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ABSTRACT

The elements of an instructional system are discussed and some literature bearing on these is reviewed. The discussion is intended to stimulate thought about an instructional system as a computer-assisted instructional (CAI) test-bed and to point out some noteworthy laboratory research results, particularly in cognitive psychology. Following this, parts of CAI projects underway at the Behavioral Technology Laboratories are described in relation to instructional system elements to give an overview of this research. Among these is work on computer graphics to: 1) simulate front-panel topography and functional organization of circuits; 2) facilitate interpretation of relative motion; and 3) create visual analogies for abstract concepts and processes to serve as the basis for students to develop their own internal representations. Other projects involve work on methods for recording cortical evoked potentials and correlating them with learning and memory processes, development of a dynamic programing model for adaptive control of problem-solving types of CAI, and work on three-dimensional mock-ups of electronic equipment to be placed on-line with a CAI system. (Author/PB)

BEHAVIORAL TECHNOLOGY LABORATORIES

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Technical Report No. 71

A DISCUSSION OF BEHAVIORAL TECHNOLOGY LABORATORIES CAI PROJECTS IN RELATION TO A CAI TEST-BED CONCEPT

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Joseph W. Rigney

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In the second part of the report, selected parts of CAI projects underway at the Behavioral Technology Laboratories are described in relation to instructional system elements, to give an overview of this research. The projects include: work on computer graphics to (1) simulate front-panel topography and functional organization of circuits, (2) facilitate interpretation of relative motion, and (3) create visual analogies for abstract concepts and processes to serve as the basis for students to develop their own internal representations; work on new methods for recording cortical evoked potentials and correlating them with learning and memory processes; work on a dynamic programming model for adaptive control of problem-solving types of CAI; and work on three-dimensional mock-ups of electronic equipment to be placed on-line with a CAI system. (U)

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In the second part of the report, selected parts of CAI projects underway at the Behavioral Technology Laboratories are described in relation to instructional system elements, to give an overview of this research. The projects include: work on computer graphics to (1) simulate front-panel topography and functional organization of circuits, (2) facilitate interpretation of relative motion, and (3) create visual analogies for abstract concepts and processes to serve as the basis for students to develop their own internal representations; work on new methods for recording cortical evoked potentials and correlating them with learning and memory processes; work on a dynamic programming model for adaptive control of problem-solving types of CAI; and work on three-dimensional mock-ups of electronic equipment to be placed on-line with a CAI system.

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SECTION I. INTRODUCTION

In this report, first I will describe what I perceive as the major elements of an instructional system. A diagram of the system is given in Figure 1. This part of the report is intended to stimulate thinking about the requirements for research on instructional systems, and to call attention to literature which seems to me to be relevant to these issues. The selection of literature is strongly biased toward cognitive psychology because I am a cognitive psychologist.

Second, I will discuss what the Behavioral Technology Laboratories are doing and plan to do in CAI in terms of the constituent elements of the instructional system. I will sample from different projects to illustrate what we are doing about some particular requirements in the system. No one project will be completely described here. Detailed descriptions are or will be available in other technical reports.

The sequence of the report will be organized in terms of four headings: I. Introduction, II. Outline of Major Constituent Elements of a CAI Instructional System, III. Description of the CAI Projects at BTL in Terms of These Elements, and IV. Summary Remarks.

The Behavioral Technology Laboratories have developed a type of CAI, which in Carbonell's (1972) terms could be called Performance Structure-Oriented (PSO). It is designed: (1) to simulate essential features of task environments, (2) to create supportive learning environments, in contrast to the usual atmosphere of military training, and (3) to give military personnel drill-and-practice in performing tasks they will be expected to perform as a consequence of going through some military course of instruction. For a variety of reasons, students in these courses tend not to receive enough practice in performing.

This type of CAI is well-suited to the use of what have been called generative programming techniques. That is, we put the logic for interacting with the student in the computer programs, not in the data bases. Consequently the computer programs tend to be quite long and the data bases tend to be quite short.

A brief description of how we view human performance as being organized is in order, since our type of CAI is based on these assumptions. We consider that a technician who is troubleshooting a complicated electronic device, or a radar intercept observer in the back seat of an F-4 Phantom who is coaching the pilot through an interception, are performing at a relatively high level of integration. By this is meant that they have learned to program themselves to perform a sequence of different subtasks calling for different kinds of subskills, in response to the requirements of the situations, to monitor their own performances to adjust to local variations, and to detect and to correct their errors. According to this view, it takes a lot of practice under the proper conditions for the student to attain this high level of proficiency.

Finally, to conclude the introduction, most of our work up to this year has been concentrated on program development. We have run students only to test program logic and to sample consumer acceptance. We now have access to one, and soon will have access to two different CAI systems which we can use for collecting more substantial data. One of these systems is a smart terminal that is being developed as a small stand-alone CAI system. The other will be Plato IV with Plasma Panel terminals. These probably represent the two opposite extremes with respect to CAI hardware. I believe both have a place in the worlds of education and training, and I am pleased to have the opportunity to work with both.

SECTION II. OUTLINE OF MAJOR ELEMENTS IN CAI

It has been helpful to construct an overall block diagram to organize my thinking about what constitutes a CAI instructional system. This diagram is necessarily crude, but it may be of some use as the basis for elaboration of specifications for a particular system or identification of requirements for further research. Each box in this block diagram (Figure 1) will be discussed in some detail.

1. Internal Processing (Fig. 1). This box is intended to suggest all of the processes relevant to learning and memory that go on in the student during instruction. These processes are, of course, the chief interest of cognitive psychologists. A fascinating and growing literature on the nature of these cognitive processes is now available. For examples, see Norman (1969, 1970), Tulving and Donaldson (1972), Melton and Martin (1972), Gregg (1972), and Lindsay and Norman (1972).

We at BTL are interested in the problem of how to teach students more effective strategies for learning and remembering selected types of contents, in the context of CAI, by utilizing information from theoretical and experimental studies of cognitive processes.

It is clear that the contexts, procedures, and objectives of CAI differ in many ways from the contexts, procedures, and objectives of laboratory experimentation. Therefore no one should expect either directly to replicate effects observed in laboratory experiments or to utilize without modification the methods used to produce these effects in the laboratory, in the context of CAI. Nevertheless, knowledge about

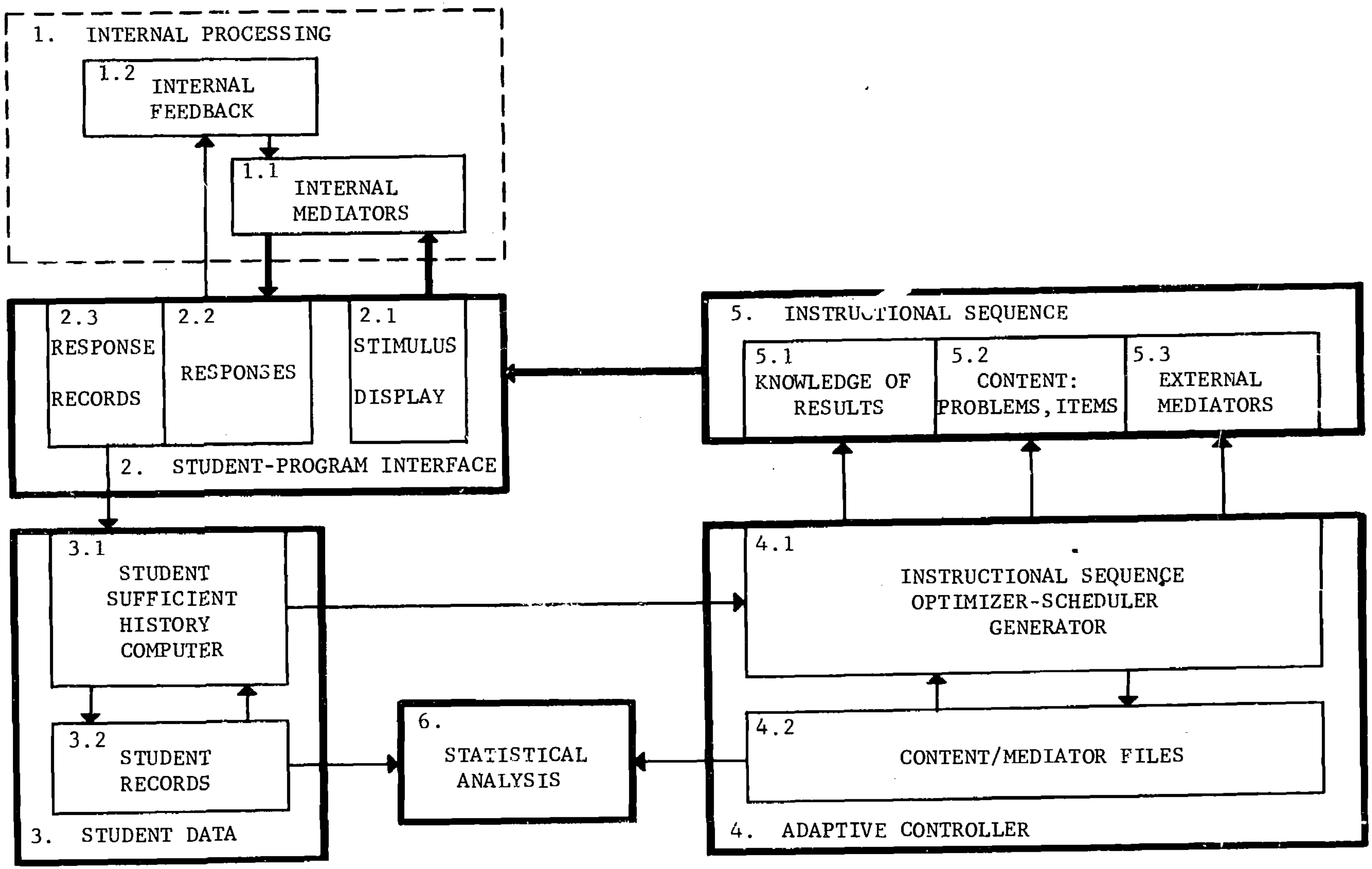

Fig. 1. Outline of major elements in CAI.

internal processes and processing does come primarily from laboratory experimentation. So we are compelled to look for the transformations, if any exist, that would allow us to utilize the information that comes to us from the laboratory for making CAI more effective.

One possible transformation might be the synthesis of models of how internal processing might occur in the learning environments of CAI, from results of a stream of laboratory experiments on related processes. The work of Bower (1972b) and others on mental imagery certainly should provide inspiration with respect to constructing models for the effects of imagery.

Another transformation from the laboratory to the instructional context might be done with operations that the experimenter has required of the student in the laboratory, that did result in large effects on learning or memory. The brilliant series of experiments Bower and his associates did on organizational variables in memory (1969a, 1969b, 1969c, 1970, 1972a) and on imagery in verbal learning (1972b), contain many descriptions of such operations, which represent successful attempts to use external methods to control internal processes. (I call these operations external mediators in the diagram in Figure 1.)

A third transformation would incorporate into CAI systems, with some modifications, models of cognitive processes that have been developed in more theoretical contexts. The work of Rumelhart, Lindsay, and Norman (1972) on the structure of memory immediately comes to mind.

An example of modeling of cognitive processes in CAI is available. Suppes and Morningstar (1972) developed models of internal processes in solving arithmetic problems. These models dealt with operations taught to students in elementary grades. Models for addition, subtraction, and multiplication were formulated and tested with data from their CAI course in elementary mathematics.

2. Student Program Interface (Fig. 1). In this box, the gap between stimulus displays and student responses is a reminder that the coupling of the student's selective attention to the stimulus display is less than certain. Not too long ago, psychologists pretended that attention did not exist. It was not on the list of approved topics for laboratory experimentation. Since the work of Cherry (1953) and Broadbent (1958), information about the processes involved in attention has been accumulating, e.g., see Trabasso and Bower (1968), Norman (1969), and Moray (1970). We all have observed the attending behavior of students in the classroom enough to know that we usually have very weak control over this behavior in this situation. The student-terminal arrangement in CAI at least requires active responding from the student, and therefore the potential is there for gaining stronger control over attending behavior.

Responses are set apart from response records to distinguish between the internal responses the student makes, which are the responses sensed by his internal feedback mechanisms, and the responses that become available for observation, which also can be sensed by external feedback mechanisms in the instructional system. Student overt responses to the program tend to be short answers entered via keyboard or light pen. Dialogue with a CAI terminal is severely limited. Work on natural language processing and on speech recognition hardware may eventually remove this bottleneck. The capacity for free verbal communication back and forth across the interface undoubtedly would extend the content areas and the ways in which CAI could be used and could reduce the possibilities for error and distraction caused by the need for the student to operate input devices.

Channels for sensing neural events related to the student's internal mediating responses may become available from experimentation with biofeedback techniques. If some evoked cortical potentials are found to be associated with internal learning and memory processes, biofeedback techniques might conceivably be used to gain external control over these processes. The implications are fascinating, although evidence of such relationships is very meager. In fact, as Bower (1972b) notes, in the case of the search for physiological correlates of imagery, the results so far have been distinctly unpromising. There is, of course, currently a flurry of interest in biofeedback techniques. As is so often the case in physiological psychology, advances depend heavily on developing improved techniques for observing and recording. Integrated circuitry is making improvements in these techniques possible.

The student-CAI system interface most often has been a teletype, or other purely alphanumeric device. The availability of relatively cheap devices for presenting graphic images adds a powerful new dimension. Information can be communicated to the student directly with graphics, bypassing verbalization. Often this can be an advantage in technical training. Objects, processes, and events can be simulated. Visual analogs for otherwise invisible processes and for abstract concepts can be displaced. Figure-ground relationships can be arranged in these graphics such that a contextual basis for interaction with the student is maintained over a series of trials.

It is interesting that recognition and recall of visual patterns is different from recognition and recall of verbal material (e.g., Shiffrin, 1973), and that at least partially different brain mechanisms are involved in processing pictorial information than are involved with processing verbal information (Milner, 1968).

3. Student Data (Fig. 1). Atkinson and Paulson (1972) describe sufficient histories as analogous to sufficient statistics. Generally, both short-term, or on-going observations of student responses and longer term records can be data for a student sufficient-history computer. Information about internal processing operations is, of course, extremely difficult to get.

Sternberg (1969) recently resurrected reaction time as an indicator of the complexity of serial processing in short-term memory. Given particular experimental conditions, inferences could be made from reaction times about which of several possible memory-scanning processes the subject was using. Wescourt and Atkinson (1973) used reaction time to investigate the scanning of information in long and short-term memory. Collins and Quillian (1972) used reaction time to investigate how people decide a sentence is true or false and to study language comprehension.

Where the mediating processes that could be required between stimulus and response can be inferred from common experience, or from prior investigations, as in performing simple computations, response latencies might be used in the context of CAI to indicate the length of the serial mediating chain. If models of these information processing operations are constructed, then latencies might be used in testing hypotheses about the models. However, it is likely that most CAI is concerned with mixtures of subject-matter that allow considerable variability in processing operations, and that may require long-term memory searches using variable amounts of time in different students.

4. Adaptive Controller (Fig. 1). Many CAI programs in use today, including those that BTL has developed, do not have very powerful procedures for on-line adaptive control. There is much to be gained from more powerful adaptive control, as Atkinson and Paulson (1972) and Chant and

Atkinson (1973) have demonstrated. However, the costs of applying mathematical programming techniques are considerations.

The appeal of on-line adaptive control for optimizing instruction, vis-a-vis using experimental paradigms traditional in educational research, is that, over a long enough period, and with enough students, an instructional system can be made more effective by a process of successive approximations.

On the other hand, the traditional experiment at best leaves us with statistically significant effects relating to one or two variables that then must be implemented in some way in an operational setting. As noted above, differences between the laboratory and the operational environments may negate experimental effects. Furthermore, as we all know from bitter experience, rigorously controlled experimentation is almost impossible to do in the context of training organizations or educational institutions (Bond, 1973).

An instructional sequence optimizer, a sequence scheduler, a sequence generator, and content/mediator files are included in this adaptive controller box. Here, mediator refers to external mediators, which I will describe in a moment. The big problem for generating the instructional sequence is that it usually must be generated by subject-matter experts, following heuristic procedures developed in the days of programmed instruction. One hears estimates of preparation hours/student hours ratios as high as 400-to-1. The expense of preparing instructional material in this way is so great that it is economically feasible to apply it only to subject-matter that can be used many times with large numbers of students.

The branch of Artificial Intelligence called Natural Language Processing might ultimately provide widely useful methods for automatically generating instructional sequences, if the semantic and syntactic mysteries of language can be reduced to programmable procedures for analyzing and synthesizing language. Techniques developed by Winograd (1972), Carbonnel (1972), Collins and Quillian (1972), Kintsch (1972) and others are examples of current progress.

Training for industrial and military jobs often is involved with performance; the control of vehicles, or the operation of devices, or the performance of any of hundreds of other tasks which require manipulative activities more than verbal activities. Course-generative methods must deal satisfactorily with structures in other domains besides language. The structure of language does seem to be inextricably intertwined with these other structures, since we communicate about them and think about them and learn about them by using language. Gagne's (1965) description of learning hierarchies emphasizes hierarchical structure, which seems to be a pervasive way of thinking about structure. However, the learning hierarchy may be, as Carroll (1972) suggested, created as a consequence of learning. Less rigidly hierarchical structures are being implemented in computer programs, e.g., Anderson's FRAN (in press), and Rumelhart, Lindsay, and Norman's model for long-term memory (1972). We have done some preliminary work on generative techniques for training involving task and device structures (Rigney and Towne, 1972). One objective of this work was to provide a learning situation in which the student could "steer toward the goal" by successively accomplishing hierarchically ordered subgoals and associated action sets, or by selecting the next steps to take in practicing problem-solving types of tasks. In both cases, the instructional sequence was generated in real time as the student performed, with its composition contingent upon his past actions.

5. Instructional Sequence (Fig. 1). It is clear that the composition of the instructional sequence is the chief means that we have for influencing what the student does during learning. The instructional sequence contains the principal variables that we can manipulate to induce the student to learn and to remember what we want him to learn and to remember. Learning may or may not be a serial process, but input to the student surely is. It is tempting to draw an analogy with a universal Turing machine (Minsky, 1967). However, such an analogy would mostly be highlighting dissimilarities between these situations. The effects of the serial instructional sequence on the internal states of a student are mostly unknown, and it is only after many repetitions of the tape that the student's behavior is changed in the desired ways.

Just what does happen when the instructional tape is input to the student is a fascinating research question, and deserves consideration by CAI technologists. The information processing branch of cognitive psychology has much to say about input processes (e.g., Norman, 1969), Lindsay and Norman (1972), as do theorists concerned more strictly with memory processes, e.g., Wescourt and Atkinson (1973). The items coming in from the instructional sequence must excite retrieval processes operating in long-term memory, as well as be stored in short-term memory. If learning as we know it evolved from a biological survival function for coping with new and potentially threatening situations, then long-term memory must be the store of the organism's history that allows quick searches for precedents and that provides the list of actions to try for coping with the new threat. We might suppose that the serial input would arouse a constellation of possibly parallel processes, a general marshalling of resources, to deal with the new material to be learned until the student can program himself adequately, or, conversely, gives up. Atkinson, Herrmann, and Wescourt (1973) describe a fascinating model of long-term store. In their research on search processes in recognition memory, they came to the conclusion that performance in a memory scanning task is a mixture of a fast, less accurate scan for familiarity, and a slower, more accurate, extended memory search. They proposed that LTS is divided into two components, a conceptual store (CS) and an event knowledge store (EKS). The CS acts as a high-speed interface between perceptual processes and the EKS, providing entry points into EKS where more detailed information may be located. Furthermore, they view LTS as a partially connected memory network in which the only connections are those within a given CS node and within a given memory structure in EKS. Retrieval depends on the availability during retrieval of features used for placement of a memory structure during learning. Partially connected memory networks use directed retrieval processes.

The part of the instructional sequence box labelled external mediators requires some explanation. In one sense, everything that the instructional system does is external mediation. Thus, one might put everything outside of the student in a big box labelled external mediation. In another sense, external mediators are the formal operations characteristic of some content area that we attempt to teach to students. Initially, students must be led by the hand through these operations until they can learn how to perform them without detailed instructions. In this sense, as learning progresses, external mediation is largely supplanted by internal mediation. However, the external mediators box also is intended to suggest operations the system could perform to induce the student to use more effective strategies for learning and remembering. For example, we would like to investigate the possible effectiveness of imagery in facilitating the learning of abstract concepts in electronics. We would call the methods we would use to induce students to use mental imagery external mediation.

Bower (1972b) cites several examples of what we call external mediation. The simplest is instructions to the students to, in effect, "turn on their imagers." Another, which was used by Brooks (1968) was to require subjects first to learn a short sentence and then to report, on signal, a particular categorization of successive words in the sentence (e.g., noun vs. non-noun words). This was used in connection with studies of modality-conflicting processing, but it is potentially adaptable to control some kinds of internal processing, including imaging.

Prather (1973) used tape recordings to prompt student pilots to "mentally practice landing a T-37 aircraft." Students sat in a cockpit mock-up and listened to tapes designed to give instructions in the landing pattern. The students were told to imagine the situations as vividly as possible and to perform the same motor activities and eye movements as they would in the actual landing pattern. The instructions on the tapes became more general as the landing sequences were repeated. These students subsequently were rated by instructor pilots as significantly ($P < .05$) better at landing in the actual situation than a control group. It is to be noted, however, that overt practice as well as mental imagery was involved.

6. Statistical Analysis (Fig. 1). The computer is a great tool for automatically recording detailed response data, and a great tool for

analyzing these data. But these operations neither are simple nor are inexpensive to implement, and they can represent a substantial amount of the cost of CAI that must be included in cost-effectiveness estimates for an operational system. Clearly, the type of statistical analysis that is undertaken is a function of the investigator's plans and objectives, which oftentimes are constrained by the realities of the environment in which the CAI system must operate. Thus far, researchers in CAI, with a few notable exceptions, have tended to use the standard statistical techniques of educational research. On-line adaptive control requires rapid analysis to provide information to use in scheduling instruction.

7. Feedback Loops (Fig. 1). Internal feedback in the student, and external feedback to the instructional system, are indicated in the diagram. This second loop provides information for adaptive control, and also is an external source of knowledge of results for the student. This knowledge of results, which is at least partially controllable by the system, is to be distinguished from that produced by internal feedback, which is much less accessible to external controls.

According to this conception, the system's external feedback to the adaptive controller is the source of information used for adjusting the composition of the instructional sequence. This information results from sensing overt responses of the student, responses that, at best, are only end results of internal processes and are poor indicators of those processes.

In addition to such well known feedback processes as visual-motor coordination, the neuroscientists are telling us that internal feedback is a pervasive phenomenon in the nervous system. There is some evidence that the association cortex influences sensory channels via efferent feedback loops. There is afferent feedback in efferent systems. There are many loops between major centers in the CNS; e.g., basal ganglia and cerebellum. This functional organization of the nervous system is most evident in the lower motor system and in the autonomic systems. In the case of the motor systems, voluntary behavior may be made up of concatenations of reflexes organized by anticipatory "biasing" signals sent to the lower motor servomechanisms (Easton, 1972). Might this arrangement also extend into higher structures responsible for internal processes in learning and memory? This evidence suggests that we should pay more attention to the nature of this servomechanism-like organization and to the importance of internal feedback relative to externally-provided knowledge of results for control over learning.

Are hierarchically functioning neural mechanisms the basis for the chunking that is so often observed as a result of learning? Some sort of hierarchical organization is apparent in verbal (Norman, 1969) and in motor (Kay, 1970) behavior. Are there hierarchically organized neural mechanisms that shift control of learned subskills to lower more automatic levels, and shift attention to control at higher levels of the system? Is this a fundamental phenomenon of learning? If so, what are the implications for CAI? Perhaps the instructional sequence could be shifted more accurately toward higher levels of cognitive organization as learning progresses, if it could be guided by external feedback indicating the momentary states of this internal reorganization of control. This would require that the instructional sequence be constituted to elicit appropriate overt indicators from the student, if that is possible. Perhaps, some of the experimental work with the free recall paradigm would be suggestive of useful indicators, or, possibly, some kinds of evoked potentials would be candidates, if reliable shifts in their characteristics could be found to be correlated with this chunking phenomenon in learning.

In our search for functional interconnections between learned and wired-in behavior, we might look for transition stages between these two forms of behavioral control. For example, the work of Miller (1969) on operant conditioning of the autonomic would seem to be concerned with processes in the nervous system that are at a transition stage between what up to this time had been conceived of as two different levels of the nervous system with respect to the capacity to learn, and reinforces the speculation that fundamental internal processes of the learning and memory that concern the instructional technologist, might, as have these autonomic functions, be brought under control by biofeedback techniques. This is not to say that autonomic and these higher learning and memory processes are necessarily all that similar, other than that some of the latter which are now inaccessible to external control might be made more accessible by using similar techniques. Effects of autonomic processes such as increases in temperature, evidently are a consequence of changing the bias in homeostatic mechanisms controlling appropriate parts of the parasympathetic and sympathetic divisions and using circulatory feedback. These autonomic effects are more accessible to observation. How do you observe storage processes in long-term memory without also involving retrieval and motor output processes? We need concurrent indicators that would tell us and the student that, for example, storage in long-term memory is occurring right now, so that the storage processes could be influenced by biofeedback techniques at the appropriate times.

SECTION III. DESCRIPTION OF BTL PROJECTS

The third part of this report is an overview of the CAI projects at the Behavioral Technology Laboratories. These can be categorized in terms of hardware, projects, and sponsors, as shown in Table 1.

Table 1

Behavioral Technology Laboratories CAI Projects
Related to Sponsors and Computer Systems

PROJECTS	TIME-SHARING	SYSTEMS IMLAC PDS-1D	PLATO IV
1. Alphanumeric TASKTEACH			
Troubleshooting	ONR		
Oper. Procedures	ONR		
2. Graphics TASKTEACH		ONR/ARPA	
3. RIO		NTEC/ARPA	
4. Visual Electronics			ONR/ARPA
5. K-Laws	ONR/ARPA		
6. CNV		ONR/ARPA	ONR/ARPA

Of these six projects, the fourth (VE), fifth (K-Laws) and sixth (CNV) are in formulative stages. We currently are devoting most of our resources to the development of graphics TASKTEACH and to planning for using the Plato IV system, and to the refinement of the RIO program. Historically speaking, alphanumeric TASKTEACH has been finished, and is described in a technical report (Rigney, et al., 1972). The Radar Intercept Observer (RIO) project has been through a field evaluation. This work currently is funded by ARPA, and is monitored by NTEC. However, it is based upon the approach to performance training developed under ONR funding, and should be regarded as an application of this approach. It is described in an NTEC technical report (Rigney, Morrison, Williams and Towne, 1973).

Aspects of these projects will be discussed, in relation to the block diagram on the CAI system, according to the matrix in Table 2 relating projects to boxes in that diagram. An X entry in a cell in the matrix indicates that project will be discussed in relation to that box in the CAI system diagram.

Table 2

Behavioral Technology Laboratories CAI Projects
Related to Instructional System Elements

CAI ELEMENT	AT	GT	RIO	VE	K-LAWS	CNV
1. Internal Processing						X
2. Student/Program Interface		X	X			
3. Student Data						X
4. Adaptive Controller	X		X		X	
5. Instructional Sequence		X	X	X		
6. Statistical Analysis			X			

1. Internal Processing

In most of what we do, we are trying to get students to develop cognitive representations of devices, events, or task structures, and to incorporate operations in these structures that will generate appropriate performance in job environments. So far, we have approached this objective primarily through simulation of essential features of these structures and of the performance environments. We would like to find better ways to control internal mediators that theorists are finding so effective in facilitating learning and retention, so that they may be more effectively coupled to processing the instructional sequence. We refer, of course, to operations like imaging, verbalizing, rehearsing, organizing, and recalling.

The CNV project is a rather "blue sky" search for the basis for one type of controlling mechanism. We wonder if Contingent Negative Variation, which is a slowly shifting cortical potential, or other evoked cortical potentials, could be reliable correlates of some kinds of internal processing events during learning or remembering. The first task will be to construct amplifying and noise-rejection circuits from integrated-circuit building blocks that will let us record evoked potentials on a trial-by-trial basis. If we are successful in developing this technique, the next step will be to explore the value of evoked potentials as processing indicators. For example, changes in CNV might be related to variations in a student's certainty about his knowledge (Shuford, 1972).

Evidence in the literature (Tecce, 1972) suggests that CNV, like EEG, is correlated at least some of the time with general states of arousal of the CNS. But, what is going on in the CNS when it shifts to a general state of arousal and back to local arousal, perhaps of a cortical analyzer? One hypothesis could be that large parts of the cerebral cortex are recruited to help cope with strange (unexpected) signals; that these signals cause the CNS to call up the emergency reserves. Once the signals have been matched to something familiar stored in long-term memory, special cortical analyzers are assigned the signal-monitoring task, releasing the remaining cortical areas back to "reserve" status.

In connection with our strong interests in mental imagery, it is likely that we should look for a physiological indicator over the occipital cortex. At least some mental imagery may be sensory-modality specific, and thus visual imagery should engage the visual cortex more than other regions. Since one of the difficulties of studying mental imagery is to know when students are imaging (Anderson and Kulhavy, 1972), it would be nice to have an objective correlate. It takes only a bit more speculation to wonder if, given such a correlate, it could be the key to bringing imaging under the control of biofeedback techniques, which could give us the power to control imaging during learning. We are mindful of the unpromising results of earlier studies, but these used less sensitive recording and analyzing techniques than those we propose to develop.

2. Student/Program Interface

The graphics for TASKTEACH illustrate the ease with which a student can do troubleshooting from a graphics simulation of unit front-panels of, in this case, a Navy transceiver, by using a light pen to operate on the graphics. The student's task is to collect symptom information from front-panel indicators by setting front-panel controls in the proper positions to check particular sections of circuitry with a particular indicator. The student then must interpret this symptom information to isolate the malfunction to the smallest possible fault area.

We are also developing three-dimensional front-panel simulators for two Navy devices, a transceiver, and a radar repeater. These will be attached to smart terminals through an interface that will allow the computer program to sense front-panel control positions. We are acquiring a digital voice synthesizer to use with these simulators to give the student auditory instructions under program control. However, these developments are not far enough along to discuss in detail at this point. They are intended to be alternatives to the computer graphics. We will run some comparative studies between these alternatives.

The graphics for the RIO program include a simulation of a display found in the RIO's operating environment, the B-scan, and auxiliary graphics provided for instructional purposes. These are an array, called a toteboard, to display values of intercept triangle variables; latencies for computing these values; a geographic plot of the interceptor and bogey movements; actual and optimum flight paths; and a display of bogey and fighter positions at the moment of firing in a Sidewinder attack. Generally, the RIO student starts off in what we call the static mode (bogey and interceptor speeds are zero) to practice doing mental arithmetic until he achieves a fluency criterion. Then, he is automatically sequenced to the dynamic mode, in which bogey and fighter are flying at 220 knots. When the student achieves a fluency criterion at this speed level, he is automatically sequenced to the next level, 40 knots faster, until he finishes the highest level, which is 500 knots. Any time a student fails to achieve a hit probability ≥ .80 when he fires a Sidewinder missile, he must repeat the problem in a third mode, called the free-fly mode. In this mode, all intercept triangle information is given to him, and all the instructional graphics are continuously displayed (see Fig. 2).

3. Student Data

Collecting response data with a computer is, in some respects, so easy that there is the danger of collecting mountains of unanalyzable or useless data. We all know this problem. Still, it is prudent to collect more data in the first tryout of a project than would be necessary later,

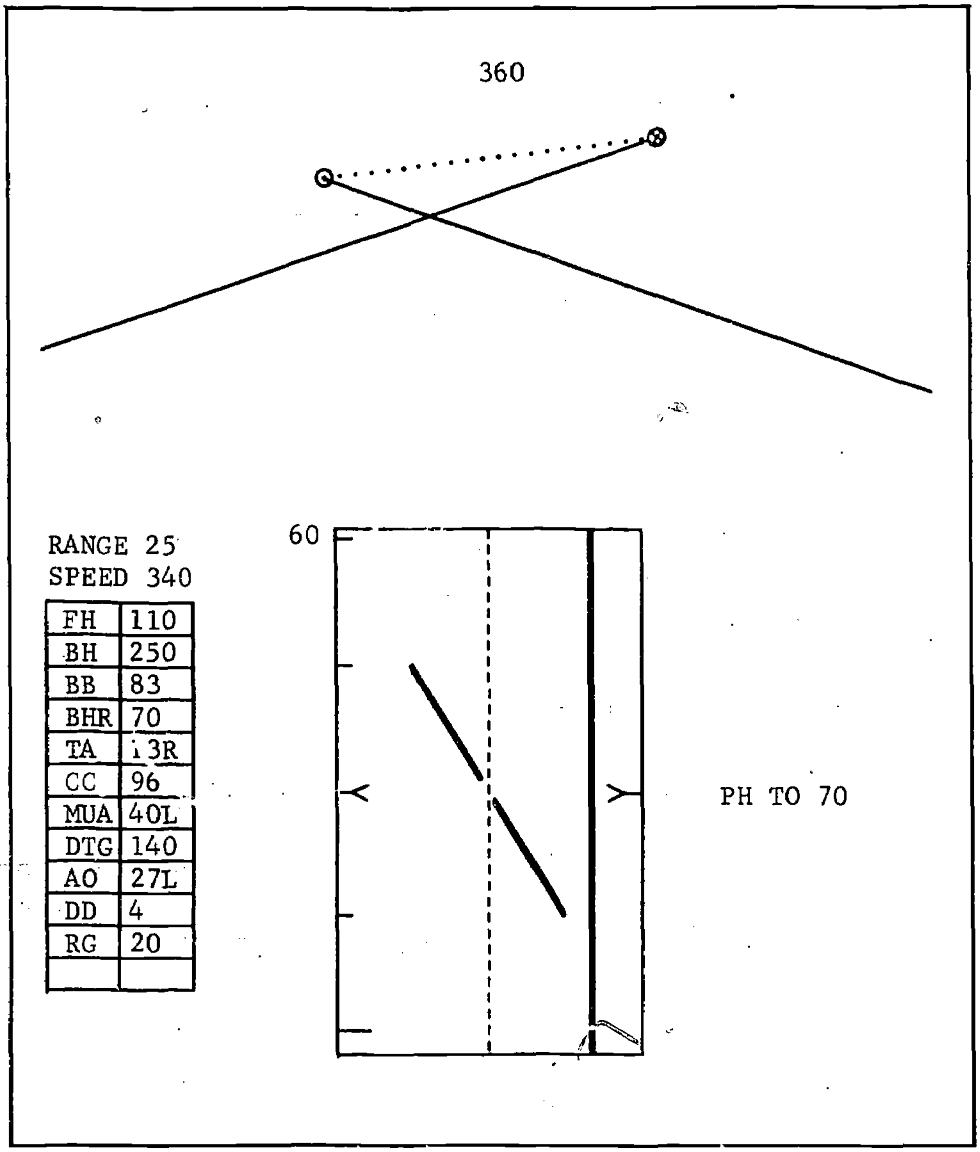

Fig. 2. Free-fly mode display: Intercept triangle and "Tote-board" values continually displayed and updated to reflect relative motion. B-scan reflects relative positions of Fighter and Bogey. Aircraft in hard-turn-to-port.

to find out what is going on. For example, we recorded values for 36 variables in the field trial of the RIO trainer. In this regard, mini-computers pose a special set of problems for data-collection, since they are likely to be severely core-limited, requiring frequent dumping to an external medium. We are using punched paper tape to record as the student responds. This tape then is reloaded into the smart terminal with a statistical analysis program which provides sums and sums-of-squares. These intermediate values then may be used in subsequent statistical analyses. For the initial trials of graphics TASKTEACH, we will use magnetic tape as the recording medium.

For the CNV project, the shift of the DC baseline for EEG will be sampled every 25 milliseconds, and run through an AD converter. The EEG frequencies riding on the baseline shift will be mathematically "filtered" by a running average technique applied to successive samples. The "smoothed" data will be stored in core. These data then could be used to draw a real-time, graphic image of the CNV on the IMLAC CRT for the student to see, and for subsequent analyses in which different parameters of the envelope are related to other variables. The student might be taught to control selected parameters of this potential shift, using the graphic feedback, if useful relationships with other variables were found.

Earlier studies of CNV have used conventional computer averaging across <u>many successive trials</u> to produce an average of all the potentials recorded during these trials; what we propose here is averaging within a <u>single trial</u> and using each evoked potential. If successful, this will be a distinctly more sensitive procedure, and is the basis for our current optimism.

4. Adaptive Controller

Our programs are adaptive, in rather unsophisticated ways, to individual differences among students. These features will be discussed briefly. The way we generate the instructional sequence from very simple lists also will be discussed, because the adaptive features are inherent in the generative logic.

We put the logic for generating the interaction with the student in the computer program rather than in the data module. Furthermore, the logic in the TASKTEACH programs is designed to accept data bases describing many different kinds of equipment and many different kinds of tasks. We have developed data bases for a transceiver and for radar repeater. The same TASKTEACH program will be used to give students practice in troubleshooting either of these devices. Changing from one course to the other will be a matter of loading a tape casette.

You may have some interest in the forms of the data modules we used and in the types of interactions we generated from them with the alphanumeric TASKTEACH programs. The troubleshooting program operated on lists of things shown below.

(1) FRONT-PANEL TESTS

(2) FRONT-PANEL SYMPTOMS

(3) FRONT-PANEL CONTROLS AND THEIR POSITIONS

(4) FAULT AREAS

(5) RELATIONSHIPS AMONG FAULT AREAS, TESTS, CONTROL POSITIONS, AND SYMPTOMS

(6) TEST SUFFICIENCY CONDITIONS

(7) PRACTICE PROBLEMS

(8) TEST PROBLEMS

Using these lists, and the student's inputs, the program created an environment in which the student could practice troubleshooting. The program would let a student proceed at his own rate and determine his own solution paths, intervening only to inform him of errors in making tests and in interpreting symptoms. The student was provided with the options listed below.

STUDENT OPTIONS FOR PRACTICING TROUBLESHOOTING:

- ANY FRONT-PANEL TESTS IN ANY ORDER
- ANY FRONT-PANEL CONTROL(S) SETTING(S) IN ANY ORDER
- COMPONENT REPLACEMENT ANY TIME
- GUIDED DRILL IN MAKING FRONT-PANEL TESTS
- GUIDED DRILL IN RELATING SYMPTOMS TO KNOWN MALFUNCTION
- TAKE A SELF-TEST ANY TIME
- TAKE FINAL TEST ANY TIME
- ON-DEMAND ADVICE FROM THE PROGRAM

The program provided the student with what we call on-demand advice during his practice. He could obtain this advice by using the functions shown below.

ON-DEMAND ADVICE DURING TROUBLESHOOTING PRACTICE:

<u>NEXT</u>: TELLS THE STUDENT A GOOD NEXT TEST TO MAKE, BASED ON PREVIOUS TESTS HE HAS MADE.

<u>PROG</u>: TELLS THE STUDENT HOW MANY POSSIBILITIES HE HAS ALREADY ELIMINATED, OR HOW MANY REMAIN.

<u>REV</u> : COMMENTS ON THE VALIDITY OF A LIST OF POSSIBILITIES THE STUDENT PRESENTS TO THE PROGRAM.

<u>SET</u> : REMINDS THE STUDENT OF THE LAST CHANGES HE MADE IN FRONT-PANEL CONTROL POSITIONS.

<u>OVER</u>: COMMENTS ON ANY SELECTED PART OF THE STUDENT'S WORK, AT THE END OF THE PROBLEM.

Two examples of this on-demand advice are REV and NEXT. The REV function allowed the student to ask the program's advice about possible fault areas. This is illustrated as follows.

REV Use this when troubleshooting to ask the program to REView a list of possibilities for malfunctions which you wish to know about. The program will tell you the following about each possibility you listed:

(1) It is a good possibility--at this point it could be the malfunction.

(2) You obtained enough information in a preceding step (Step No.) to have eliminated this possibility.

The program also will tell you the following:

(1) You are not suspecting the actual malfunction. The program will list possibilities you overlooked.

(2) The actual malfunction is among those you suspect.

The following is an example of the use of REV. Observe that you must identify each possibility you list with M followed by a number, and that this must be followed by a comma to separate it from the next possibility.

EXAMPLE:

ACTION(S);? REV

ENTER THE MALFUNCTION(S) WHICH YOU SUSPECT? M35,M36,M45

S16A-9 OPEN CONTACT COULDN'T BE THE MALFUNCTION
CHECK YOUR STEP NUMBER 2

A6R38 OPEN IS A GOOD POSSIBILITY

A6R93 OPEN; OR C12 SHORTED COULDN'T BE THE MALFUNCTION
CHECK YOUR STEP NUMBER 2

THE ACTUAL MALFUNCTION IS AMONG THOSE WHICH YOU SUSPECTED

What we called "look ahead advice" was provided by the NEXT function, as illustrated on the following page. To generate this advice, the program had to start with where the student was in the problem and look at the effects, in terms of reducing the remaining possibilities, of making different tests next. It then selected the most powerful test (in the long run) it found, and suggested it to the student. The student was free to take this advice or not, as he chose.

NEXT Use this command if you want advice about the next test to make during troubleshooting. The program will tell you an efficient next test to make, and will give you a list of front-panel controls that are important for making this test. It will not, however, tell you the positions to which these switches must be set.

<u>EXAMPLE</u>:

```
ACTION(S):? NEXT

IF YOU CHECK THE RANGE RING ELEMENT IN THE
APPROPRIATE SWITCH CONFIGURATION(S), YOU
WILL OBTAIN USEFUL INFORMATION

DO YOU WANT A LIST OF SWITCHES THAT ARE
IMPORTANT? YES

THE FOLLOWING SWITCHES ARE IMPORTANT FOR THIS
INDICATOR

RANGE RINGS/MILES SWITCH S16
RADAR SELECTOR SWITCH S13
SWEEP-BOTH-CURSOR SELECTOR A7S1
NORM/ALIGN SWITCH S2

ACTION(S):? S13-2
8. RADAR SELECTOR SWITCH S13 NOW SET TO ELSCAN

ACTION(S):? I4
9. RANGE RING ELEMENT IS NORMAL
```

The procedural program in TASKTEACH functioned in an analogous fashion. However, this program was concerned with teaching students how to operate equipment, so it used lists describing task structures instead of equipment. These lists were composed of statements describing goals and actions and of alphanumeric codes describing relationships among them. In this case, several clustering operators were required to describe these relationships, as shown in the following list:

GOAL-ACTION CLUSTERING OPERATORS:

SEQ :	DO ALL IN PRESCRIBED ORDER
ANY :	DO ANY ONE
ALL :	DO ALL IN ANY ORDER
ANYK:	DO K OUT OF N IN ANY ORDER
REP :	REPEAT IT
REPU:	REPEAT UNTIL DESIRED RESULT OCCURS
IFIN:	IF A PRIOR INTERNAL CONDITION IS TRUE, DO IT
IFIC:	IF AN INITIAL CONDITION IS TRUE, DO IT
UNDO:	REPEAT ACTIONS IN REVERSE ORDER

The procedural program operated on these lists to create a practice environment for the student. In this case the student had the options shown below:

STUDENT OPTIONS FOR PRACTICING PROCEDURAL TASKS:

SELECT ANY PART OF TASK STRUCTURE TO LEARN

SELECT ANY OF THREE MODES

- INSTRUCT MODE
- PRACTICE MODE
- TEST MODE

TAKE FINAL TEST ANY TIME

ON-DEMAND ADVICE FROM THE PROGRAM

The on-demand advice that was available to the student through program functions is listed on the following page.

ON-DEMAND ADVICE DURING PRACTICE OF PROCEDURAL TASKS:

<u>NEXT</u>: TELLS THE STUDENT THE NEXT GOAL TO WORK ON, OR NEXT ACTION TO PERFORM.

<u>M</u> : GIVES THE STUDENT "TO DIG DEEPER" INFORMATION ABOUT A GOAL OR AN ACTION.

<u>D</u> : LISTS FOR THE STUDENT ALL THE ACTIONS REQUIRED TO ACCOMPLISH A SELECTED GOAL.

<u>HELP</u>: TELLS THE STUDENT WHERE HE IS IN THE TASK STRUCTURE AND SHOWS HIM A MAP OF THE ENTIRE STRUCTURE.

Another project to be discussed under this Adaptive Controller heading is the Kirchhoff's laws project. At the present time, this is a very small project using part-time personnel.

We use the term, instructional bandwidth, to suggest that there is a range between some hypothetical, fully-instructed baseline, and the top level, at which the expert can function more or less autonomously with no explanation or instruction. You would simply tell him to go and do it! The problem we are concerned with is how to handle the in-between. How do you find out as quickly and as simply as possible about a student's cognitive structure, i.e., his skills and knowledge appropriate to the learning task, and how do you use this information to adjust the instructional sequence? Obviously, initial sampling is required to adjust entering levels; and subsequent, intermittent, sampling is required to adjust to the individual's pattern of progress.

We would like to find a way to provide each entering student with an instructional sequence tailored to his own pattern of knowledge and skills, and with practice that is sensitive to his own patterns of achievement of the subskills involved.

On the assumption that learning to perform the kinds of tasks we are concerned with involves a good bit of self-programming, we would expect the amount of detailed instruction required to tell the student how to do something should decrease as learning progresses. We would expect that each student might be capable of starting somewhere above, or at least partially above, a fully-instructed baseline. But where? Perhaps a situation could be so arranged that the program could decompose the top level of instruction into more detailed, simpler terms. In the task of applying Kirchhoff's voltage and current laws to a simple network, some students might know Ohm's law and some might not, some might know how to solve the algebraic equations required and some might not. Perhaps some would not be acquainted with the concepts of voltage, current, and resistance, etc.

Some work is underway to investigate the applicability of mathematical programming techniques to scheduling the instructional sequence for this type of content, where the student learns to solve problems composed of several subskills. We are deeply indebted to Atkinson and his associates for their pioneering work in applying these techniques in CAI (Atkinson and Paulson, 1972; Chant and Atkinson, 1973). We are attempting to develop a model and to work out the algorithms for scheduling various types of external mediators, in addition to scheduling practice. The objectives are to investigate the feasibility of applying mathematical programming in this context, and, if it is feasible to develop a procedure with some generality. We have no particular interest in just teaching Kirchhoff's laws.

5. Instructional Sequence

We are strongly interested in the possibility that induced mental imagery will make the austere abstractions of electronics less formidable to learn. Since to do this, we have to use external mediators, our plans will be discussed in relation to this part of the instructional sequence.

We are using computer graphics to simulate features of the environment, such as front panels. We also would like to use them to illustrate concepts and relationships. The experimental literature on mental imagery and paired-associates learning indicates that the student should generate his own imagery. Bower (1972b) suggested that mental imagery provides a relational context in which paired-associates are embedded. (No one supposes that there is a screen in the CNS, upon which images corresponding to those in the external world appear.) We subscribe to the idea that the student ought to generate his own imagery (it is his own cognitive structure!) but we believe that he should be given assistance in doing so where the subject of learning is a complicated device, a difficult abstract concept, a complicated serial task, or confusing spatial relationships. In these cases, we propose to provide visual analogs with computer graphics and to require the student to operate on those visual analogs in ways that are designed to require him to build up his own mental representations from the starting images we have provided. We do not recall that anyone has approached mental imagery in quite this way. We do recognize that the validity of the visual analogs and the nature of the operations required of the student will be absolutely crucial. This cannot be a matter simply of showing students pictures, instructional television notwithstanding. Furthermore, there is evidence in the literature that merely instructing students to "turn on their imagers" sometimes is successful and sometimes is not (e.g., Anderson and Kulhavy, 1972), which suggests that we must devise better external mediators than simple verbal instructions.

Graphics TASKTEACH. We have under development a method for presenting interactive block diagrams with computer graphics. The student will be able to learn the functional organization of a device by interacting with these diagrams. The assumption is that these graphics will provide the "starting imagery" from which the student can develop through controlled interactions his own mental representations of these structures. The student will be required to explore the functional relations among elements in these diagrams by using a light pen to change control settings. These actions will change the structure of the diagrams to highlight blocks of circuitry in the new signal or power flow paths created by these actions. A "floating indicator" will be provided, which will be analogous to portable test equipment. The student will be able to "attach" the floating indicator at the input or output of any block in the diagram and obtain information about the state of that block.

Visual Electronics for Plato IV. The basic idea here again is that abstract concepts, rules, and relationships can be illustrated by animated graphics, and that the student can develop his own internal imagery from these external visual analogs by interacting with them. To reduce the explanatory verbalization as much as possible, the student will have a light pen, or the equivalent, and will operate on images on the screen by pointing at appropriate parts of them. There might be several types of animated graphics:

1. To illustrate primitive concepts of electron flow, voltage, resistance, and current.

2. To illustrate how resistors, capacitors, inductors, diodes, transistors work in terms of primitive concepts.

3. To illustrate events and relationships in basic circuits, under DC and AC conditions.

4. To illustrate relationships among variables with dynamic graphs.

5. To relate simple mathematical expressions to dynamic graphs.

In keeping with our general approach to teaching performance, we would expect to start students with the visual analogs of basic circuits. The students could, by appropriate operations, see currents flowing in their different paths, and values of voltages and currents changing in response to an input signal. The student would be able to manipulate the input signal to note effects on events in the circuit, as well as to change the values of certain components in the circuit and to observe their effects. He would be learning, at a visual perceptual level, how a circuit works; something goes in one end, certain events occur all over the network, something comes out at the other end, without getting bogged down in lengthy verbal descriptions of circuit functioning, or being intimidated by the austere symbolism of mathematics.

Non-verbal visual pattern recognition has interesting properties. Studies of visual pattern recognition suggest astonishing memory for these patterns (Haber, 1970). Possibly this is a survival feature built into the CNS; recognizing that <u>that</u> is the bush where the lion likes to hide, or finding your way to the waterhole, depended on it.

Sperling's (1967) classical studies indicated that visual short-term memory may hold more than can be recalled by using the process of (serial) rehearsal. Perhaps, the visual pattern recognition capabilities of the CNS could provide a more direct way to represent abstract relationships to the student, particularly if these representations can be interactive so that the student can "see for himself" how things work.

RIO. A somewhat different use of computer graphics to stimulate mental imagery is exemplified in the RIO project. We are providing a continually updated picture of bogey and fighter positions and headings--a true geographic plot--just above the B-scan representation, which is of relative motion (see Figure 2, page 24). The B-scan could be thought of as a window attached to the fighter's nose, through which the RIO must perceive the world. The student can compare the true with the relative picture and in this way hopefully achieve a better understanding of the dynamic geometry involved, and learn how to interpret the otherwise confusing display on the B-scan. Students and instructors in the RIO school believe this is a valuable feature in helping the student to visualize what is going on in an intercept problem.

We are designing a study to test this feature this Summer. We will run two versions of the program, one with and one without the triangle, and collect comparative data from two groups working the same problems, and from the transfer test in which both groups receive a new set of problems in random sequences.

6. Statistical Analysis

Summary statistics from the RIO program indicate that practice under at least an approximation of proper conditions does result in improvement in proficiency. We were trying to increase fluency in performing mental arithmetic, as measured by decreasing latency, and increase proficiency in putting the interceptor into position to fire a Sidewinder, as indicated by decrease in the amount of turning to get into position and increase in probability of hit score. In ten hours of practice mean values of response latencies for 29 students decreased by an average factor of 2.5, variability in latencies decreased by a factor of 4.9 (Table 3), mean number of turns per intercept decreased from 4.7 to 3.4 (Table 4), and mean hit probabilities increased from .804 to a maximum of .943 (Table 5).

Table 3

Latencies* (in seconds) from First and Last
Blocks of Trials
N = 29

LATENCY VARIABLE		FIRST BLOCK	LAST BLOCK	FIRST / LAST
To Complete Tote-board	M	67.9	25.8	2.6
	SD	46.4	10.0	4.6
To Collision Course (CC) Input	M	35.7	13.3	2.7
	SD	55.9	5.7	9.8
CC To Fire	M	238.1	101.7	2.3
	SD	83.5	25.0	3.3
Per Triangle Variable	M	11.5	4.8	2.4
	SD	12.4	3.2	3.9
Bogey Heading Reciprocal	M	8.3	3.8	2.2
	SD	8.0	2.2	3.6
Target Aspect	M	12.6	4.1	3.1
	SD	16.5	2.5	6.6
Collision Course	M	14.8	5.4	2.7
	SD	19.4	3.4	5.7
Make-Up Angle	M	13.9	4.8	2.9
	SD	15.7	3.3	4.8
Degrees-To-Go	M	6.9	3.1	2.2
	SD	8.2	2.3	3.6
Angle Off	M	11.4	4.6	2.4
	SD	12.7	3.2	3.9
			OVERALL: MEAN	2.5
			SD	4.9

*Per intercept problem

Table 4

Mean Number of Turns Per Intercept Problem
N = 29

	STATIC PHASE	220	260	300	340	380	420	460	500	ROWS
				DYNAMIC LEVELS:			SPEED			
MEAN	0.	5.3	4.5	4.7	3.9	3.7	3.9	4.0	3.7	4.3
STD DEV	0.	2.7	2.0	2.2	1.3	1.4	1.4	1.4	1.3	1.9
MEAN	0.	4.7	4.2	3.5	3.9	3.7	3.8	3.6	3.4	3.9
STD DEV	0.	2.6	1.9	1.1	1.7	1.7	1.1	1.3	1.2	1.8
MEAN	0.	4.1	3.5	3.7	3.7	3.6	3.4	3.3	3.1	3.5
STD DEV	0.	1.8	1.4	1.9	1.6	1.1	1.2	1.1	1.1	1.5
MEAN	0.	4.7	3.7	3.6	3.4	3.6	3.3	3.2	3.3	3.7
STD DEV	0.	2.5	1.5	1.4	1.0	1.3	1.1	1.1	1.3	1.7
COLS	0.	4.7	4.0	3.9	3.7	3.6	3.6	3.5	3.4	3.8
	0.	2.4	1.7	1.8	1.4	1.4	1.2	1.2	1.2	1.8

Table 5

Mean Hit Probability (x 100) Per Intercept Problem
N = 29

	STATIC PHASE	220	260	300	340	380	420	460	500	ROWS
				DYNAMIC LEVELS:			SPEED			
MEAN	0.	77.6	78.6	88.5	91.5	93.8	89.7	93.0	90.8	87.1
STD DEV	0.	39.3	39.3	30.6	25.6	21.0	30.1	24.1	27.4	31.7
MEAN	0.	78.7	91.9	87.8	97.5	98.3	90.2	83.6	81.5	85.1
STD DEV	0.	38.4	24.9	31.0	14.0	5.3	27.0	35.7	37.6	33.7
MEAN	0.	84.7	95.4	95.0	96.0	94.4	89.3	89.8	88.8	90.1
STD DEV	0.	33.6	18.5	19.8	18.3	22.1	27.8	28.4	29.5	27.7
MEAN	0.	80.0	86.3	90.1	92.7	89.3	96.3	89.2	89.5	87.8
STD DEV	0.	35.6	31.9	27.7	24.5	28.6	14.0	30.2	27.6	29.6
COLS	0.	80.4	88.4	90.7	94.3	93.8	91.3	89.3	87.9	87.7
	0.	36.8	29.8	27.1	21.3	21.5	25.7	29.3	30.6	30.6

SECTION IV. SUMMARY

I have tried to describe one way of looking at CAI as an instructional system, and to highlight in these terms those aspects of our projects that illustrate particular approaches in parts of this system. It is our hope that this discussion will be useful to suggest elements of the instructional system deserving continued research attention, and to provide the outlines of a CAI test-bed which might be developed to serve as a method for testing out various concepts and procedures, so that the many problems remaining to be solved in each of the constituent parts of the test-bed may be approached in a more systematic fashion.

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