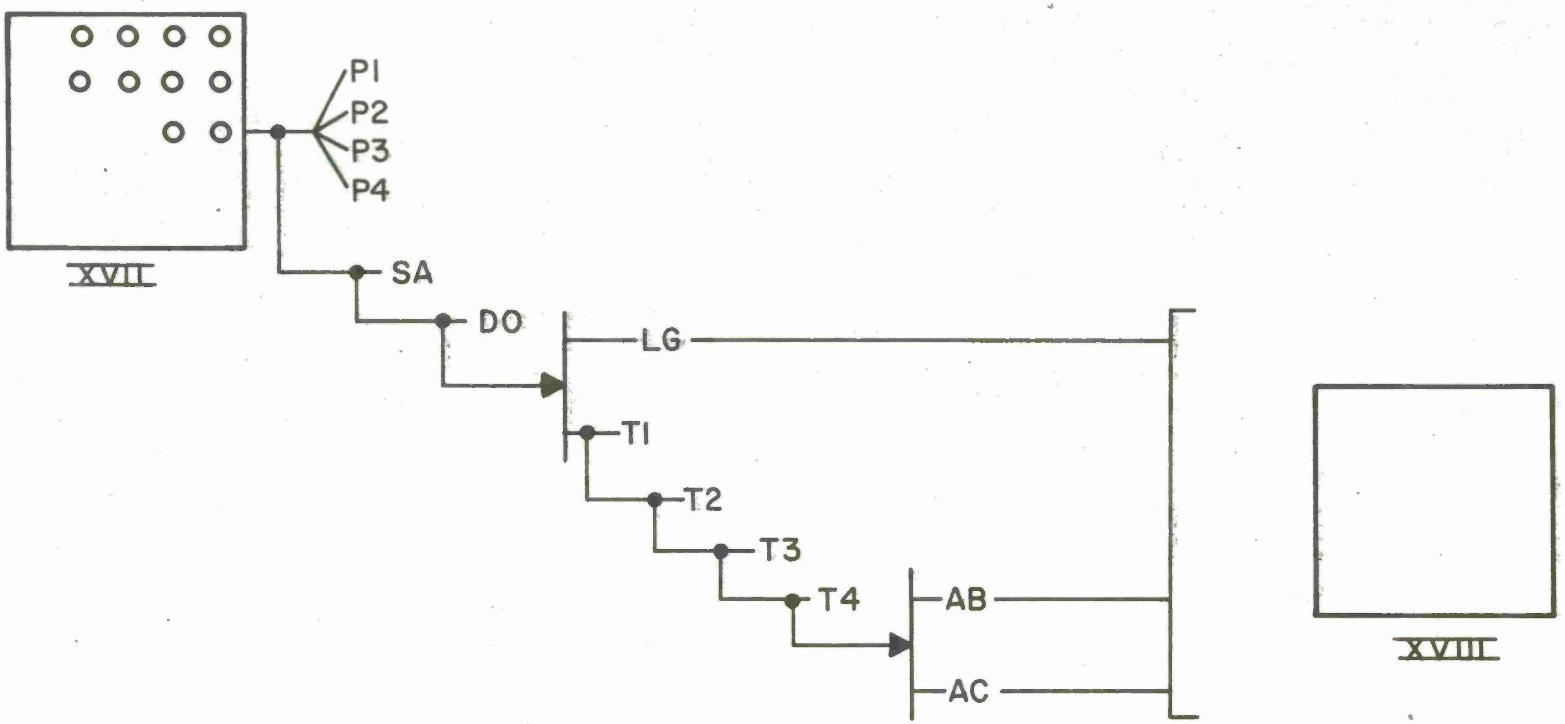

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BIO-DYNAMICS, INC.

MODEL TASK
MINOR SEQUENCE 16

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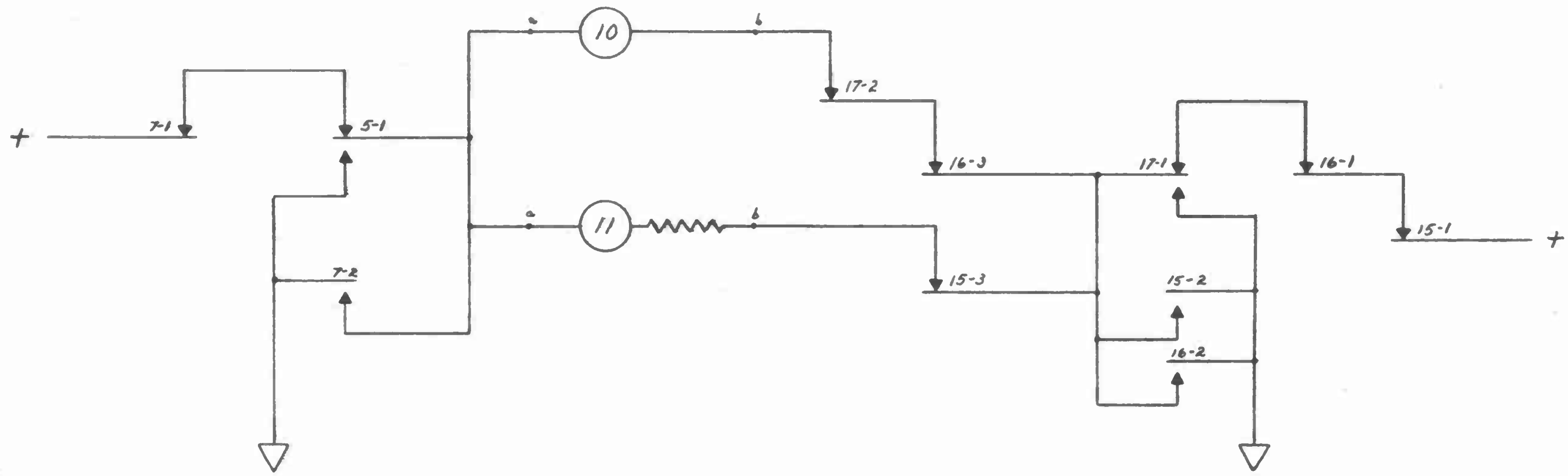
CHK'D	DATE	DRAWING NO. A-201-16
TRACED	APP'D	

RELAY / LAMP	5	7	15	16	17
10	X	X	X		
11	X	X		X	X

X = LAMP ON WHEN RELAY OPERATED



TYPICAL DISPLAY CIRCUIT

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MODEL TASK

BIO-DYNAMICS INC.

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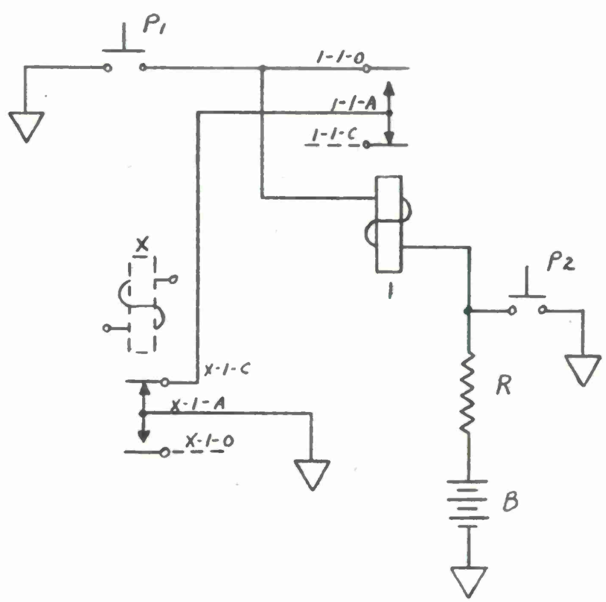
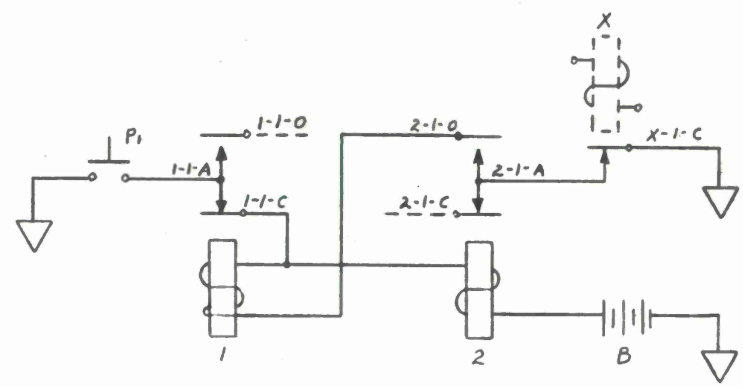
CHK'D	DATE 1-9-63	DRAWING NO. B-201-1
TRACED	APP'D	

NO. 179NP—11X17

SELF-LATCHING RELAY



PRIME PAIR



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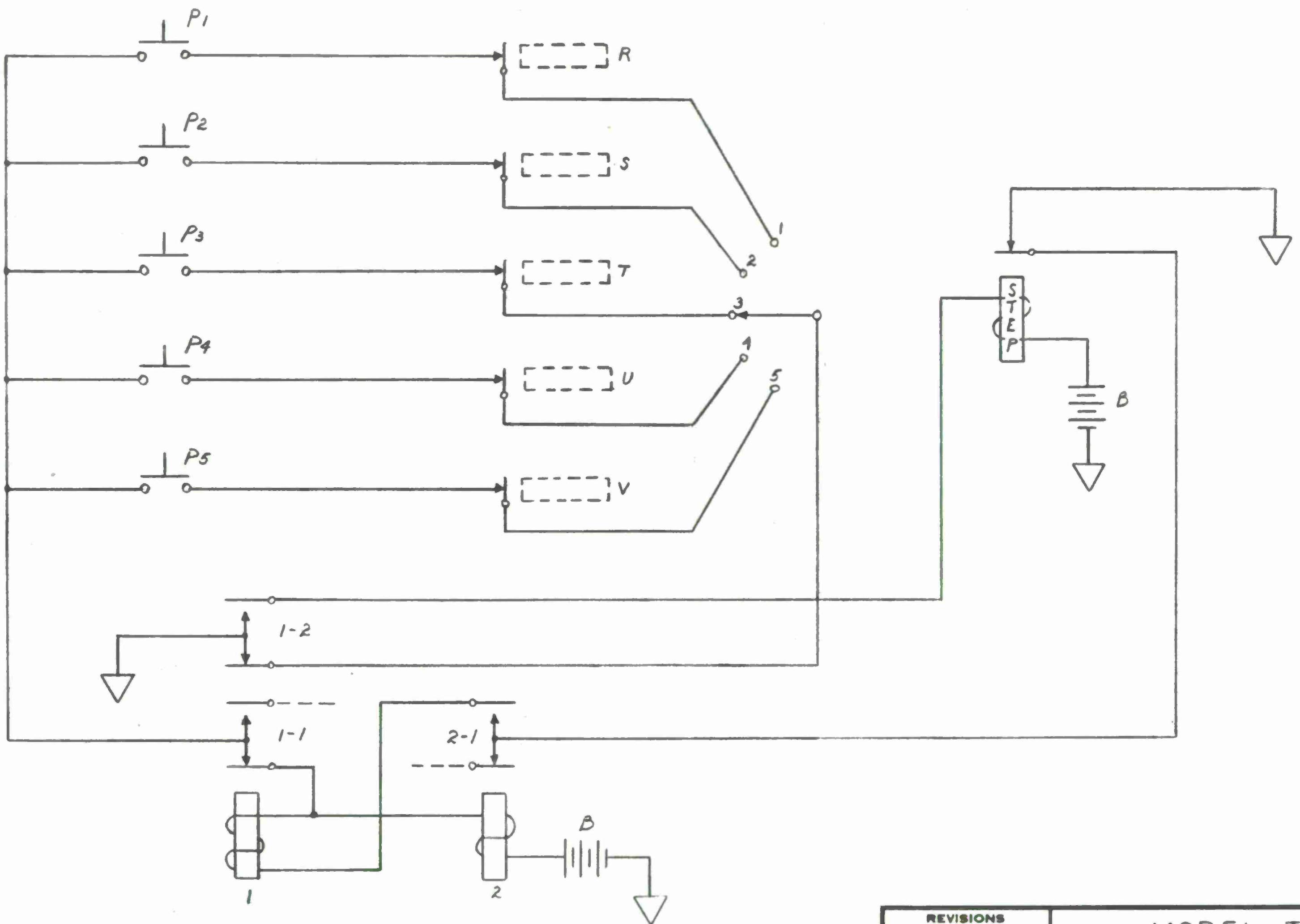
TRACED	APP'D	

NO. 179HP—11X17



MAJOR SEQUENCE CONTROL

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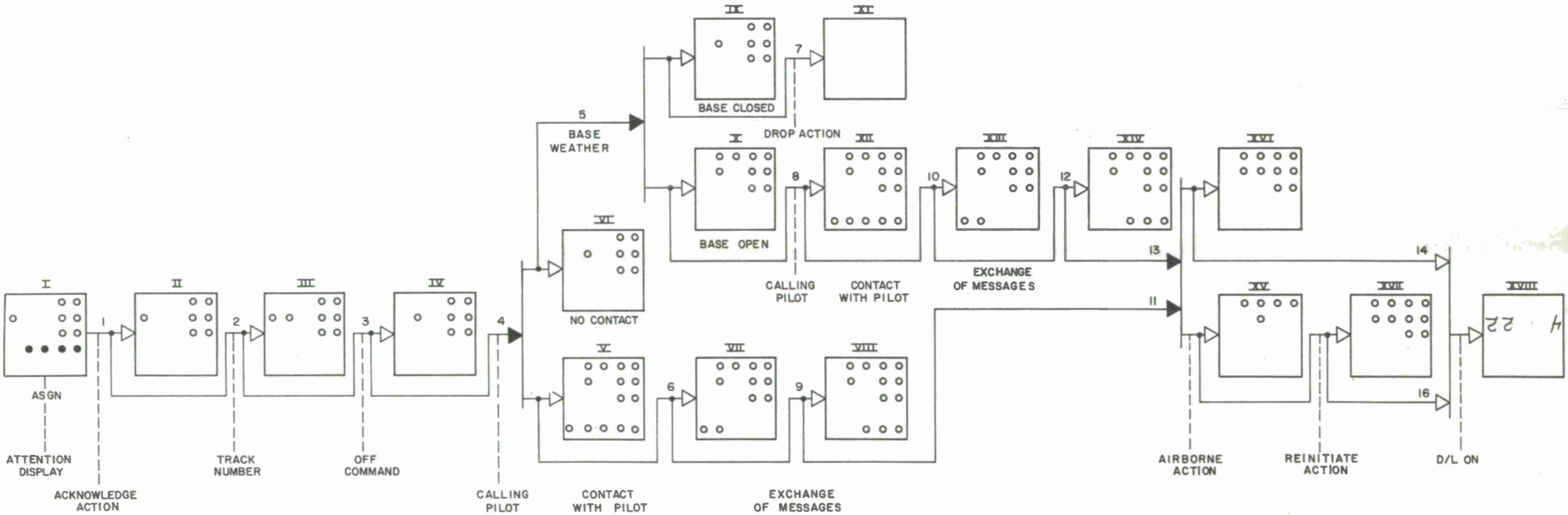
TRACED	APP'D	B-201-3



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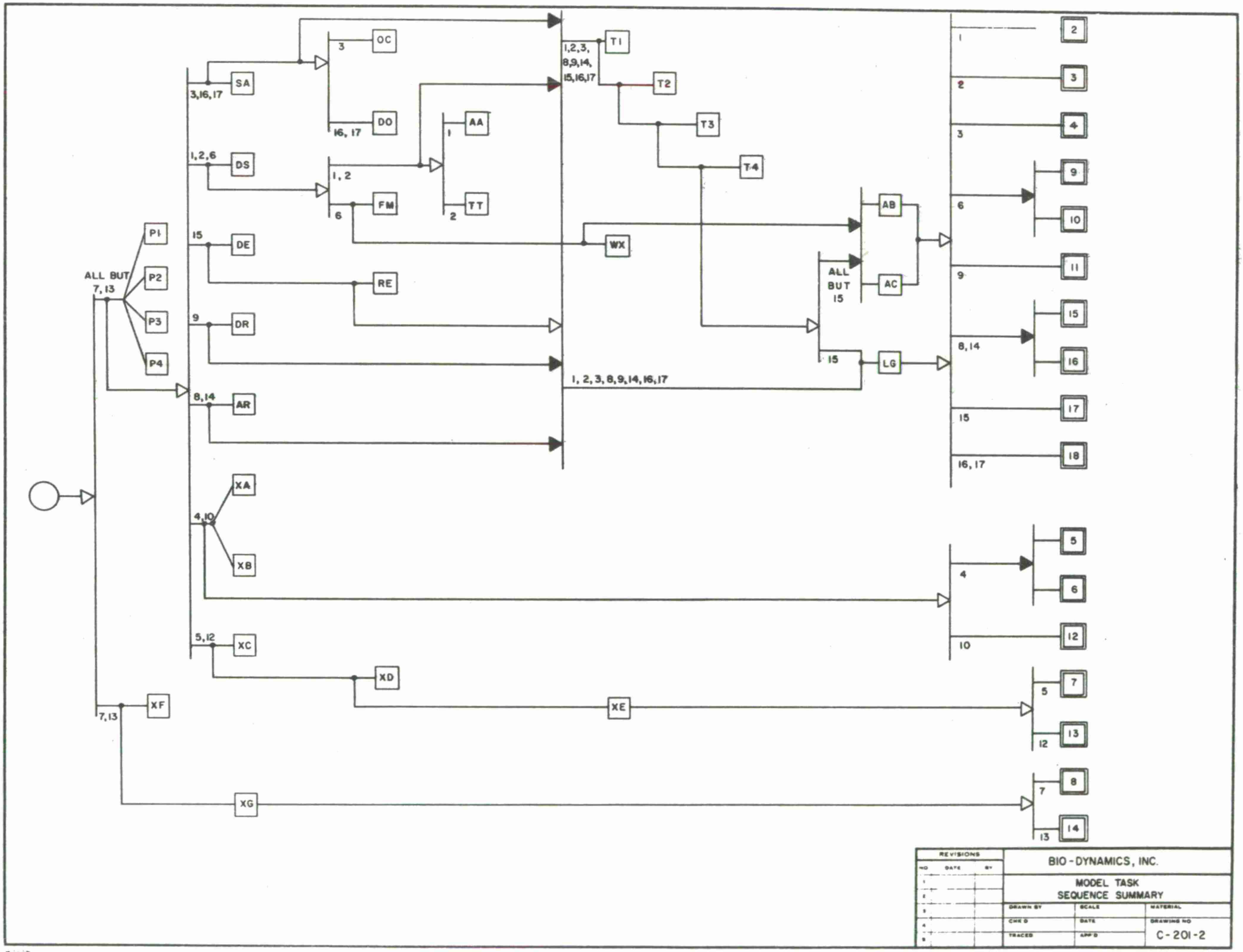

ALL BUT 7, 13
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P2
P3
P4
7, 13
XF
XG
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SA
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DS
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DE
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DR
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AR
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XA
XB
5,12
XC
XD
XE
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OC
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DO
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FM
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T3
T4
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ALL BUT 15
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AB
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REVISIONS
BIO-DYNAMICS, INC.
MODEL TASK SEQUENCE SUMMARY
C-201-2

Appendix III

A summary of hypotheses and lemmas to be used as a guide in the development of the phylogenic method

1. The creator of a system knows that system best, both functionally and mechanically, since each component added was born of his real and current need for its specific function.

2. The actual evolutionary steps through which a system has developed are a good starting point for a phylogenic teaching program.

3. The information displayed to an operator, on the basis of which he must make decisions to control his actions, has a semantic content rather than being merely a description of some current state of the system.

4. The training problems or environmental situations need not proceed in a real time or geometry.

5. Each control or display presented in answer to a request must provide only one additional function at that time.

6. Trainees must be taught to abstract the simplest possible verbalization, in the machine language, of the function being requested.

7. At the time of presentation a new control, wherever possible, should offer to the subject a means for continuous perturbation of the system or environment.

8. Some requests by the trainee may be irrelevant or impossible to grant or forehanded; he should be informed of this at the time of the request.

9. The trainee's role in the phylogenic teaching process must be taught to him initially.

10. The trainee need only request functions, not structures.

11. Retraining of operators on updated systems requires only the further application of a process already learned by him.

12. In the interests of a smooth and logical development, some components may have to be offerred to the trainee which are later destined to atrophy through disuse.

Appendix IV

A suggested experimental model of the phylogenic teaching method.

A simple approach to the building of an experimental system for study of the phylogenic method and using a minimum of special instrumentation would involve the manipulation of Lissajou figure displays on an oscilloscope screen. By means of a relay or stepper-switch commutation system a number of figures may be presented in sequence and if they are all displayed on a long-persistence phosphor, they will all appear to exist simultaneously. Each figure will be controlled by a separate passive network allowing control of position, size, as over-all gain and in each axis separately, and "roundness" (quadrature of phase), and for each there will be a diode "breakpoint" in each axis which may be placed anywhere in the figure. While the above controls are all of a continuous nature, toggle switches will be provided to flip the figure to a mirror image about itself or about either of the axes of the scope. A single sinusoidal oscillator source and DC bias supply will provide the input signals for all networks.

A goal will be set for the subject in the form of a pattern on a transparent overlay on the scope face which he is to imitate precisely with the figures at his command. In this first model an experimenter or instructor will be at hand to act as interpreter between the subject and the system and to reveal controls as their function is requested. Later, the experiments may be performed using a digital computer generating patterns on an output scope and providing the subject with one or more "light pens" with which to indicate on the pattern itself the perturbation desired. Even in the initial experiments more complexity in the figures and the controlling functions may be achieved by using an analogue computer with operational amplifiers to generate the figures.

The teaching process might start with the presentation of a single elliptical figure of the correct size, shape, and orientation to match the first overlay but out of position in one direction, the next overlay would require displacement in both directions, the next a change in orientation or size, the next the insertion of a breakpoint, and so on. Eventually a second figure would be required, and if all of the manipulations of a single one have already been tought, then when the second is requested, its entire control panel may be revealed at once. Shortcut functions such as a change of gain over the whole scope face might be requested and may be offered.

Two other figure variations which could be included easily are a brightening (or z-axis) control and a broadening of the figure's lines in either direction achieved by the insertion of low-gain, high-frequency signals from another oscillator source.

At any point during training the subject's current proficiency may be tested by presenting him with a new and different overlay which may be matched using only the controls he has acquired already and measuring the time necessary to achieve a duplicate.