DOCUMENT RESUME

ED 097 873 IR 001 233

AUTHOR Rigney, Joseph W.; Lutz, Kathy A.
TITLE CAI and Imagery: Interactive Computer Graphics for Teaching About Invisible Process. Technical Report No. 74.
INSTITUTION University of Southern California, Los Angeles. Behavioral Technology Labs.
SPONS AGENCY Advanced Research Projects Agency (DOD), Washington, D.C.; Office of Naval Research, Washington, D.C. Personnel and Training Research Programs Office.
REPORT NO USC-BTL-TR-74
PUB DATE Oct 74
NOTE 60p.

EDRS PRICE MF-$0.75 HC-$3.15 PLUS POSTAGE
DESCRIPTORS Analog Computers; *Computer Assisted Instruction; *Computer Graphics; *Data Analysis; Digital Computers; *Information Storage; Learning; Literature Reviews; Memory
IDENTIFIERS *PLATO IV

ABSTRACT

In preparation for a study of using interactive computer graphics for training, some current theorizing about internal and external, digital and analog representational systems are reviewed. The possibility is considered that there are two, overlapping, internal, analog representational systems, one for organismic states and the other for external world dimensionalities and objects. The concept of a working memory, or "mind's eye", and its importance in learning is described along with some conceptions of how this might serve in the generation of mental imagery from digital propositional information stored in long-term memory. Some research bearing on the use of external imagery for facilitating learning and improving retention is also reviewed. Illustrations of how the plasma panel display and the touch panel are used for interactive, animated computer graphics to illustrate invisible processes are presented. (Author)

DEPARTMENT OF PSYCHOLOGY

UNIVERSITY OF SOUTHERN CALIFORNIA

Technical Report No. 74

CAI AND IMAGERY: INTERACTIVE COMPUTER GRAPHICS FOR TEACHING ABOUT INVISIBLE PROCESSES

October 1974

Joseph W. Rigney
Kathy A. Lutz

Sponsored by

Personnel and Training Research Programs
Psychological Sciences Division
Office of Naval Research

and

Advanced Research Projects Agency
Under Contract No. N00014-67-A-0269-0025

ARPA TECHNICAL REPORT

31 October 1974

1.	ARPA Order Number	:	2284/8-30-72
2.	ONR NR Number	:	NR 154-326
3.	Program Code Number	:	1B729
4.	Name of Contractor	:	University of Southern California
5.	Effective Date of Contract	:	74 January 1
6.	Contract Expiration Date	:	74 December 31
7.	Amount of Contract	:	$200,000.00
8.	Contract Number	:	N00014-67-A-0269-0025
9.	Principal Investigator	:	J. W. Rigney (213) 746-2127
10.	Scientific Officer	:	Marshall Farr
11.	Short Title	:	Learning Strategies

This Research Was Supported

by

The Advanced Research Projects Agency

and by

The Office of Naval Research

And Was Monitored by

The Office of Naval Research

BEST COPY AVAILABLE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: Technical Report 74	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): CAI AND IMAGERY: INTERACTIVE COMPUTER GRAPHICS FOR TEACHING ABOUT INVISIBLE PROCESSES		5. TYPE OF REPORT & PERIOD COVERED: Semi-annual Technical Report 1 Jul. - 31 Dec. 74
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Joseph W. Rigney, Kathy A. Lutz		8. CONTRACT OR GRANT NUMBER(s): N00014-67-A-0269-0025
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Behavioral Technology Laboratories, University of Southern California, Los Angeles, California 90007		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 61153N NR 154-326 RR 042-06 RR 042-06-1
11. CONTROLLING OFFICE NAME AND ADDRESS: Personnel and Training Research Programs, Office of Naval Research (Code 458), Arlington, VA 22217		12. REPORT DATE: October 1974
		13. NUMBER OF PAGES: 46
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report): Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

imagery, CAI, computer graphics, mediating processes, cognitive psychology, memory

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Some current theorizing about internal and external, digital and analogue representational systems was reviewed. The possibility that there are two, overlapping internal analogue representational systems, one for organismic states and the other for external world dimensionalities and objects was considered. The concept of a working memory, or "mind's eye", and its importance in learning was described. Some conceptions of how this might serve in the generation of mental imagery from digital propositional

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-014-6601

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

#20.

information stored in long-term memory were noted.

Some research bearing on the use of external imagery for facilitating learning and improving retention was reviewed. A project to use the Plato IV system for automatically running subjects and collecting and analyzing data anywhere in the Plato IV network was described. Illustrations of how the plasma panel display and the touch panel is used for interactive, animated computer graphics to illustrate invisible processes were presented. Description of the experimental design in detail, and results of the first study will be presented in a subsequent report.

ACKNOWLEDGMENTS

The research discussed in this report was monitored by Dr. Marshall Farr and Dr. Joseph Young, Personnel and Training Research Programs, Office of Naval Research, and by Thomas O'Sullivan, Program Manager, Human Resources Research, Advanced Research Projects Agency.

Their support and encouragement is gratefully acknowledged.

ABSTRACT

Some current theorizing about internal and external, digital and analogue representational systems was reviewed. The possibility that there are two, overlapping internal analogue representational systems, one for organismic states and the other for external world dimensionalities and objects was considered. The concept of a working memory, or "mind's eye", and its importance in learning was described. Some conceptions of how this might serve in the generation of mental imagery from digital propositional information stored in long-term memory were noted.

Some research bearing on the use of external imagery for facilitating learning and improving retention was reviewed. A project to use the Plato IV system for automatically running subjects and collecting and analyzing data anywhere in the Plato IV network was described. Illustrations of how the plasma panel display and the touch panel is used for interactive, animated computer graphics to illustrate invisible processes were presented. Description of the experimental design in detail, and results of the first study will be presented in a subsequent report.

TABLE OF CONTENTS

LIST OF FIGURES

I. REPRESENTATIONAL SYSTEMS

Attneave (1974) reminded us that the world as we know it is an internal representation created by our brains, and that language is an elaborate external representational system for communicating among brains. He divided all representational systems, both internal and external, into two categories: analogue processes and digital processes. Education and training involve manipulating external representational systems to influence internal representational systems in ways that will support predictable behavior in prescribed situations. In Attneave's terms, this would be behavior that demonstrates that the student knows how to change situation S_1 into situation S_2 by doing R: S_1, R→S_2.

With the growing availability of interactive graphics terminals for use in computer-aided instruction, the differential uses of external analogue (graphic) or digital (alphanumeric) representational systems in educational and training processes will require better definition. Analogue representations that can interact with the student are unique to these terminals. With a light pen or a touch panel, the student can respond to changes in elements of a figure or cause elements in a figure to be changed. This is quite a different capability than merely changing the sequence of slides, film strips, or TV frames. The prescriptions for mixing verbal and graphic representations in these media, though useful, are inadequate guides here.

The relative effectiveness of alphanumeric versus graphic displays in communicating efficiently, facilitating learning, and promoting long-term retention should receive more investigation.

Current Conceptions of Internal Representational Systems

This discussion can be no more than a brief characterization of major areas, leaving aside any attempt to review the extensive literature concerning the organization of memory and cognitive processes. The intent is to summarize and to highlight a few issues of importance to the current study.

Theorists currently hold that information in long-term memory is organized in a relational network. Several differing specifications of possible organizations can be found in Collins and Quillian (1969), Rummehart, Lindsay, and Norman (1972), Tulving and Donaldson (1972), and Anderson and Bower (1973). Storage of information in long-term memory modifies or adds to the relational network. Retrieval from long-term store involves searches, either in parallel or in serial fashion, among "pathways" connecting nodes in the relational system.

All this is highly speculative; in intelligent adult humans, little is known about storage and retrieval processes and relational networks, which must be overwhelmingly vast and complicated. Futhermore, some theorists seem to be suggesting that this is dynamic storage and that operations on the relational network may be going on all the time at preconscious levels (Singer, 1974). Other theorists suggest semantic organization changes dynamically according to the context (Anderson and Ortony, 1973).

Perhaps it is partly a Chomskian influence, that theorizing about the structure of long-term memory has been done mostly in terms of semantic characteristics of language. The models of long-term memory described in the above references are essentially "language understanders." In humans, this must be a major function of long-term memory. Understanding language seems to depend upon comprehending first the context in which the language occurs, then the instructions inherent in the syntax of the sentences, which function to delimit the search patterns to be used; then directed retrieval from (or stimulation of?) appropriate parts of the relational network, and formulation of some option for responding.

Language plays a pre-eminent role as an external representational system, being particularly suited to communicating the concepts and other abstractions that are the basis for human societies. If this is so, then what do the external analogue representational systems contribute? Do the functions of the two kinds of systems overlap in long-term memory?

Some theorists (e.g., Anderson and Bower (1973) and Pylyshyn (1973)) maintain that the structure of long-term memory is propositional and that it can be used to generate either images or words and can accept inputs of either images or words with more or less equal facility. These theorists described mechanisms whereby such translations could be mediated; they contend that perceptual descriptions are stored as inferential conclusions and that "the only difference between the internal representation for a linguistic input and a memory image is detail of information" (Anderson and Bower, 1973, p. 460). Leeuwenberg (1971) developed a descriptive language for representing tridimensional visual forms that is reversible. The descriptions can be used as instructions for regenerating the forms.

Experimental support for the notion that long-term memory is propositional includes a study showing that subjects store and remember only the salient features and perceptual interpretations of scenes rather than the raw, detailed representations of sensory information. Wiseman and Neisser (1971) found that complex visual pictures (unstructured blobs of ink) are remembered only if the subject interprets the picture--the subject "sees" something in the picture. If the picture was not interpreted during a study period, the subject will not recognize the raw picture during a test trial. The findings of Chase and Clark (1972) also favor the propositional hypothesis. Their studies on reaction time to verify sentences against pictures indicate that the sentence and picture must be represented in a common format for comparison and that the format must be propositional in nature. Another basis of support for the propositional hypothesis of memory may be the demonstrated effectiveness of "interactive" imagery in paired-associate learning. A number of studies have shown that a mediating image is facilitative if it involves an interaction between the to-be-associated items (see Table 1 in the Appendix). One study defined several types of interactive imagery and found that the most facilitative type is that which achieves maximum figural unity of the two elements (Lippman and Shanahan, 1973). When the critical element of interaction is omitted and items are shown in a non-interactive and separate imaginal space, the benefit of imagery as an associative aid is greatly reduced or lost altogether (Bower, 1970; Bernback and Stalonas, 1973; Neisser and Kerr, 1973). According to the propositional theory, the interactive image provides a single proposition directly linking the two items to be associated whereas a non-interactive image affords no such direct link, thus making recall more difficult.

Still, it is clear that external digital and analogue representational systems do have many differing representational functions. Also, analogue representation of internal states and of the dimensionality of the external world would seem to be a fundamental function of parts of the nervous system. Attneave (1974) made this requirement clear, when he spoke of "a tridimensional analog model of physical space," and when he cited evidence from the experimental literature: Shepard and Metzler's (1971) and Cooper and Shepard's (1973) studies of reaction times for rotating mental images; Stevens, Mack and Stevens' (1960) finding that handgrip force "tracks" changes in intensities in sensory modalities; and Corbin's (1942) and Attneave and Block's studies of the relationship between physical separation of two lights and their apparent movement.

Also, the physiological psychologists commonly speak of right and left hemisphere tasks, based on evidence that at least some of the neural systems for information processing are different for analogue and for digital information processing tasks. Milner's studies of patients with brain lesions revealed that patients with lesions in the right temporal lobe showed marked deficits in visual memory compared with patients having lesions in the left, frontal, or parietal regions (1968).

These and similar studies suggest that the right hemisphere of the brain is responsible for tasks performed poorly by individuals with damage to the right brain region. But discovering the activities of the two hemispheres by comparing the disabilities due to injury of one side or the other has serious shortcomings as Nebes (1974) has noted. When comparing the performances of patients with damage to one or the other hemisphere, difficulties arise in matching the groups for size and locus of injury, age, sex, and pre-injury intelligence. Semmes (1968) points out that perhaps both hemispheres are equally proficient in performing a task, but the neural substrate involved is more focally organized in one hemisphere than in the other so that limited damage to that hemisphere will be more apt to produce a severe deficit causing that side of the brain to appear as if it were responsible for the capacity being tested.

A more powerful line of research has been conducted using subjects whose brain hemispheres have been (partially) surgically disconnected so that each hemisphere can be examined independently on the same task. Such "split-brain" patients make ideal subjects for the investigation of lateralization of brain function because it is possible to restrict a stimulus to just one hemisphere by presenting physical stimuli to just one side of the body or visual stimuli to one visual field for a duration too short to allow eye movements. Several researchers have found that subjects can correctly name words presented to the right visual field (which connects with the left hemisphere) but not words presented to the left visual field (which connects with the right hemisphere) although they can retrieve the item named with the left hand yet still not be able to verbalize its name (Gazzaniga, 1967; Sperry, 1968; Bogen, 1969; Nebes, 1974). But the right hemisphere outperforms the left in perceiving and remembering stimuli which either have no verbal labels or are too complex to specify in words. These findings add to the evidence that verbal processes are controlled by the left hemisphere while spatial-imaginal processes are controlled by the right side of the brain.

In addition to the evidence from behavioral studies, there is some physiological support for the notion that there is hemispheric specialization. Calloway and Harris (1974) developed a statistical measure of EEG coupling between cortical areas that revealed shifts between right and left hemisphere associated with shifts between graphics processing and language processing tasks.

It seems likely that there could be two interrelated analogue representational systems in the brain. These systems presumably function in real time, like an analogue computer. One would be functionally similar to a hierarchically-organized system of negative-feedback control loops and would be concerned with continually tracking and modulating internal states, from muscle tensions to drive states (Powers, 1973). The other would generate Attneave's tridimensional analogue model of physical space, which would represent the dimensionality of the external world and the organism's position in it. It would seem that this representational system also would require feedback loops for adjusting its representations. Indeed, feedback loops are found in many places in the nervous system. There also are "feedforward" loops to sensory receptors, which leads to speculations about the significance of central control over sensory systems. Here, there is a broad range of phenomena to speculate about, from adjustment of muscle-spindle tension reference signals to deGroot's master chess players who could reconstruct chess positions perfectly after looking at the board for only five seconds (deGroot, 1966), and central control over perceiving chimerical images (Nebes, 1974).

It may be that the internal analogue representational systems provide the real-time substrates of information upon which the internal digital representational system operates, perhaps by time sampling, to create abstractions that are more economically stored in propositional form in long-term memory. The digital representational system could be directed to look "inward," represented by the current outputs of one analogue system, or "outward," represented by the outputs of the other. But, it clearly is more complicated than this. The head is full of ghosts. Some of these can be called up at will as daydreams, and some appear, unbidden, to haunt our sleep. There must be a "mind's eye" where we can imagine things not present, with the internal model of the real-time, tridimensional external world not continually pre-empting the focus of attention.

This "working memory" may be where the mental imagery that is the subject of much recent research occurs. And it may be there that some kind of propositional language of the brain could use digital abstractions retrieved from long-term memory for creating analogue mental images. This appears to be what Attneave (1974) had in mind with his diagram, and his description of the diagram, reproduced below (p. 497, 1974).

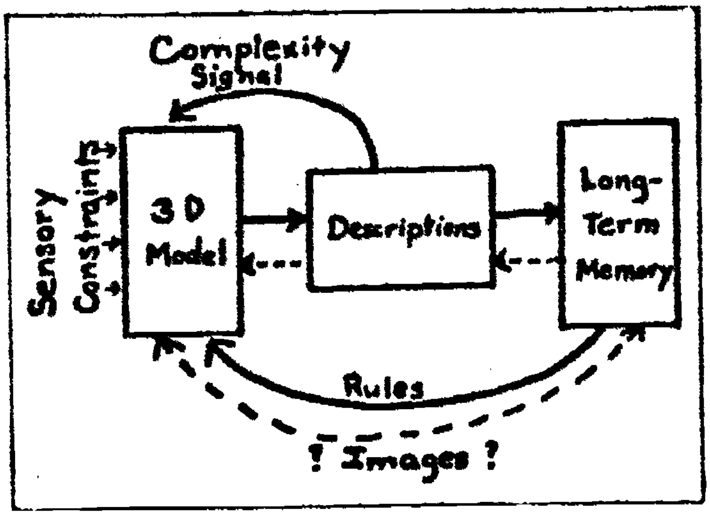

Figure 2. Outline of a system for achieving economical representations.

Figure 1. Attneave's outline of a system for achieving economical representations.

An arrangement of this sort is suggested in Figure 2. On the left, we have a tridimensional modeling medium, in which any representation consistent with the stimulus constraints might be constructed. This representation is described in the center box in Figure 2, and if it changes from one moment to the next, any resulting change in the complexity of the description is then fed back as a hot-cold signal into the tridimensional system, thereby guiding it into a simplest representation as a stable state. This is essentially a hill-climbing machine, and the analogue medium provides a smooth terrain, so to speak, for the hill climber to operate on.

An analogue stage like this also makes a great deal of sense in terms of the identification or categorizing of objects, because the descriptive machinery is taking its descriptions, or its defining features of objects, not from the flat picture on the retina but from a model of the tridimensional world. It is describing solid objects rather than plane projections of the objects.

. . . .

This brings up the business of imagination and images, and I would like to suggest that this tridimensional modeling medium can be used not merely to represent the current input but also to represent images that are taken from memory, that is, that imaginary scenes can be reconstructed in space and that the organism can then proceed to use this as a work space in which he tries out things and sees what happens. He can engage in vicarious manipulation; he can engage in vicarious locomotion. He can try out the results of particular forms of behavior before he commits himself to them in practice. This highly developed facility for handling spatial information may be used in various ways. Consider, for example, the popularity of graphs, in psychology and other sciences, in which nonspatial continua are mapped onto spatial coordinates in order to make functional relationships more easily apprehended.

Now, if images in this space can be generated from memory, the question immediately arises, In what form do they exist in memory? We might suppose, of course, that they are stored in an imagelike, or picturelike, form. Alternatively, we could suppose that they are stored as languagelike descriptions, which are reversible in the sense that images can be reconstructed from them.

(pp. 497, 498)

The capability to use this work space to try out things and to see what happens, or to judge the reasonableness of new information in terms of the relational network in long-term memory, must be of fundamental importance in learning. Suppose that this mind's eye is being used to image S_1, vicariously try out R, and to image S_2; in Attneave's terms, to implicitly try out "knowing how." If the student had not learned how to make S_2 follow S_1, he would fail on that "trial." He would have to get more information somewhere; from long-term memory, or from the external world. And, he might run back over the failed trial again in his mind's eye, trying to guess what he did wrong or what he should do next. In the early stages of learning he would not have enough propositional material stored in long-term memory to use to create valid mental imagery for S_1, or for R, or for S_2; or, perhaps his working memory could not hold enough information to allow him to operate effectively. The educational strategy is to simplify the task in some way: to break it down into small steps, to provide advance organizers, to use familiar analogies, to give rules. Eventually, after some number of trials, the student is able to do more of the task "in his head." Control is transferred from external to internal instructions and from external content mediators to internal mediators.

It would seem that, during learning, the tridimensional modeling system functions to represent the real-time external world, and to provide a working memory where mental images may be created and would be operated upon (Hayes, 1973). The external world representation would serve as a source of information, instructions, and feedback to modify mental images and operations until the student could make S_2 follow S_1 with acceptable regularity. The working memory would serve for imaging situations, for formulating operations, and for self-testing.

What happens between unsuccessful trials and successful trials, how do many subskills become integrated into higher level performance, and how do overlearned tasks become automatized? Learning phenomena like these may someday be explainable in terms of representational and control systems in the nervous system. LaBerge and Samuels (1974) described an information-processing model of intermediate stages in learning to read. According to this conception, visual information is

> . . . transformed through a series of processing stages involving visual, phonological, and episodic memory systems until it is finally comprehended in the semantic memory system. The processing which occurs at each stage is assumed to be learned and the degree of this learning is evaluated with respect to two criteria: accuracy and automaticity. At the accuracy level of performance, attention is assumed to be necessary for processing, at the automatic level it is not.
>
> (P. 293)

They assumed that humans can process many things at a time, so long as only one requires attention. During learning, different component subskills are learned one at a time to criteria of accuracy, requiring that the learning of each be in the focus of attention. As learning a subskill approaches the level of automaticity, its performance requires less attention. Somewhere near this second stage is the time to have the student start blending the subskill with a second one. Selective attention in this model is viewed as an indispensable process during learning that can "selectively activate codes at any level of the system, not only at the deeper levels of meaning but also at visual and auditory levels near the sensory surface." (LaBerge and Samuels, 1974, p. 295)

It remains somewhat unclear how subskill learning progresses to a stage of automaticity, where performance of the subskill requires little or no attention. Perhaps that elucidation will come from the area of control theory. Power's (1973) speculations about the organization of the brain as hierarchical, negative feedback loops stimulate further speculation along these lines. Higher levels of control may be reserved for coping with unfamiliar events, of which new subskills to be learned are examples. Once the system discovers the settings of reference signals to set into comparators for successively lower levels of control loops so as to null out error signals, control over performance can become automatic; i.e., the functioning of lower levels does not require continual adjustment. This would seem to require a sort of successive approximations approach to finding these settings, and to require that a higher level, perhaps the level at which attention resides, engage in performing these successive approximations up and down the hierarchy. It may be a matter of programming into the comparators a particular pattern of reference settings for that particular class of control operations demanded by the exemplar subskill. These settings might be part of what is stored in long-term memory (in the cerebellum for motor skills) and is used to reconstitute the performance of the subskill at later times.

These speculations lead to others about the differences between classical conditioning and the kinds of cognitively controlled, everyday learning characteristic of humans and other higher animals. It is tempting to think of classical conditioning as involving mostly the internal, real-time, analogue representational systems and very little of the digital; there is a "real-time" flavor about classical conditioning, with its very short time-coupling between CS and UCS; and to think of it as involving primarily lower organizational levels in the CNS. Perhaps, the elaboration of internal digital representational systems is a fairly recent evolutionary development that adds digital control not necessarily always closely coupled to real-time events, to older analogue levels.

II. RESEARCH ON ANALOGUE REPRESENTATIONAL PROCESSES IN LEARNING AND MEMORY

Here, again, the objectives are to summarize at very general levels and to consider particular issues relevant to the current study. There is, by now, a large body of literature documenting research on mental imagery. A reasonably up-to-date categorization and bibliography of this literature is included in the Appendix. The results of much of this research have been reviewed by Bower (1972), Paivio (1969), Marks (1972) and others. The findings concerning imagery are essentially that 1) image-evocation as a stimulus attribute is positively correlated with the material's learnability, 2) humans differ in mental imagery ability, with "good imagers" performing better on some tasks than poor imagers, and 3) inducement to use mental imagery as a mnemonic device aids recall.

Image-evocation as a stimulus attribute refers to the degree of concreteness of the stimulus materials; it ranges from concrete words, with high imagery value, to abstract words at the low end of the scale. The studies listed in Table 1 of the Appendix offer support that there is learnability-ordering from abstract words to concrete words. However, recent research by Morris and Reid (1974) questions the assumption of Paivio and others that differences between high I and low I words are due to the differential arousal of imagery. Rather, Morris and Reid conclude from their experiment that better recognition of high I words than low I words is caused by "greater semantic similarity and perhaps associative relatedness among low I than among high I words."

The superiority of visual memory to linguistic memory has been well demonstrated. Loftus (1972) reviewed a number of such studies. Some concluded that long-term recognition memory for pictures is remarkably good (Shepard, 1967; Nickerson, 1964; Haber, 1970). In a later study, Erdelyi and Becker (1974) found hypermnesia for pictures, but not for words, on multiple recall trials, for most of their subjects. A few of their subjects did obtain net recoveries of word items over trials. These S's, it was found during post-experimental interviews, had tried to "visualize" or form "mental images" of word items during input and retrieval phases. The majority of S's, on the other hand, had tried to form conceptual clusters, (semantic networks) of the items based on meaningful categories.

Loftus concluded from his review of the memorability literature that recognition memory for pictures may be far from perfect under some circumstances. For example, Potter and Levy (1969) found that recognition accuracy ranged from 15% for exposure times (study times) of 125 msec. to over 90% for 2 sec.

Loftus attempted, in a series of studies, to specify some of the major variables affecting memory for pictures in terms of how these variables regulate the encoding processes carried out by a person at the time he originally views the picture. Loftus found that number of fixations (NF) while a picture is being viewed is a strong predictor of subsequent accuracy of recognition performance. Furthermore, number of fixations during viewing modulated the effects of other variables; e.g., differential pay-off values of paired pictures, and amount of viewing time. Loftus also found that requiring the subjects to count backward while viewing a picture reduced the fixation rate, and resulted in a recognition performance decrement that was greater than would have been predicted from NF alone.

Number of fixations when viewing a picture seems to be analogous to number of rehearsals for verbal learning. This suggests that active processing of a picture improves recognition memory for the picture, and that the reason for processing, e.g., high payoff value, will in fact influence the amount of processing (NF) that is done.

Results of Rock, Halper, and Clayton's (1972) studies in perception and recognition of complex figures suggest a similar conclusion. They found that S's tended not to remember nuances of complex figures seen only once, but did later recognize the global shapes of these figures. Varying exposure times from 2 sec. to repeated exposures did not change this result: "Neither prolonged nor repeated exposure to the complex figure alters the fact that inner configuration fails to establish a memory trace adequate enough to mediate recognition in a test which occurs only seconds after the exposure" (p. 663). It is likely that, in the tasks given the S's, there was no reason to process details of these nonsense figures.

These studies suggest that merely showing students graphic displays would not be very effective. Their attention must be directed to those features that are supposed to convey information about the subject-matter, and there must be reasons for processing this information.

Experimental manipulations which caused the subject to create his own contextual mental imagery in which to embed the to-be-remembered items have been very successful. (See Table 1 in the Appendix)

Bower (1972) demonstrated the power of student-generated mental imagery for recall in verbal learning laboratory tasks. Raugh and Atkinson (1974) confirmed this effect for vocabulary learning in several studies that bridged between the verbal-learning laboratory and the computer-aided instruction environments. In a sense, these studies may have been concerned with getting students to supply a specific relational network for some isolated nodes, words, or nonsense syllables.

The problem for using this method in teaching technical subject-matter is that the material to be taught has its own, formal relational structure, and that remembering these relations often is more important than remembering the nodes in the network. The students need somehow to incorporate the formal relational structure into their own semantic networks. This may require that they generate mental imagery about these formal relations. Often, such relations are expressed as highly abstract mathematical formulas or equations, or in almost equally abstract circuit diagrams. Perhaps "seed imagery," in the form of external visual analogies, could be provided to the student to assist him in generating appropriate mental imagery. On the other hand, perhaps verbal description, if rich or concrete enough, could evoke imagery in each student that would serve to structure additional self-generated mental imagery. It may be that abstract concepts, once described in understandable verbal terms, become tied into the student's existing semantic network in long-term memory and are remembered because of these ties, without the necessity for external visual analogies.

Inducing imagery, and other procedures which require the student to really process the material, seem to result in better learning and retention. Anderson's studies of orthographic, phonological, and semantic processing indicated that a learner must "semantically encode" verbal material at the time of input if it is to be later available in long-term memory (Anderson, 1971, 1973). Semantic encoding means bringing to mind "meaningful representation for words," (Anderson, 1971). The other levels of processing alone may not result in the material entering long-term memory storage. Orthographic processing refers to the perceptual encoding of the physical features of the words and has a very short memorial life. Phonological processing involves encoding the acoustical properties of the words (speech), which enters short-term memory. Mandler and Worden (1973) experimentally confirmed the common observation that material can be adequately processes at the time of input yet be unavailable for subsequent recall as in the case of skilled typists who can rarely recall the content of material typed, although they pay attention to such features as grammar, punctuation, etc.

Where possible facilitory effects of interactive computer graphics for learning and remembering meaningful material are to be studied, it is essential that tests be sensitive to effects of different processing levels. Computer graphics might be more memorable than verbal statements at the level tested by recognition tests, but this might not hold for tests of semantic processing.

Although the literature indicates that imagery is a potent facilitator in some laboratory learning situations, less support exists that imagery functions as a facilitator in more complex learning situations. However, literature concerning the reported use of imagery in complex thinking may help clarify the possible use of imagery in teaching complex subject-matter. Probably mankind's greatest thinker, Einstein, reported his reliance on mental imagery during thought rather than on words or language (Hadamard, 1945). Kebule discovered the benzene ring through a vision of a series of linked atoms biting its tail like a snake (Beveridge, 1957). Michael Faraday, the father of field theory, "visualized" the electric and magnetic lines of force (Arnheim, 1969). One contributor of inventive ideas who holds some 97 patents did a study of creativity in his co-workers at a large industrial research institute. He concluded that creative persons have the ability to visualize in the area in which they are creative. He reported that, ". . . inventors with whom I have talked report thinking visually about complex mechanisms" (Walkup, 1965). He described in detail, the mental processes of creative electrical engineers in thinking about Ohm's law:

> They seem to be able to produce a vivid, almost hallucinatory, vision and feeling about something like a fluid stuff, trying to flow through a solid stuff which opposes the flow, and they feel that the harder the electrical stuff is pushed, the more rapidly it flows through the resistance opposing its movement. Furthermore, the electrical stuff is kept within bounds. The bits of stuff that resist the flow of the current are mentally combined in various ways, for example, so that the current must flow through a number of them in sequence, or so that it can split up and flow through any one of a number of them in parallel. This vivid and manipulatable image system of the flow of electrical currents has to be elaborated considerably when current must flow through inductances and capacitances but this can be done with the same success, to the final result that one is able to perform a myriad of mental experiments in a very short time.
>
> (p. 37)

These reports from outside the field also can give us valuable information on the nature and process of imaging. In the study cited earlier by Walkup (1965), where a number of creative inventors were interviewed and studied, visual thinking was described as "almost a <u>feeling like</u> the object being visualized." William Gordon, a psychologist-inventor, investigated several successful mechanisms, called direct analogy and personal analogy, for understanding complex processes. The latter type--personal analogy--involves an individual's empathetic identification with the situation under contemplation until "new visual images grow out of the identification process" (Gordon, 1965).

Although Gordon's work was primarily aimed at delineating and explicating the creative process, his work holds relevance to the issue of imagery's role in complex learning situations. The techniques that he taught his subjects to use for solving problems cretively are called personal analogy, direct analogy, symbolic analogy, and fantasy analogy. These are techniques for inducing students to generate imagery. Applied to learning, these techniques of generating representational images evidently were facilitative; Gordon's students did achieve positive results by using imaginal techniques to understand difficult concepts in science.

Hayes (1973) found that college students in mathematics reported using mental imagery in the solution of elementary mathematical problems. In his studies, the subjects integrated the experimenter-supplied image with their own to create what he termed a "hybrid image" during the problem-solving process.

Establishing the value of external imagery and discovering the relationship between internal and external imagery is important if we are to justify using interactive graphic terminals. It is not, however, an either-or proposition. Language is indispensable for communicating about complicated subject matter. Visual analogies may represent aspects of that subject matter, but they cannot communicate all the relations that language does communicate so efficiently. A "pure" external imagery condition is difficult, if not impossible to achieve. At least some language is necessary. Therefore, research on the effectiveness of external imagery, say, interactive animated graphics, must take this complication into account.

III. INTERACTIVE COMPUTER GRAPHICS FOR ILLUSTRATING INVISIBLE PROCESSES

It could be said that science deals with the unknown by translating it into the invisible: quarks, hadrons, electrons, atoms, energy bands, gravity, ether . . . Although mathematics is the language of science, there are many occasions for teaching about science and its technologies to mathematically unsophisticated students. This is a common requirement in the military services, where essentially temporary personnel must be initiated into the mysteries of fantastically complex weapon systems. The austere beauties of mathematics may fire the imaginations of professional mathematicians, but the high school graduate who finds himself in the Service, struggling through some watered-down engineering course in electronics, is not likely to find these abstractions so stimulating.

The interactive graphics capability of a computerized educational system such as Plato IV would seem to be an ideal medium for reducing the austerity of these abstractions with animated visual analogies of invisible processes. Recognizing that the "true picture" of these processes does not exist, visual analogies might be used similarly to the way verbal analogies are used: to illustrate processes in more familiar, albeit highly simplified, terms. But unlike verbal analogies, animated illustrations can quickly communicate the nature of changes in events that might require long complicated verbal descriptions to explain.

The touch panel accessory for the plasma panel terminal is an extremely convenient way to implement the interaction between student and graphics. The student's pointing responses can be sensed and that information can be used by the program to control what is subsequently displayed.

Basically through this means, the student can be required to actively process information and his attention can be directed to that area of the screen containing the information that is to be actively processed. It is apparent that what actually goes on in such interactions, in terms of human information processing, is complex, subtle, and poorly understood. It would seem to be all too easy to program interactions that would not induce the right levels of processing after all. If the student's task calls only for perceptual processing, in Anderson's terms, then it would be surprising if the student did well on subsequent tests of semantic processing. Or, the graphical characteristics of the visual analogy on the screen could fail to stimulate the right semantic processing. For one thing, as Norman, Gentner, and Stevens (1974) demonstrated so well, there must be a substantive context.

Providing appropriate and valid external images that will stimulate the proper cognitive processing is important. Langer (1960) distinguished between ordinary pictures and this kind of external imagery, which she called logical pictures:

> A "logical picture" differs from an ordinary picture in that it need not look the least bit like its object. Its relation to the object is not that of a <u>copy</u>, but of an <u>analogy</u>.
>
> The dissimilarity in appearance between a logical picture and what it represents is . . . marked in the case of a graph. . . . The graph is spatial, its form is a shape, but the series of events does not have shape in a literal sense. The graph is a picture of events only in a logical sense; . . . Most of us have no difficulty in seeing an order and configuration of events graphically; yet the only form which the graph and the events have in common is a logical form. They have an analogous structure, though their contents are more incongruous than cabbages and kings.

This kind of external image may be described as a set of propositions about the subject-matter, stated in visual terms rather than verbal. It is a pictorial abstraction which visually symbolizes the critical (as beaker, electrodes, connecting wire, light bulb, water and chemicals -- are provided for the student. His task is to construct a battery by assembling the electrodes in the beaker, wiring them with the light bulb, pouring in the water, and then adding the chemicals. All of this is done using the touch panel to make objects appear on the screen at appropriate places. The student then "activates" the electronic and chemical reactions, one-by-one, by touching spots, indicated by a flashing arrow, on the plasma panel. The student's attention is directed by the flashing arrow and the semantic processing is defined by the questions and other instructions the student sees on the plasma panel. When the student has serially activated all the processes in the battery, all these processes then are turned on again and are allowed to run concurrently, so the student can observe that this is an analogy to what would be happening in a "real" battery.

The following "before" and "after" pictures illustrate the nature of these interactions, without showing the actual movements of symbols for ions or electrons or for the flow of current. Important concepts are conveyed by the type of movement and animation. For example, current flow is shown not to be the flow of specific electrons, but rather the transmission of movement from one electron to another.

The experimental design in full detail and other particulars of the first study will be described in a subsequent report. Basically, it involves comparisons between mixed interactive graphics and verbal, and "pure" verbal conditions, and between no context (serial lists) and context (as described above) conditions on several retention tests designed to be sensitive to the effects of different processing levels.

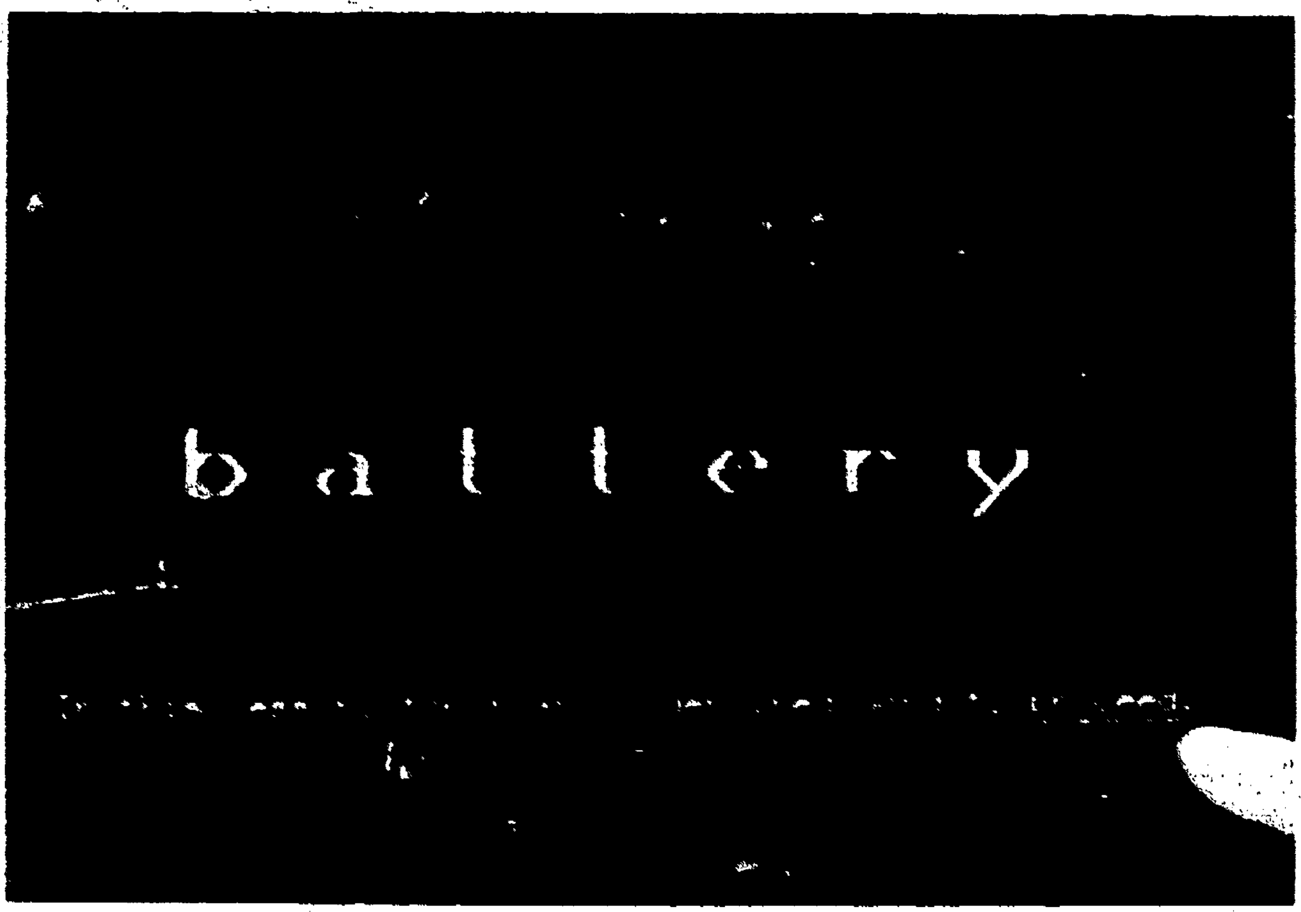

Figure 2. Title page of lesson. Student responds accordingly.

Figure 3. Title page. Following appropriate response, the following chemical reaction is animated:

$$Zn^{++} + 2Cl^{-} \rightarrow ZnCl_2$$

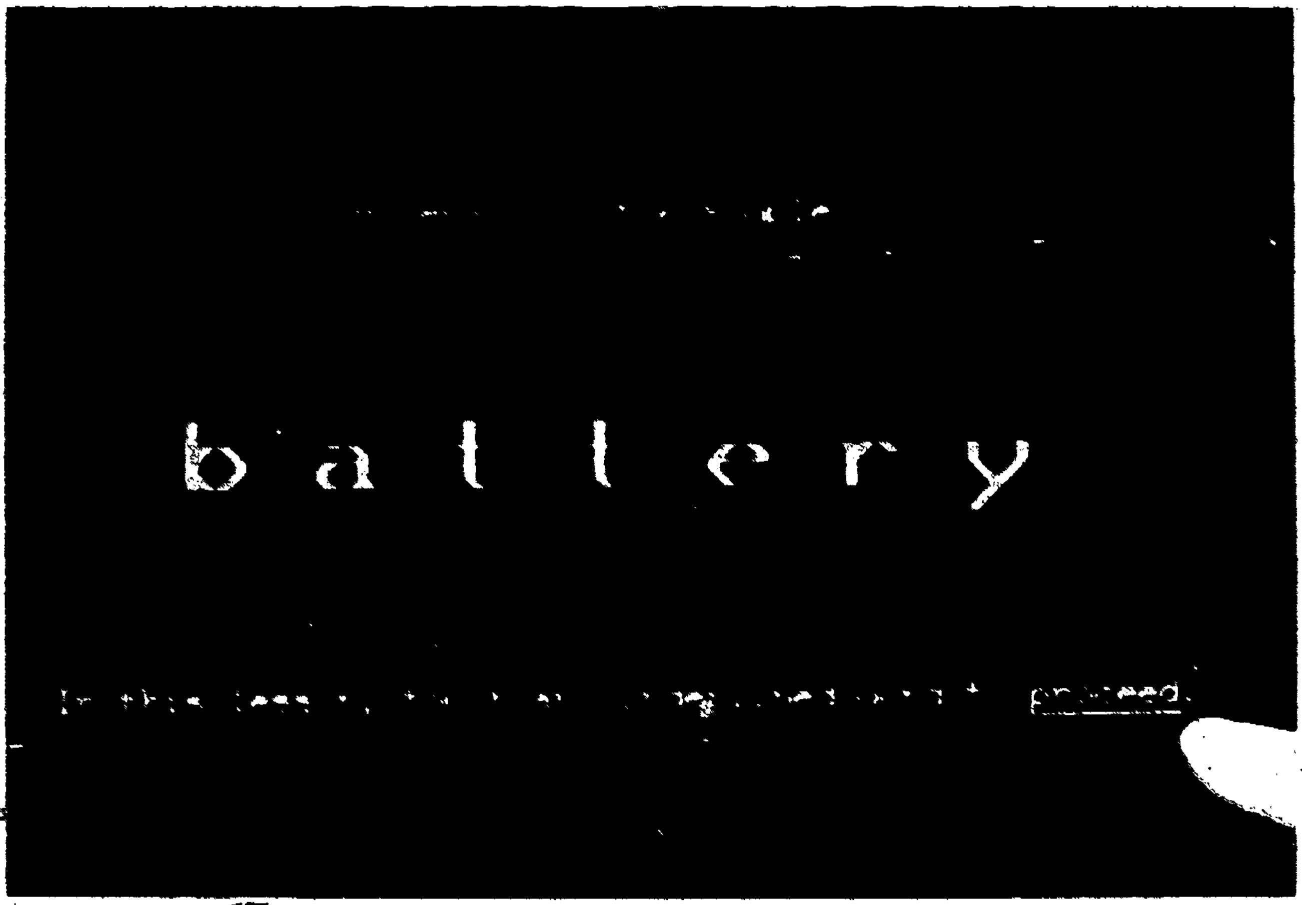

Figure 2. Title page of lesson. Student responds accordingly.

Figure 3. Title page. Following appropriate response, the following chemical reaction is animated:

$$Zn^{++} + 2Cl^{-} \rightarrow ZnCl_2$$

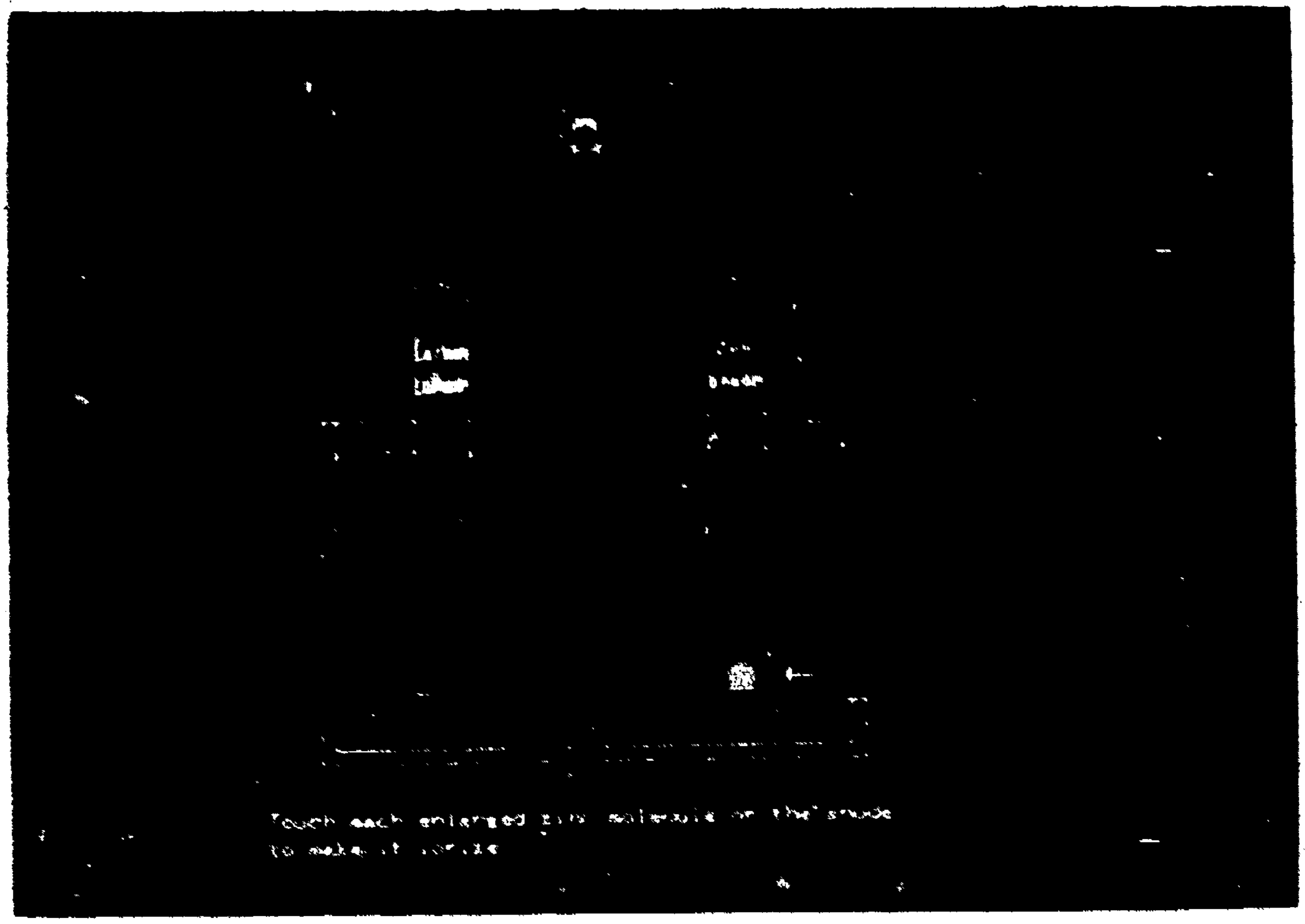

Figure 4. Before response, the student sees a model of the battery with a non-ionized zinc molecule on the anode.

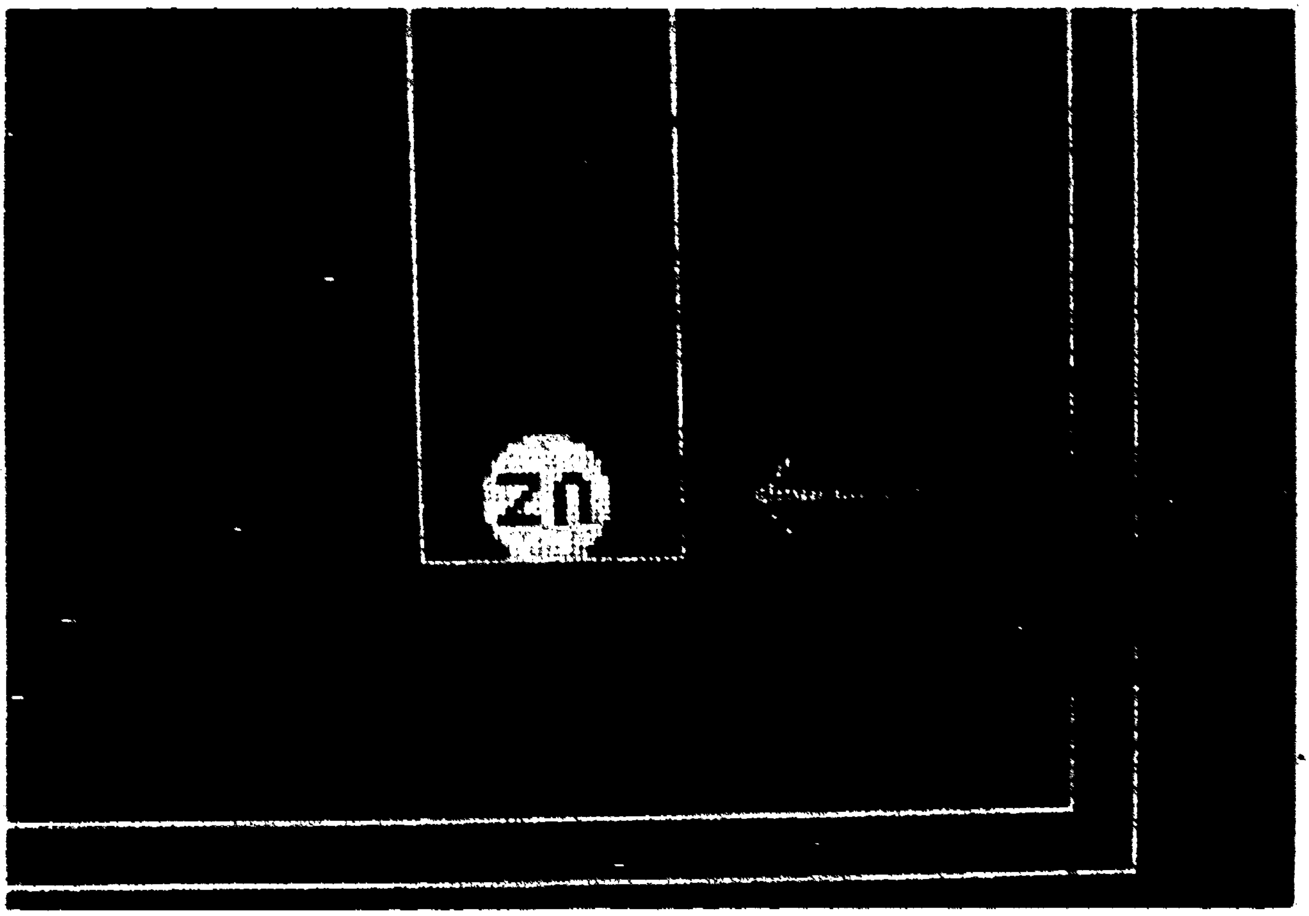

Figure 5. Close up of display before response.

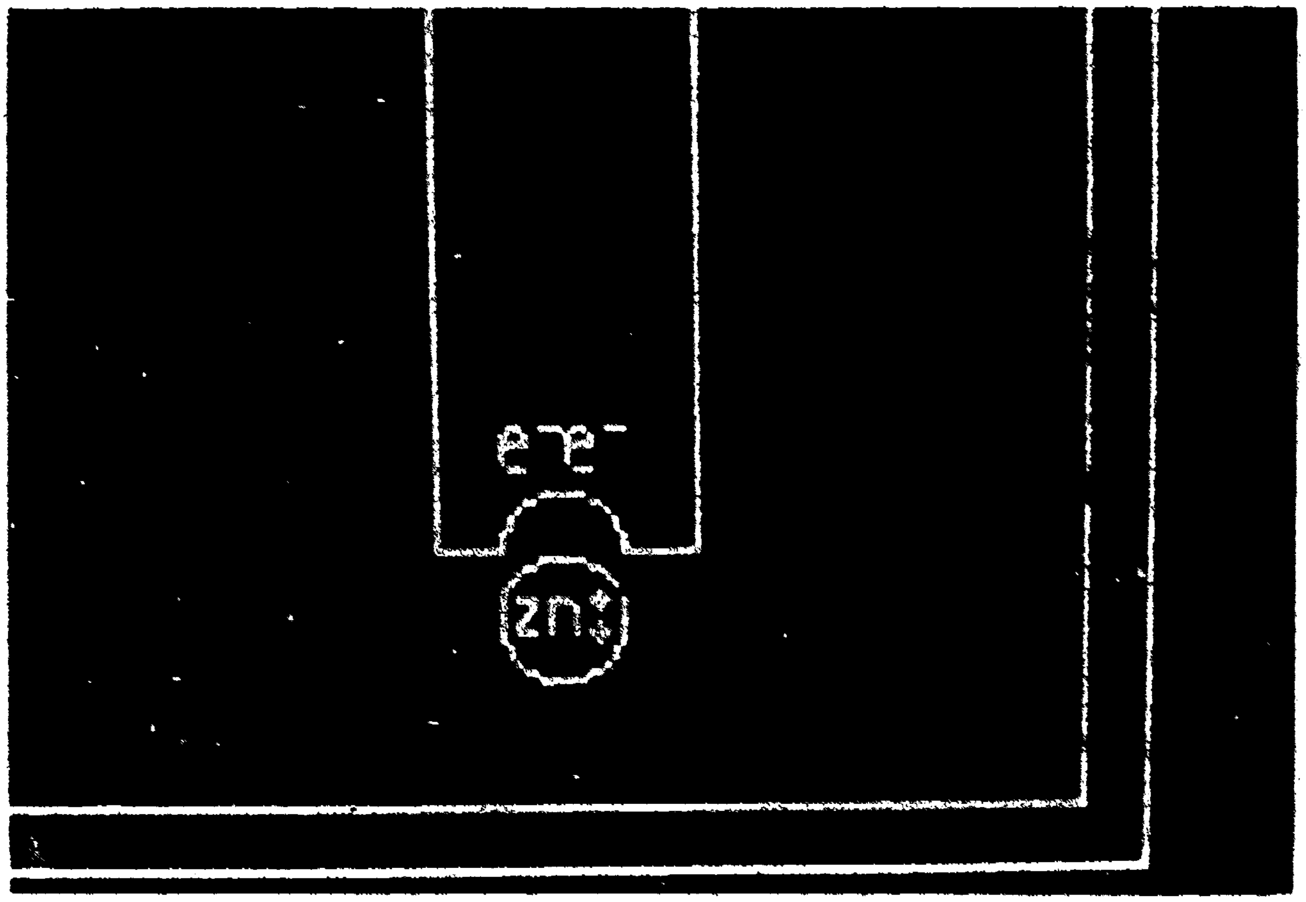

Figure 6. After response, the zinc ionizes leaving two excess electrons in the anode, which then shows the effects of corrosion.

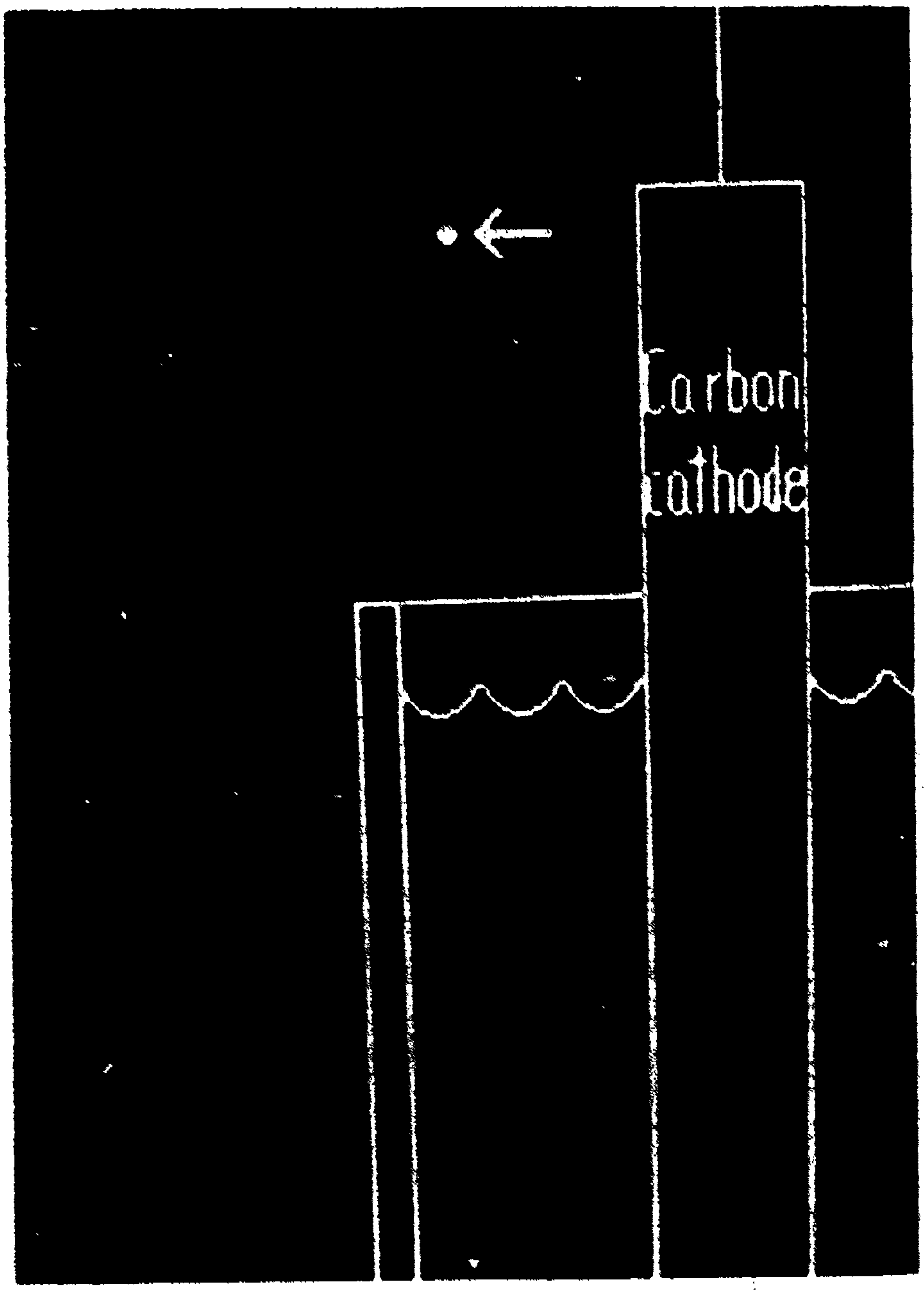

Figure 7. Before response, a dot representing the salt ammonium chloride (NH_4Cl) is about to drop into the water.

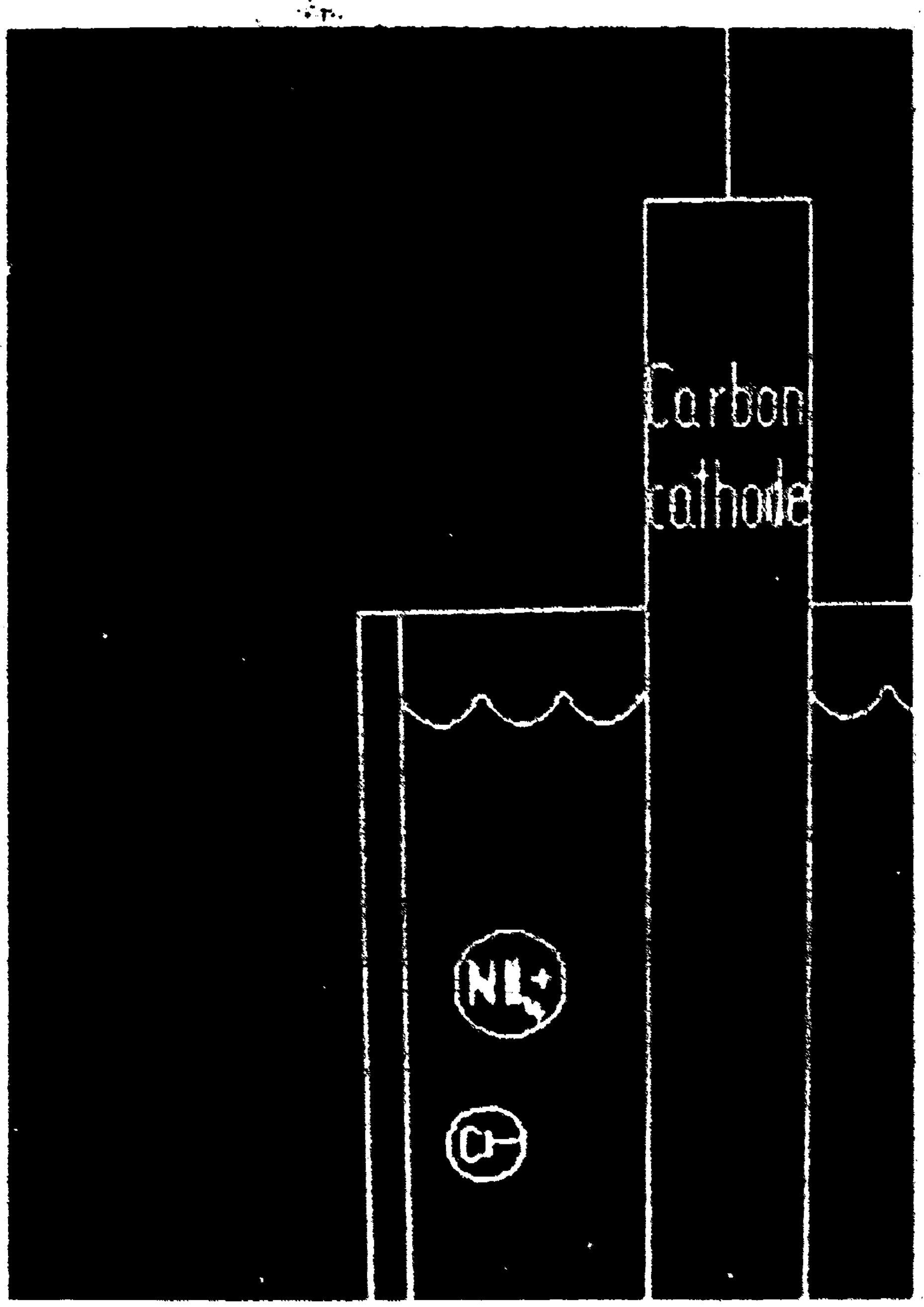

Figure 8. After response, the molecule NH_4Cl appears and drops into the liquid ionizing immediately into NH_4^+ and Cl^-.

IV. SUMMARY

Some current theorizing about internal and external, digital and analogue representational systems was reviewed. The possibility that there are two, overlapping internal analogue representational systems, one for organismic states and the other for external world dimensionalities and objects was considered. The concept of a working memory, or "mind's eye", and its importance in learning was described. Some conceptions of how this might serve in the generation of mental imagery from digital propositional information stored in long-term memory were noted.

Some research bearing on the use of external imagery for facilitating learning and improving retention was reviewed. A project to use the Plato IV system for automatically running subjects and collecting and analyzing data anywhere in the Plato IV network was described. Illustrations of how the plasma panel display and the touch panel is used for interactive, animated computer graphics to illustrate invisible processes were presented. Description of the experimental design in detail, and results of the first study will be presented in a subsequent report.

REFERENCES

Anderson, J. R. and Bower, G. H. Human Associative Memory. New York: Wiley and Sons, 1973.

Anderson, R. C. Encoding processes in the storage and retrieval of sentences. Journal of Experimental Psychology, 1971, 91, 338-340.

________. Semantic organization and retrieval of information from sentences. Journal of Verbal Learning and Verbal Behavior, 1972, 11, 794-800.

________. Substance recall of sentences. Training Research Lab, University of Illinois, Mimeo, 1973.

________, and Ortony, A. On putting apples into bottles: A problem of polysemy. Training Research Laboratory, University of Illinois, Mimeo, 1973.

Arnheim, R. Visual Thinking. Berkeley: University of California Press, 1969.

Attneave, F. How do you know? American Psychologist, 1974, 29, 493-499.

________, and Block, G. Apparent movement in tridimensional space. Perception and Psychophysics, 1973, 12, 301-307.

Bernbach, H. A. and Stalonas, P. M. The effect of isolated imagery on free recall. Bulletin of Psychonomic Science, 1973, 1, 227-228.

Beveridge, W. I. B. The Art of Scientific Investigation. New York: Norton, 1957.

Bogen, J. E. The other side of the brain II: an appositional mind. Bulletin of the Los Angeles Neurological Societies, 1969, 34, 191-220.

Bower, G. H. Analysis of a mnemonic device. American Scientist, 1970, 58, 496-510.

________. Mental imagery and associative learning. In L. Gregg (Ed.), Cognition in Learning and Memory. New York: Wiley and Sons, 1972.

Callaway, E. and Harris, P. R. Coupling between cortical potentials from different areas. Science, 1974, 183, 873-875.

Chase, W. G. and Clark, H. H. Mental operations in the comparison of sentences and pictures. In L. Gregg (Ed.), Cognition in Learning and Memory. New York: Wiley and Sons, 1972.

Collins, A. M. and Quillian, M. R. Retrieval time from semantic memory. Journal of Verbal Learning and Verbal Behavior, 1969, 8, 240-247.

Cooper, L. A. and Shepard, R. N. Chronometric studies of the rotation of mental images. In W. G. Chase (Ed.), Visual Information Processing. New York: Academic Press, 1973.

Corbin, H. H. The perception of grouping and apparent movement in visual depth. Archives of Psychology, 1942, Pt. 1, No. 273.

de Groot, A. D. Perception and memory versus thought: Some old ideas and recent findings. In Kleinmuntz, B. (Ed.), Problem Solving: Research, Method, and Theory. New York: Wiley and Sons, 1966.

Erdelyi, M. H. and Becker, J. Hypermnesia for pictures: Incremental memory for pictures but not words in multiple recall trials. Cognitive Psychology, 1974, 6, 159-171.

Gazzaniga, M. A. The split brain in man. Scientific American, 1967, 217, 24-29.

Gordon, W. J. J. The metaphorical way of knowing. In G. Kepes, (Ed.), Education of Vision. New York: George Braziller, 1965.

Haber, R. N. How we remember what we see. Scientific American, 1970, 222, 104-112.

Hadamard, J. The Psychology of Invention in the Mathematical Field. Princeton: Princeton University Press, 1945.

Hayes, J. R. On the function of visual imagery in elementary mathematics. In W. G. Chase (Ed.), Visual Information Processing. New York: Academic Press, 1973.

LaBerge, D. and Samuels, S. J. Toward a theory of automatic information processing in reading. Cognitive Psychology, 1974, 6, 293-323.

Langer, S. K. Philosophy in a New Key. Cambridge: Harvard University Press, 1960.

Leeuwenberg, E. L. J. A perceptual coding language for visual and auditory patterns. American Journal of Psychology, 1971, 84, 307-350.

Lippman, M. Z. and Shanahan, M. W. Pictorial facilitation of paired-associate learning: Implications for vocabulary training. Journal of Educational Psychology, 1973, 64, 216-222.

Loftus, G. R. Eye fixations and recognition memory for pictures. Cognitive Psychology, 1972, 3, 525-551.

Mandler, G. and Worden, P. E. Semantic processing without permanent storage. Journal of Experimental Psychology, 1973, 100, 277-283.

Marks, D. F. Individual differences in the vividness of visual imagery and their effect on function. In P. W. Sheehan (Ed.), The Function and Nature of Imagery. New York: Academic Press, 1972.

Milner, B. Visual recognition and recall after right temporal-lobe excision in man. Neuropsychologia, 1968, 6, 191-209.

Morris, P. E. and Reid, R. L. Imagery and recognition. British Journal of Psychology, 1974, 65, 7-12.

Nebes, R. D. Hemispheric specialization in commissurotomized man. Psychological Bulletin, 1974, 81, 1-14.

Neisser, U. and Kerr, N. Spatial and mnemonic properties of visual images. Cognitive Psychology, 1973, 5, 138-150.

Nickerson, R. S. Short-term memory for complex meaningful visual configurations: A demonstration of capacity. Canadian Journal of Psychology, 1964, 19, 155-160.

Norman, D. A., Gentner, D. R. and Stevens, A. L. Learning and Teaching. La Jolla, Calif.: Center for Human Information Processing, March, 1974.

Paivio, A. Mental imagery and associative learning and memory. Psychological Review, 1969, 76, 241-263.

Potter, M. C. and Levy, E. I. Recognition memory for a rapid sequence of pictures. Journal of Experimental Psychology, 1969, 81, 10-15.

Powers, W. T. Feedback: Beyond behaviorism. Science, 1973, 179, 351-356.

Pylyshyn, Z. W. What the mind's eye tells the mind's brain: A critique of mental imagery. Psychological Bulletin, 1973, 80, 1-24.

Raugh, M. R. and Atkinson, R. C. A Mnemonic Method for the Acquisition of a Second-language Vocabulary. Stanford, Calif.: Institute for Mathematical Studies in the Social Sciences, March 15, 1974. (Tech. Rep. 224)

Rock, I., Halper, F., and Clayton, T. The perception and recognition of complex figures. Cognitive Psychology, 1972, 3, 655-673.

Rumelhart, D. E., Lindsay, P. H., and Norman, D. A. A process model for long-term memory. In E. Tulving and W. Donaldson (Eds.), Organization of Memory. New York: Academic Press, 1972.

Semmes, J. Hemispheric specialization: A possible clue to mechanism. Neuropsychologia, 1968, 6, 11-26.

Shepard, R. N. Recognition memory for words, sentences and pictures. Journal of Verbal Learning and Verbal Behavior, 1967, 6, 156-163.

________, and Metzler, J. Mental rotation of three-dimensional objects. Science, 1971, 701-703.

Singer, J. L. Daydreaming and the stream of thought. American Scientist, 1974, 62, 417-425.

Sperry, R. W. Hemisphere deconnection and unity in conscious awareness. American Psychologist, 1968, 23, 723-733.

Stevens, J. C., Mack, J. D. and Stevens, S. S. Growth of sensation on seven continua as measured by force of handgrip. Journal of Experimental Psychology, 1960, 59, 60-67.

Tulving, E. and Donaldson, W. (Eds.), Organization of Memory. New York: Academic Press, 1972.

Walkup, L. Creativity in science through visualization. Perceptual and Motor Skills, 1965, 21, 35-41.

Wiseman, G. and Neisser, U. Perceptual organization as a determinant of visual recognition memory. Paper presented at meeting of the Eastern Psychological Association, Spring, 1971.

APPENDIX

TABLE 1

SELECTED RESEARCH ON IMAGERY FROM 1971

Author(s)	Stimulus Materials	Independent Variables Levels	Dependent Measure	Design/Results	Subjects
Anderson (1971)	E1: ** sentences	A: type of instructions 1) imagery 2) rote repetition B: type of test item 1) verbatim 2) paraphrase	recall of subject noun	2x2 ANOVA $A_1 > A_2$ ($p < .01$) $B_1 > B_2$ ($p < .01$) A.B(NS)	48 undergrads, EdPsy
Anderson (1973)	E1: sentences	A: sentence-cue combination 1) both concretely modified 2) concretely-modified s only 3) both unmodified B: recall instructions 1) verbatim 2) substance	recall of words verbatim*	3x2 ANOVA $A_1 > A_3$ ($p = .002$) B(NS) AxB(NS)	47 undergrads, EdPsy
	E2: sentences	A: type of modifier 1) concrete modifier 2) redundant modifier B: two mixed lists	recall of words verbatim*	2x2 ANOVA $A_1 > A_2$ ($p = .001$) B(NS) AxB($p < .05$)	28 undergrads, EdPsy
Anderson and Hidde (1971)	sentences	A: type of instructions 1) imagery 2) pronunciability	recall of verbs and objects	T-test $A_1 > A_2$ ($p < .01$)	24 student volunteers

Author(s)	Stimulus Materials	Independent Variables Levels	Dependent Measure	Design/Results	Subjects
Bower (1972)	noun pairs	A: type of instructions 1) oral repetition 2) interactive imagery 3) separation imagery	recall	one-way ANOVA $A (p < .0001)$ $A_2 > A_1 (p < .001)$ $A_2 > A_3 (p < .001)$	30 high-school grads
Craig (1973)	words	A: item imagery 1) high I words 2) low I words B: subject group 1) normal 2) deaf 3) blind	recall	3x2 ANOVA $A_1 > A_2 (p < .01)$ $B_1 > B_2 (p < .01)$ $B_1 > B_3 (p < .01)$ $AB_1 > AB_3 (p < .01)$	40 undergrads, psy 20 deaf adolescents 20 blind adolescents
Elliott (1973)	nouns	A: type of instructions 1) imagery 2) rote repetition B: item imagery 1) high I words 2) low I words C: four levels of interpolated activity	recall*	2x2x4 ANOVA $A_1 > A_2 (p < .05)$ $B_1 > B_2 (p < .01)$ $A_1B_1 > A_2B_2 (p < .01)$ AxBxC (NS)	48 college students, ps.
Erdelyi and Becker (1974)	E1: pictures words	A: type of stimulus 1) pictures 2) words B: type of interval 1) free association 2) think 3) no interval	R: 3 recall trials: R_1 R_2 R_3	2x3 ANOVA repeated measures $A (p < .01)$ $A_1 > A_2$ $R (p < .01)$ $R_3 > R_2 > R_1$ $AxR (p < .01)$ B (NS)	51 undergrads, psy

Author(s)	Stimulus Materials	Independent Variables Levels	Dependent Measure	Design/Results	Subjects
Erdelyi and Becker cont.	E2: pictures words	A: type of stimulus 1) pictures 2) words B: type of interval 1) think 2) no interval	R: 3 recall trials: R_1 R_2 R_3	2x2 ANOVA repeated measures A($p<.01$) $A_1>A_2$ R($p<.01$) $R_3>R_2>R_1$ B(NS) BxR($p<.05$)	48 undergrads, psy
Griffith and Johnston (1973)	E1** noun pairs	A: type of instructions 1) imagery 2) rote repetition B: item imagery 1) high 2) low C: signal type 1) aural 2) visual	recall*	2x2x2 ANOVA A($p<.001$) $A_1>A_2$ B($p<.001$) $B_1>B_2$ C(NS)	64 undergrads
Johnson et al, (1972)	E1** sentences	A: type of sentence 1) concrete 2) abstract B: type of change 1) S-O reversal 2) synonym substitution	recognition of same meaning of original sentence	2x2 ANOVA AxB($p<.001$) $A_1B_1>A_2B_1$ $A_1B_2<A_2B_2$	42 undergrads, psy

Author(s)	Stimulus Materials	Independent Variables Levels	Dependent Measure	Design/Results	Subjects
Kerst and Levin (1973)	pictures	A: presentation condition 1) control (2 pictures side by side) 2) S-generated sentence 3) S-generated imagery 4) E-provided sentence 5) E-provided interactive imagery	recognition R: (3 trials)	one-way ANOVA w/ repeated measures $A (p < .01)$ $A_1 < A_2, A_3, A_4, A_5$ $AxR (p < .01)$	119 fourth- and fifth-graders
Levin (1973)	printed stories pictorial stories	A: story treatment 1) sentences 2) sentences with image instructions 3) pictures B: stories-two	comprehension of story (13 oral questions)	2x3x3 ANOVA $A_2 > A_1 (p < .01)$	54 fourth graders (3 levels of reading ability
Levin et al. (1973)	S: 1) words 2) pictures	A: type of instructions 1) regular PA 2) sentence generation 3) imagery generation 4) sentence-imagery generation	R: 1) recall 2) recognition	2x4x2x2 ANOVA $A (p < .001)$ $A_1 < A_2, A_3, A_4$ $S (p < .01)$ $S_1 > S_2$ $\underline{S} (p < .001)$ $\underline{S}_2 > \underline{S}_1$ $\underline{S}xRxS (p < .01)$	S: 1) 32 second-graders 2) 32 fifth-graders
Lippman and Shanahan (1973)	El: paralog-noun pairs pictures	A: type of stimulus presentation 1) control, written paralog 2) picture of paralog 3) accentuation of paralog a) superimposition b) one letter c) inclusion	recall recognition	one-way ANOVA $A (p < .01)$ $A_3 > A_1, A_2$ one-way ANOVA repeated measures $3c > 3a, 3b (p < .01)$	80 third-graders

Author(s)	Stimulus Materials	Independent Variables Levels	Dependent Measure	Design/Results	Subjects
Lippman and Shanahan (cont.)	E2: paralog-noun pairs pictures	A: Type of presentation 1) control 2) picture 3) accentuation 4) verbal context 5) picture interpretation	recall	5x3x2 ANOVA A($p<.01$) $A_1<A_2<A_3<A_4=A_5$($p<.01$) except $A_3<A_4$($p<.05$)	240 grade school pupils (3 grades, and both boys and girls)
Marks (1973)	E1: color photos	A: imagery ability 1) good 2) poor	recognition	2x2 ANOVA A($p<.01$) $A_1>A_2$ Sex($p<.01$) f>m AxSex(NS)	36 college students, psy ½ male, ½ female
	E2: color photos	A: same as above	recognition	2x2 ANOVA A($p<.005$) $A_1>A_2$ Sex($p<.025$) f>m AxSex(NS)	16 students (16-18 yr.)
Montague and Carter (1973)	paragraphs	A: type of organization 1) random 2) syntactic B: type of instructions 1) imagery 2) no imagery C: item imagery 1) high I value 2) low I value	recall (5 categories)	C($p<.05$) $C_1>C_2$ B(NS) A(NS)	71 undergrads, psy

Author(s)	Stimulus Materials	Independent Variables Levels	Dependent Measure	Design/Results	Subjects
Nelson and Brooks (1973)	words pictures	A: type of representation 1) picture 2) picture-name 3) word B: type of similarity 1) phonetically similar 2) phonetically dissimilar C: 2 lists	errors in recall*	3x2x2 ANOVA A($p<.01$) $A_1<A_2<A_3$ B($p<.01$) $B_2<B_1$ AxB($p<.01$)	96 students, psy
Paivio and Csapo (1973)	E1: pictures words	A: stimulus attribute 1) pictures 2) concrete words 3) abstract words B: learning set 1) incidental 2) intentional control 3) standard free recall	recall	3x3 ANOVA for unequal cells A($p<.001$) $A_1>A_2>A_3$ B($p<.01$) $B_3>B_2>B_1$ AxB($p<.01$)	142 undergrads
	E2: pictures nouns	A: stimulus mode 1) pictures 2) words B: encoding mode 1) written labels 2) drawings	recall	2x2 ANOVA A($p<.001$) $A_1>A_2$ B($p<.001$) $B_2>B_1$ AxB($p<.001$) $A_2xB_2>A_2B_1$	81 undergrads, psy
	E5:** pictures concrete words	A: stimulus mode 1) pictures 2) words (concrete) B: learning set 1) incidental 2) intentional control 3) standard free recall	recall	3x2 ANOVA A($p<.001$) $A_1>A_2$ B($p<.001$) $B_1<B_2<B_3$	124 students, psy

Author(s)	Stimulus Materials	Independent Variables Levels	Dependent Measure	Design/Results	Subjects
Raugh and Atkinson (1974)	E1: printed Sp words with associated keywords & Eng words	A: type of instructions 1) imagery (keyword & Eng translation) 2) rote repetition	R: recall 1) spoken Sp to written Eng 2) printed Sp to written Eng 3) spoken Sp to written keyword	T-test for R_1: $A_1 > A_2$ ($p < .001$) for R_2: $A_1 > A_2$ ($p < .001$) for R_3: A (NS)	40 undergrads
	E2: oral Sp word written keyword & Eng word	A: type of instructions 1) imagery (keyword & Eng translation) 2) rote repetition	R: recall 1) see 1 above 2) see 3 above	T-test for R_1: $A_1 > A_2$ ($p < .01$) for R_2: $A_1 > A_2$ ($p < .02$)	30 undergrads
	E3: Sp nouns w/ associated keyword	A: type of instructions 1) imagery (keyword & Eng translation) 2) no imagery (no keyword) B: item imagery 1) high 2) low	R: recall 1) comprehensive test 2) delayed comprehensive test learning strategy	T-test for R_1: $A_1 > A_2$ ($p < .001$) for R_2: $A_1 > A_2$ ($p < .01$)	32 undergrads
	E4: Sp nouns w/ associated keyword	A: type of instructions 1) imagery (instructions) 2) no imagery (keyword) 3) free choice B: items imagery 1) high 2) low	recall* learning strategy	T-test $A_1, A_3 > A_2$ ($p < .05$)	25 undergrads

Author(s)	Stimulus Materials	Independent Variables Levels	Dependent Measure	Design/Results	Subjects
Wortman and Sparling (1974)	Words	A: item imagery 1) high I value 2) low I value B: mediation instructions 1) bizarre images 2) common images 3) verbal mediator (sentence or phrase) C: 3 lists of to-be-learned response words	R: recall 1) immediate 2) delayed T: learning time	2X3X3X2 ANOVA R: A ($p < .001$) $A_1 > A_2$ B(NS)[2] for T: $B_1 > B_2 > B_3$	36 undergrads

* Other dependent measures were taken but are not reported here.

** Other experiments were included in the research but are not reported here.

s = sentence

Eng = English

Sp = Spanish

BIBLIOGRAPHY

Anderson, R. C. Encoding processes in the storage and retrieval of sentences. Journal of Experimental Psychology, 1971, 91, 338-340.

________. Concretization and sentence learning. Journal of Educational Psychology, 1974, 66, 179-183.

________, and Hidde, J. L. Imagery and sentence learning. Journal of Educational Psychology, 1971, 62, 526-530.

Atwood, G. An experimental study of visual imagination and memory. Cognitive Psychology, 1971, 2,290-299.

Begg, I. and Paivio, A. Concreteness in sentence meaning. Journal of Verbal Learning and Verbal Behavior, 1969, 8, 821-827.

Bernbach, H. A. and Stalonas, P. M. The effect of isolated imagery on free recall. Bulletin of Psychonomic Science, 1973, 1, 227-228.

Bower, G. H. Imagery as a relational organizer in associative learning. Journal of Verbal Learning and Verbal Behavior, 1970, 9, 529-533.

________. Mental imagery and associative learning. In L. Gregg (Ed.) Cognition in Learning and Memory. New York: Wiley and Sons, 1972.

Bugelski, B. R. Images and mediators in one-trial paired-associate learning. II: Self-timing in successive lists. Journal of Experimental Psychology, 1968, 77, 328-334.

________. The image as mediator in one-trial paired-associate learning: III: Sequential functions in serial lists. Journal of Experimental Psychology, 1974, 103, 298-303.

________, Kidd, E. and Segmen, J. Image as a mediator in one-trial paired-associate learning. Journal of Experimental Psychology, 1968, 76, 69-73.

Cooper, L. A. and Shepard, R. N. Chronometric studies of the rotation of mental images. In W. G. Chase (Ed.) Visual Information Processing. New York: Academic Press, 1973.

Craig, E. M. Role of mental imagery in free recall of deaf, blind, and normal subjects. Journal of Experimental Psychology, 1973, 97, 249-253.

Davidson, R. E. Mediation and ability in paired-associate learning. Journal of Educational Psychology, 1964, 55, 352-356.

Elliott, L. Imagery versus repetition encoding in short-hand long-term memory. Journal of Experimental Psychology, 1973, 100, 270-276.

Erdelyi, M. H. and Becker, J. Hypermnesia for pictures: Incremental memory for pictures but not words in multiple recall trials. Cognitive Psychology, 1974, 6, 159-171.

Ernest, C. H. and Paivio, A. Imagery ability in paired-associate and incidental learning. Psychonomic Science, 1969, 15, 181-182.

________, and Paivio, A. Imagery and verbal associative latencies: A function of imagery ability. Canadian Journal of Psychology, 1971, 25, 83-90.

Goldberg, F. Effects of imagery on learning incidental material in the classroom. Journal of Educational Psychology, 1974, 66, 233-237.

Griffith, D. and Johnson, W. A. An information-processing analysis of visual imagery. Journal of Experimental Psychology, 1973, 100, 141-146.

Gupton, T. and Frincke, G. Imagery, mediational instructions, and noun position in free recall of noun-verb pairs. Journal of Experimental Psychology, 1970, 86, 461-462.

Johnson, M. K., Bransford, J. D., Wyberg, S. E. and Cleary, J. J. Comprehension factors in interpreting memory for abstract and concrete sentences. Journal of Verbal Learning and Verbal Behavior, 1972, 11, 451-454.

Judd, W. A., O'Neil, H. F. and Spelt, P. F. Individual Differences and Learner Control II: Investigation of Control Over Pictorial Mediators in Computer-assisted Instruction. Air Force Human Resources Laboratory, (AFHRL-TR-74-30) July 1974.

Kerst, S. and Levin, J. R. A comparison of experimenter-provided and subject-generated strategies in children's paired-associate learning. Journal of Educational Psychology, 1973, 65, 300-303.

Levin, J. R. Inducing comprehension in poor readers: A test of a recent mode. Journal of Educational Psychology, 1973, 65, 19-24.

________, Davidson, R. E., Wolff, P. and Citron, M. A comparison of induced imagery and sentence strategies in children's paired-associate learning. Journal of Educational Psychology, 1973, 64, 306-309.

Levin, J. R., Divine-Hawkins, P., Kerst, S. M. and Guttmann, J. Individual differences in learning from pictures and words: The development and application of an instrument. Journal of Educational Psychology, 1974, 66, 296-303.

Lippman, M. Z. Shanahan, M. W. Pictorial facilitation of paired-associate learning: Implications for vocabulary training. Journal of Educational Psychology, 1973, 64, 216-222.

Lowry, D. H. The effects of mnemonic learning strategies on transfer, interference, and 48-hour retention. Journal of Experimental Psychology, 1974, 103, 16-20.

Marks, D. F. Visual imagery differences in the recall of pictures. British Journal of Psychology, 1973, 64, 17-24.

Milgram, N. A. Verbal context versus visual compound in paired-associate learning by children. Journal of Experimental Child Psychology, 1967, 5, 597-603.

Montague, W. E. and Carter, J. F. Vividness of imagery in recalling connected discourse. Journal of Educational Psychology, 1973, 64, 72-75.

Neisser, V. and Kerr, N. Spatial and mnemonic properties of visual images. Cognitive Psychology, 1973, 5, 138-150.

Nelson, D. L. and Brooks, D. H. Functional independence of pictures and their verbal memory codes. Journal of Educational Psychology, 1973, 98, 44-48.

Paivio, A. and Csapo, K. Concrete-image and verbal memory codes. Journal of Experimental Psychology, 1969, 80, 279-285.

________, and Csapo, K. Picture superiority in free recall: Imagery or dual coding? Cognitive Psychology, 1973, 5, 176-206.

________, and Madigan, S. A. Imagery and associative value in paired-associate learning. Journal of Experimental Psychology, 1968, 76, 35-39.

________, and Madigan, S. A. Noun imagery and frequency in paired-associate and free recall learning. Canadian Journal of Psychology, 1970, 24, 353-361.

________, and Okovita, H. W. Word imagery modalities and associative learning in blind and sighted subjects. Journal of Verbal Learning and Verbal Behavior, 1971, 10, 506-510.

________, Rogers, T. B. and Smythe, P. C. Why are pictures easier to recall than words? Psychonomic Science, 1968, 11, 137-138.

________, and Rowe, E. J. Noun imagery, frequency, and meaningfulness in verbal discrimination. Journal of Experimental Psychology, 1970, 85, 264-269.

________, and Smythe, P. C. Word imagery, frequency, and meaningfulness in short-term memory. Psychonomic Science, 1971, 22, 333-335.

________, and Yuille, J. C. Mediation instructions and word attributes in paired-associate learning. Psychonomic Science, 1967, 8, 65-66.

________, and Yuille, J. C. Changes in associative strategies and paired-associate learning over trials as a function of word imagery and type of learning set. Journal of Experimental Psychology, 1969, 79, 458-463.

________, Yuille, J. C. and Rogers, T. B. Noun imagery and meaningfulness in free and serial recall. Journal of Experimental Psychology, 1969, 79, 509-514.

Peterson, M. J. and McGee, S. H. Effects of imagery instructions, imagery ratings, and number of dictionary meanings upon recognition and recall. Journal of Experimental Psychology, 1974, 102, 1007-1014.

Raugh, M. R. and Atkinson, R. C. A Mnemonic Method for the Acquisition of a Second-language Vocabulary. Stanford, Calif.: Institute for Mathematical Studies in the Social Sciences, March 15, 1974. (Tech. Rep. 224)

Reese, H. W. Imagery in paired-associate learning in children. Journal of Experimental Child Psychology, 1965, 2, 290-296.

Rowe, E. J. and Paivio, A. Discrimination learning of pictures and words. Psychonomic Science, 1971, 22, 87-88.

Rowher, W. D., Jr., Lynch, S., Levin, J. R., and Suzuki, N. Pictorial and verbal factors in the efficiency learning of paired-associates. Journal of Educational Psychology, 1967, 58, 278-284.

Sampson, J. R. Free recall of verbal and nonverbal stimuli. Quarterly Journal of Experimental Psychology, 1970, 22, 215-221.

Sheehan, P. W. Functional similarity of imaging to perceiving: Individual differences in vividness of imagery. Perceptual and Motor Skills, 1966, 23, 1011-1033.

________. A shortened form of Betts' questionnaire upon mental imagery. Journal of Clinical Psychology, 1967, 23, 386-389.

________, and Neisser, U. Some variables affecting the vividness of imagery in recall. British Journal of Psychology, 1969, 60, 71-80.

Wortman, P. M. and Sparling, P. B. Acquisition and retention of mnemonic information in long-term memory. Journal of Experimental Psychology, 1974, 102, 22-26.

ONR DISTRIBUTION LIST

Navy

4 Dr. Marshall J. Farr, Director
Personnel and Training Research Programs
Office of Naval Research (Code 458)
Arlington, VA 22217

1 ONR Branch Office
495 Summer Street
Boston, MA 02210
ATTN: Research Psychologist

1 ONR Branch Office
1030 East Green Street
Pasadena, CA 91101
ATTN: E. E. Gloye

1 ONR Branch Office
536 South Clark Street
Chicago, IL 60605
ATTN: M. A. Bertin

6 Director
Naval Research Laboratory
Code 2627
Washington, DC 20390

12 Defense Documentation Center
Cameron Station, Building 5
5010 Duke Street
Alexandria, VA 22314

1 Special Assistant for Manpower
OASN (M&RA)
Pentagon, Room 4E794
Washington, DC 20350

1 LCDR Charles J. Theisen, Jr.
MSC, USN
4024
Naval Air Development Center
Warminster, PA 18974

1 Chief of Naval Reserve
Code 3055
New Orleans, LA 70146

1 Dr. Harold R. Booher
Naval Air Systems Command
NAVAIR 04A4
Washington, DC 20361

1 Commander
Naval Air Systems Command
Department of the Navy
AIR-413C
Washington, DC 20361

1 Dr. Lee Miller
Naval Air Systems Command
AIR-413E
Washington, DC 20361

1 CAPT John F. Riley, USN
Commanding Officer
U.S. Naval Amphibious School
Coronado, CA 92155

1 Chief
Bureau of Medicine & Surgery
Research Division (Code 713)
Washington, DC 20372

1 Chairman
Behavioral Science Department
Naval Command & Management Division
U.S. Naval Academy, Luce Hall
Annapolis, MD 21402

1 Chief of Naval Education & Training
Naval Air Station
Pensacola, FL 32508
ATTN: CAPT Bruce Stone, USN

1 Mr. Arnold Rubinstein
Naval Material Command (NAVMAT 03424)
Room 820, Crystal Plaza #6
Washington, DC 20360

1 Commanding Officer
Naval Medical Neuropsychiatric
Research Unit
San Diego, CA 92152

1 Director, Navy Occupational Task
Analysis Program (NOTAP)
Navy Personnel Program Support
Activity
Building 1304, Bolling AFB
Washington, DC 20336

1 Dr. Richard J. Niehaus
Office of Civilian Manpower
Management
Code 06A
Washington, DC 20390

1 Department of the Navy
Office of Civilian Manpower
Management
Code 263
Washington, DC 20390

1 Chief of Naval Operations (OP-987E)
Department of the Navy
Washington, DC 20350

1 Superintendent
Naval Postgraduate School
Monterey, CA 93940
ATTN: Library (Code 2124)

1 Commander, Navy Recruiting Command
4015 Wilson Boulevard
Arlington, VA 22203
ATTN: Code 015

1 Mr. George N. Graine
Naval Ship Systems Command
SHIPS 047C12
Washington, DC 20362

1 Chief of Naval Technical Training
Naval Air Station Memphis (75)
Millington, TN 38054
ATTN: Dr. Norman J. Kerr

1 Commanding Officer
Service School Command
U.S. Naval Training Center
San Diego, CA 92133
ATTN: Code 3030

1 Dr. William L. Maloy
Principal Civilian Advisor
for Education & Training
Naval Training Command, Code 01A
Pensacola, FL 32508

1 Dr. Alfred F. Smode, Staff
Consultant
Training Analysis & Evaluation
Group
Naval Training Equipment Center
Code N-00T
Orlando, FL 32813

1 Dr. Hanns H. Wolff
Technical Director (Code N-2)
Naval Training Equipment Center
Orlando, FL 32813

1 Chief of Naval Training Support
Code N-21
Building 45
Naval Air Station
Pensacola, FL 32508

1 Dr. Robert French
Naval Undersea Center
San Diego, CA 92132

1 CDR Richard L. Martin, USN
Fighter Squadron 124
NAS Miramar, CA 92145

1 Dr. John Ford
Navy Personnel R & D Center
San Diego, CA 92152

5 Navy Personnel R & D Center
San Diego, CA 92152
ATTN: Code 10

Army

1 Headquarters
U.S. Army Administration Center
Personnel Administration Combat Development Activity
ATCP-HRO
Ft. Benjamin Harrison, IN 46249

1 Armed Forces Staff College
Norfolk, VA 23511
ATTN: Library

1 Director of Research
U.S. Army Armor Human Research Unit
Building 2422 Morade Street
Fort Knox, KY 40121
ATTN: Library

1 Commandant
United States Army Infantry School
ATTN: ATSH-DET
Fort Benning, GA 31905

1 Deputy Commander
U.S. Army Institute of Administration
Fort Benjamin Harrison, IN 46216
ATTN: EA

1 Dr. Frank J. Harris
U.S. Army Research Institute
1300 Wilson Boulevard
Arlington, VA 22209

1 Dr. Ralph Dusek
U.S. Army Research Institute
1300 Wilson Boulevard
Arlington, VA 22209

1 Mr. Edmund F. Fuchs
U.S. Army Research Institute
1300 Wilson Boulevard
Arlington, VA 22209

1 Dr. Leon H. Nawrocki
U.S. Army Research Institute
1300 Wilson Boulevard
Arlington, VA 22209

1 Dr. J. E. Uhlaner, Technical Director
U.S. Army Research Institute
1300 Wilson Boulevard
Arlington, VA 22209

1 Dr. Joseph Ward
U.S. Army Research Institute
1300 Wilson Boulevard
Arlington, VA 22209

1 HQ USAREUR & 7th Army
ODCSOPS
USAREUR Director of GED
APO New York 09403

Air Force

1 Research Branch (AF/DPXYR)
Pentagon, Room 5C428
Washington, DC 20330

1 Dr. G. A. Eckstrand (AFHRL/AS)
Wright-Patterson AFB
Ohio 45433

1 Dr. Ross L. Morgan (AFHRL/AST)
Wright-Patterson AFB
Ohio 45433

1 Dr. Martin Rockway (AFHRL/TT)
Lowry AFB
Colorado 80230

1 Major P. J. DeLeo
Instructional Technology Branch
AF Human Resources Laboratory
Lowry AFB, CO 80230

1 AFOSR/NL
1400 Wilson Boulevard
Arlington, VA 22209

1 Commandant
USAF School of Aerospace Medicine
Aeromedical Library (SUL-4)
Brooks AFB, TX 78235

1 Dr. Sylvia R. Mayer (MCIT)
Headquarters Electronic Systems Division
LG Hanscom Field
Bedford, MA 01730

1 CAPT Jack Thorpe, USAF
Flying Training Division (HRL)
Williams AFB, AZ 85224

Marine Corps

1 Mr. E. A. Dover
Manpower Measurement Unit (Code MPI)
Arlington Annex, Room 2413
Arlington, VA 20380

1 Commandant of the Marine Corps
Headquarters, U.S. Marine Corps
Code MPI-20
Washington, DC 20380

1 Director, Office of Manpower Utilization
Headquarters, Marine Corps (Code MPU)
MCB (Building 2009)
Quantico, VA 22134

1 Dr. A. L. Slafkosky
Scientific Advisor (Code RD-1)
Headquarters, U.S. Marine Corps
Washinton, DC 20380

Coast Guard

1 Mr. Joseph J. Cowan, Chief
Psychological Research Branch (G-P-1/62)
U.S. Coast Guard Headquarters
Washington, DC 20590

Other DOD

1 Lt. Col. Henry L. Taylor, USAF
Military Assistant for Human Resources
OAD (E&LS) ODDR&E
Pentagon, Room 3D129
Washington, DC 20301

1 Mr. William J. Stormer
DOD Computer Institute
Washington Navy Yard, Building 175
Washington, DC 20374

1 Col. Austin W. Kibler
Advanced Research Projects Agency
Human Resources Research Office
1400 Wilson Boulevard
Arlington, VA 22209

1 Mr. Thomas O'Sullivan
Advanced Research Projects Agency
Human Resources Research Office
1400 Wilson Boulevard
Arlington, VA 22209

Other Government

1 Dr. Eric McWilliams, Program Manager
Technology and Systems, TIE
National Science Foundation
Washington, DC 20550

1 Dr. Andrew R. Molnar
Technological Innovations in Education
National Science Foundation
Washington, DC 20550

Miscellaneous

1 Dr. Scarvia B. Anderson
Educational Testing Service
17 Executive Park Drive, N.E.
Atlanta, GA 30329

1 Dr. John Annett
The Open University
Milton Keynes
Buckinghamshire
ENGLAND

1 Dr. Richard C. Atkinson
Stanford University
Department of Psychology
Standord, CA 94305

1 Mr. Kenneth M. Bromberg
Manager -- Washington Operations
Information Concepts, Inc.
1701 North Fort Myer Drive
Arlington, VA 22209

1 Dr. Ronald P. Carver
American Institutes for Research
Foxhall Square
3301 New Mexico Avenue, N.W.
Washington, DC 20016

1 Centry Research Corporation
4113 Lee Highway
Arlington, VA 22207

1 Dr. Allan M. Collins
Bolt Beranek and Newman, Inc.
50 Moulton Street
Cambridge, MA 02138

1 Dr. Rene' V. Dawis
University of Minnesota
Department of Psychology
Minneapolis, MN 55455

1 ERIC
Processing and Reference Facility
4833 Rugby Avenue
Bethesda, MD 20014

1 Dr. Victor Fields
Montgomery College
Department of Psychology
Rockville, MD 20850

1 Dr. Edwin A. Fleishman
American Institutes for Research
Foxhall Square
3301 New Mexico Avenue, N.W.
Washington, DC 20016

1 Dr. Dexter Fletcher
University of Illinois at
Chicago Circle
Department of Psychology
Chicago, IL 60680

1 Dr. Robert Glaser, Director
University of Pittsburgh
Learning Research & Development
Center
Pittsburgh, PA 15213

1 Dr. Henry J. Hamburger
University of California
School of Social Sciences
Irvine, CA 92664

1 HumRRO
Division No. 3
P.O. Box 5787
Presidio of Monterey, CA 93940

1 HumRRO
Division No. 6, Library
P.O. Box 428
Fort Rucker, AL 36360

1 Dr. Lawrence B. Johnson
Lawrence Johnson & Associates, Inc.
200 S. Street, N.W., Suite 502
Washington, DC 20009

1 Dr. Milton S. Katz
MITRE Corporation
Westgate Research Center
McLean, VA 22101

1 Dr. Steven W. Keele
University of Oregon
Department of Psychology
Eugene, OR 97403

1 Dr. David Klahr
Carnegie-Mellon University
Department of Psychology
Pittsburgh, PA 15213

1 Dr. Alma E. Lantz
University of Denver
Denver Research Institute
Industrial Economics Division
Denver, CO 80210

1 Dr. Robert R. Mackie
Human Factors Research, Inc.
6780 Cortona Drive
Santa Barbara Research Park
Goleta, CA 93017

1 Dr. Donald A. Norman
University of California, San Diego
Center for Human Information
Processing
LaJolla, CA 92037

1 Mr. A. J. Pesch, President
Eclectech Associates, Inc.
P.O. Box 178
North Stonington, CT 06359