Algorithmic Processes for Increasing Design Efficiency

William R. Terrell
Training Analysis and Design
Department of the Navy
Orlando, FL 32813

Efforts to increase the efficiency of instructional design throughout the education and training community often attempt to: (a) increase the effectiveness of instructional materials, (b) increase the amount of instructional improvement activity impacted by the individual designer, and (c) reduce the costs of instructional design. Examples of these attempts are the dozens of instructional design models which have been expounded to improve the design process (Andrews & Goodson, 1980; Branson, 1981; Gustafson, 1981). Other efforts include attempts to reduce costs and multiply the impact of individual designers by using graduate students or interns as deputies, and training instructors to perform as designers with minimal consultant assistance.

It is not the purpose of this paper to argue the relative merits of specific efforts to increase the efficiency of instructional design. Rather, the intent is to offer for consideration as an addition or supplement to other efforts, the use of algorithmic processes as a means to increase design efficiency. Algorithmic processes and types of applications in instructional design are defined in this paper. In addition, a range of algorithmic processes which form the progression in the development of a project for the increase of design efficiency are described.

Algorithmic Processes

Three algorithmic processes for problem solution are: (1) algorithms, (2) quasi-algorithms, and (3) heuristics. An algorithm is a precise, generally comprehensible prescription for carrying out a defined sequence of elementary operations in order to solve problems belonging to a certain class (Landa, 1974, p.11). A theorem in mathematics is a good example of an algorithm. Given a set of data and accurate computation of the theorem, the results will always be correct. Error occurs through inappropriate application of a theorem to a situation. In this case a correct calculation of the theorem results in an incorrect solution to the problem.

A quasi-algorithm has characteristics similar to an algorithm but may not yield the same results every time (Good, 1973). An instructional design model is a good example of a quasi-algorithm. The design model is similar to an algorithm in the sense that there are defined steps regarding what must be done (and often well defined procedures about how to do it). However, highly proceduralized models are usually designed for a specific problem in a specific situation. The vast number of variables involved make it very unlikely that any given set of procedures could be generalized to the universe of instructional design problems. Instructional design models are useful guides to the solution of instructional problems, but there is no guarantee of achieving similar results. Two individuals applying the same model might end up with quite different results. The results in each case might be equally good or one might be superior to the other. Among the variables determining the quality of results are the abilities of the designers, the extent of client cooperation, and the adequacy of resources and support.

The heuristic is a method which considerably narrows the scope of searching for a solution without prescribing a solution. Heuristic methods presume a support of accumulated experience in problem solving and the use of this experience for specifying the direction of the search toward the greatest probability of solution (Landa, 1974, p.117). Heuristics are a set of rules-of-thumb accumulated from personal experience, observation of the experience of others, reviews of research literature and case studies, and other sources. Often one individual rule-of-thumb will contradict another; the experienced problem-solver selects from the repertoire of heuristics those relevant to the particular problem at hand. Heuristics are only intended to short-cut problem solution; there is no guarantee of results. Probably the best known works on heuristics in the area of instructional development were published by Durzo (1978) and Haney, Lange, and Barson (1981).

The instructional designer employs algorithmic processes for three types of applications: (1) content, (2) strategy, and (3) production. Landa (1974, 1976) described content applications as teaching students to solve problems by using algorithms. This approach results not only in the solution of the immediate problem, but also trains students to approach other problems in an algorithmic fashion. Content applications of algorithmic processes relate to instructional design efficiency in the sense that an increase in instructional effectiveness of the content would indicate an increase in the efficiency of the design.

Landa (1976) and Mitchell (1980) describe instructional strategy applications as algorithms which aid the student in learning. Instructional strategy applications are procedures for teaching specific kinds of learning tasks. Instructional strategies may be developed at the heuristic, quasi-algorithm, and algorithm levels. Typically, generally defined and less specific tasks are approached using heuristics. As learning tasks are more clearly defined and specific it becomes possible to use quasi-algorithms. Only the most clearly defined and highly specific learning tasks are suitable for applying algorithms.

Instructional materials production applications of algorithmic processes increase design efficiency by relieving in-

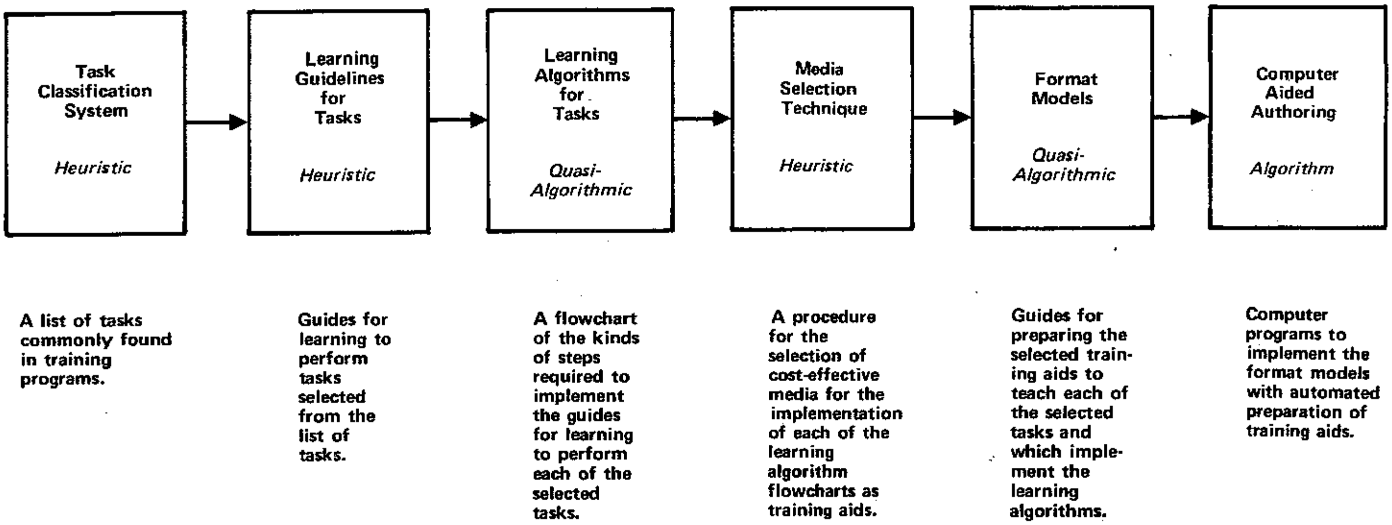


Figure 1. Progression of the TAEG development effort.

structional designers of much of the tedium and repetitious drudgery involved in the actual design and production of materials. Unskilled labor, using algorithms generated by the instructional designer, can perform such tasks as test item construction test administration, and data coding. Computer data bases can be established for task analyses, behavioral objectives, and test items. Computer aided authoring, editing, and publishing programs such as word processing, readability analysis, graphics production, exercise and test generation, and layout of the printed page are other examples of how production algorithms release the instructional designer for more creative efforts and increase designer efficiency.

The Training Analysis and Evaluation Group (TAEG), working for the Chief of Naval Education and Training, is heavily involved in the effort to increase instructional design efficiency. Figure 1 shows the progression of the TAEG effort beginning with sets of heuristics in the form of learning guidelines which were developed for training sailors to perform eleven discrete types of learning tasks. Quasi-algorithms were then developed for each set of the learning guidelines. A set of heuristics was established for selecting media to implement each of the learning algorithms. Format models were developed as quasi-algorithms for the preparation of training aids for each of the learning algorithms. Computer based production algorithms were developed to guide authors in producing training aids for the most common types of tasks. Other computer based production algorithms were also developed for text and illustration processing, and for calculating readability of text and providing a guide for editing.

Background

The Naval Training Command is responsible for teaching over four thousand courses. In contrast to general education, graduates of Navy courses are expected to perform specific tasks in their duty assignments as a result of training. The welfare and safety of their shipmates and ultimately the national security are dependent in large measure on the quality of the training program. The rapid pace of technological change creates a tremendous demand for course revision. Equipment, strategy, or tactical innovations within our own or a potential adversary's forces will usually require major revisions in all courses related to the area of change. For example, the Navy will soon adopt a hovercraft for amphibious troop landings. This innovation will require the development of operation and maintenance procedures, technical manuals, and training courses. Also, there will be a lengthy period of constant revision as maneuvering techniques and related equipment modifications develop.

Instructional Program Development (IPD) centers are charged with the basic responsibility for course development and revision within the Naval Training Command. The IPD center personnel, utilizing Instructional Systems Development (ISD) (NAVEDTRA 110) procedures, are responsible for a major portion of the Navy instructional design activity, however, the demand for course development and revision is so great that the IPD centers can handle only high priority requests. A significant portion of the course development and revision activities must be performed within the schools by the subject matter experts (SME) who have little or no training in ISD. TAEG's development of instructional design algorithms is an effort to support the IPD center activity with more efficient procedures and to provide guidance for SMEs in the development of certain kinds of instructional materials.

The development and validation of algorithms is a lengthy and costly process. The TAEG effort is limited to five kinds of learning tasks: recall of bodies of knowledge, symbol learning, rule learning, procedure learning, and classifying. These five learning tasks were selected because they occur most frequently in Navy training courses and they were considered to have a reasonably high potential for successful adaptation as algorithms. Finally, the TAEG effort is limited to the development of print and CAI media algorithms for each of the five types of learning tasks. Print was selected because of its current frequency of use in Navy training. CAI was selected because major commitments within the Naval Training Command indicate CAI will be adapted as a major medium in future course develoment activities.

Algorithms In Instructional Design

The instructional designer's role is divided among professional and routine tasks. Professional tasks place great demands on their creative insight, theoretical knowledge (e.g., evaluation systems, learning theory, diffusion/dissemination theory, etc.), and interpersonal skills. Instructional designers who are weak in some skills may compensate with strengths in others. Instructional designers have usually not been formally trained in the design processs. Rather, they acquire a repertoire of heuristics from such activities as formal course work, personal experience, and review of professional literature. The quality of instructional designers is determined by the depth of their repertoire and intuitive ability to apply heuristics in a variety of instructional problem situations. However, the instructional designer may be trained to perform the routine tasks that make up the craft of instructional design. The routine tasks include specific techniques for instructional design activities (e.g., task analysis, needs assessment, specification of objectives, test writing, etc.). The instructional designer utilizes professional skills in the process of selecting a set of routine tasks appropriate to the instructional problem. The implementation of the routine task activity might be expedited by relying on an algorithm for actual performance. Or, the instructional designer might devise an algorithm so that the task could be performed by an untrained assistant.

This assignment to lower level staff occurs after the designer has defined the input and the outcome and has limited the scope of the algorithm to the specific class of problem. The assistant (human or machine) performs only the execution of the algorithm. The instructional designer, relieved of the routine drudgery, which is often a major time consumer, is freed to perform at the professional level on other instructional problems. In this way the instructional designer is able to use differentiated staffing to increase efficiency while at the same time maximizing control through specification of algorithms.

TAEG Algorithm Development Effort

The first step (see Figure 1) in the progression of TAEG's effort to increase instructional design efficiency was identifying the learning tasks which occurred most frequently in Navy training. Eleven types of learning tasks were originally identified (Aagard & Braby, 1976) and the descriptive characteristics for each task was clearly defined. Next, a set of learning guidelines was developed for each learning task. The learning guidelines were actually a list of heuristics drawn from a review of the literature on learning theory which seemed to apply to each learning task. While the task definitions and heuristics of the learning guidelines were valuable resources for the professional designer, they would make a minimal contribution to increasing efficiency. Aagard and Braby (1976) went on to develop learning algorithms (actually quasi-algorithms) for each of the eleven learning guidelines. Figure 2 is a simplified version of the flow diagram of the quasi-algorithm for procedure learning. Though more precise and structured than the heuristics, the prescriptive directions were still not always specific enough to provide desired results. The learning algorithms, by themselves, were not sufficient to make a significant contribution toward increasing the efficiency of instructional design.

Media Selection

Effort to increase instructional design efficiency through application of algorithms was extended with the Training Effectiveness, Cost Effectiveness Prediction (TECEP) technique (Braby, Henry, Parish, & Swope, 1978). TECEP is a set of quasi-algorithms for selecting appropriate media and media mixes called delivery systems. Also included is a cost model which estimates the cost of alternate instructional delivery systems capable of producing the desired instructional events. TECEP is unique in that a separate instructional delivery system chart has been devised for each of the learning algorithms. This enables designers to tailor TECEP to the specific requirements of each learning algorithm.

It seems reasonable to assume that the selection of appropriate and cost-effective instructional delivery systems would make a major contribution to increasing the efficiency of instructional design. However, print continues as the dominant instructional medium in Navy training. The impact of TECEP is minimized when the major instructional materials production requirement is for printed materials such as training aids, job aids, operational manuals, maintenance manuals, technical manuals, and text books. The effectiveness of an individual instructional program might

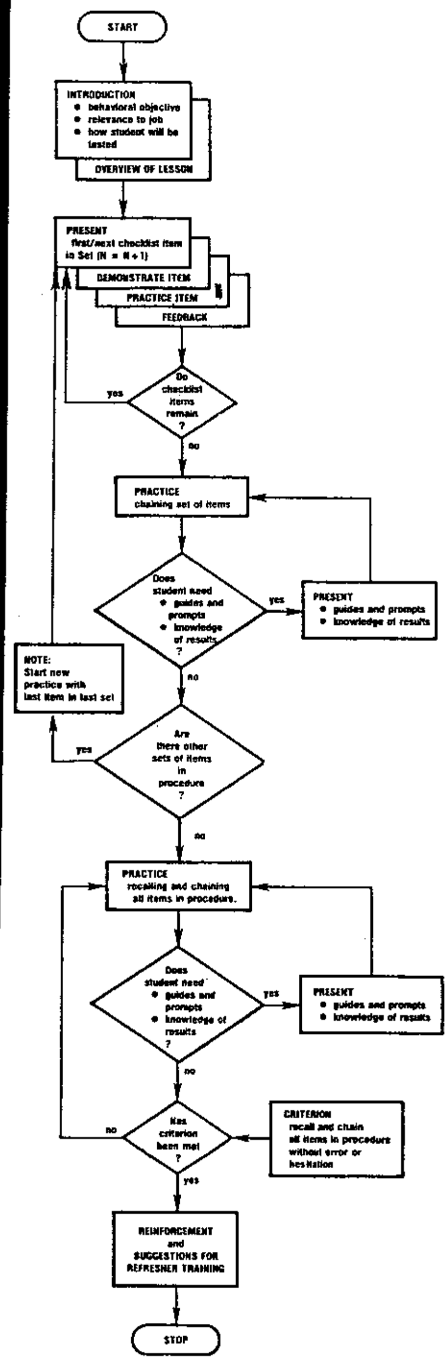


Figure 2. Learning algorithm for procedure learning.

be enhanced by TECEP, but the overall efficiency of instructional design would be most affected by reducing the cost and speeding the production of print materials.

Recent activities within the Naval Training Command indicate commitment to wide-spread use of computer assisted instruction (CAI). The potential demand for the design and production of CAI programs suggests that increased efficiency would have a major impact. It was also determined that five of the eleven learning tasks (recalling bodies of knowledge, symbol learning, rule learning, procedure learning, and classifying) were used frequently and that an increase in their production efficiency would have a major impact on overall instructional design efficiency. Thus, recently, TAEG's efforts toward increasing instructional design efficiency have concentrated first on the print medium and then CAI for the five most frequently encountered learning tasks.

Format Models

Quasi-algorithms for production were developed as guides for page layouts of printed training aids which would require students to perform the learning algorithms. Figures, 3,4,5, and 6 illustrate the sequence of page layout formats for Procedure Training Aids. These figures are taken from the *Format Models for Technical Training Materials* (Braby, Brown, & Smode, 1982) which was prepared as a guide for authors of job training materials. The format models are also published in *Procedures for Instructional Systems Design* (NAVEDTRA 110A) which is the Navy manual for authors of instructional materials.

Figure 3 illustrates the Information Page which contains all information to be taught in the Procedure Training Aid. As stipulated by the learning algorithm, the format model relies heavily on visual illustration with limited text to transmit information. Figure 4 illustrates the Paraphrase Page, which is a self-check to aid the reader to determine whether he/she remembers the information. Figure 5 illustrates the Finger Tracing Page which is a heavily prompted exercise in the sequence of steps in a procedure. The reader is expected to recall actions and responses for each step without prompts. Figure 6 illustrates the Paper Mock-Up which requires the reader to trace the sequence of steps in a procedure and recall the actions and responses at each step without prompts.

TAEG has developed training aids for validation of the format models for each of the five types of learning algorithms. Evaluation of the training aids is directed toward determining whether the learning algorithms improve students learning and whether the format models provide sufficient guidance to assure efficient and effective production of the training aids.

Evaluation Of Training Aids

Symbol Learning—Morse Code. A morse code training aid (Braby & Ainsworth, 1979) was produced using a set of computer automated page formats based on the learning algorithm for symbol learning. The training aid was tested on 160 Navy and Coast Guard enlisted men enrolled in Signalman School, Service School Command, Naval Training Center (NTC), Orlando, FL. Morse Code Sending Scores for average and above average aptitude students were higher for those using the Signal Learning Training Aid (SLTA) than for those using the traditional Morse Code Training Materials. Morse Code Receiving Scores for average and above average aptitude students were higher for those using SLTA than those using the traditional materials.

Procedure Learning—Oscilloscope. A *Probe Calibration Procedure Training Aid* for the Tektronics 545B Oscilloscope was developed using the page formats based on the learning algorithm for Procedure Learning. The Procedure Training Aid was tested against a Traditional Narrative Handbook and a Job Performance Aid. The Procedure Training Aid relied heavily on visual illustrations with limited verbal text for clarification and specific directions. It also implemented the learning algorithms for Procedure Learning by providing practice exercises and self-tests. The traditional narrative handbook relied heavily on verbal text with limited visual illustration. The Job Performance Aid relied heavily on visual illustration and verbal text similar to that of the Procedure Training Aid, however, it did not include the practice exercises and self-tests.

Higher and lower aptitude students using the Procedure Training Aid had fewer performance errors on the operation of the oscilloscope than students using the other training methods. Since the primary difference between the Procedure Training Aid and the Job Performance Aid is the practice exercises and self-tests, some support must be noted for the value of the learning algorithm for Procedure Learning. Students using the Traditional Narrative Handbook tend to score higher on Job Knowledge Tests than students in the other training methods. The Job Knowledge Test results and Performance Test results indicate that the Traditional Narrative Handbook tends to be more successful at teaching verbal information about operation of the oscilloscope and the Job Performance Aid and the Procedure Training Aid tend to be more successful at teaching operation of the oscilloscope. The relative merits of the respective treatments would depend upon whether the expected outcome of training were knowledge about, or the ability to perform, a procedure.

Procedure Learning—Helicopter Training. A Normal Start Checklist Procedure Training Aid for the SH-3D/H Helicopter was developed using the page formats based on the learning algorithm for Procedure Learning. The Procedure Training Aid was tested on thirty-five students in pilot training at Fleet Replacement Helicopter Squadron One (HS-1), Naval Air Station, Jacksonville, FL. The Normal Start Checklist is a 200 step, 31 item checklist that students found difficult to master using the traditional instructional materials. The traditional instructional materials include the *Naval Air Training and Operations Procedures Standardization* (NATOPS) manual and a student workbook. The Procedure Training Aid for the Normal Start Checklist (Figure 7) included practice exercises and self-tests prescribed by the Procedure Learning algorithm.

Over 50% of the students using the Procedure Training Aid attained proficiency on the first trial and all of the remaining students achieved proficiency by the fifth trial. Twelve percent of the students using the traditional materials attained proficiency on the first trial and it took ten trials for all the remaining students to attain proficiency.

Rules of the Road—Lights. The instructional module *Rules of the Road: Lights* (Thomas, Terrell, & Braby, 1982) has been developed and is presently being tested with students enrolled in Quartermaster School, NTC, Orlando. Section One of the module is based on the page formats for the learning algorithm for Recalling Bodies of Knowledge (Nomenclature). Students learn the names and relevant facts about ship's lights. Section Two of the module is based on the page formats for Rule Learning. Students learn the rules

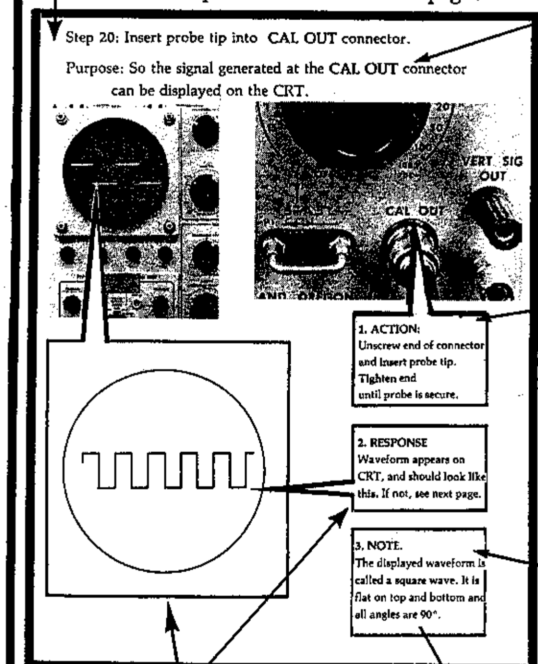
PROCEDURE FORMAT MODEL

A general format for use in designing training materials which present steps of a procedure to be performed from memory.

Procedure Format - Page 1

Use this page format to present each step in a procedure.
The purpose of this page format is to present:
- a word description of the step—emphasize human action.
- a visual display of the step—emphasize human action.
- the purpose of the step.
- the location of actions on equipment.
- the system response to actions taken.
- notes—additional needed information.

Break procedure into logical steps.
(Each step should start on a new page.)



Keep purpose short and simple.

Use line drawings or photographs.

If possible, each step should have no more than 3 or 4 actions.

State Action, and Response if there is one, and any Note. Number the boxes in the order you want them read.

Use notes to present additional information that must be recalled and used on the job.

If the system makes a response that should be noted or checked, present the response.

Underline key words.

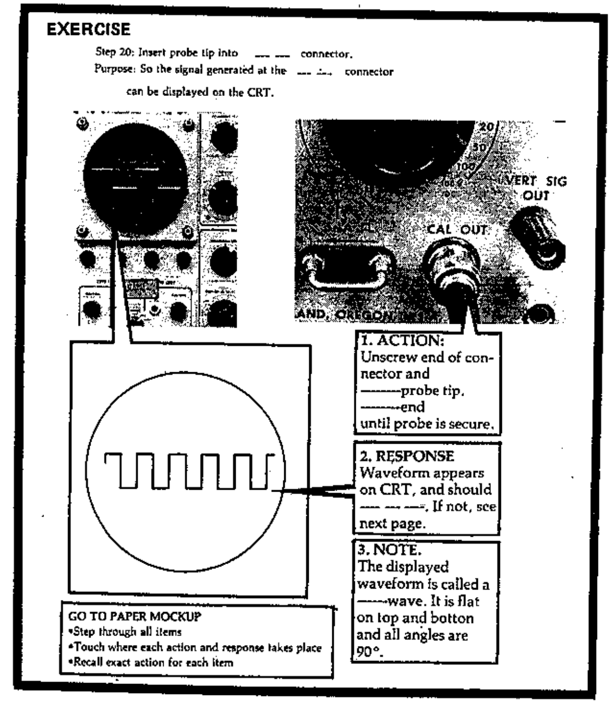
Keep pages simple, with no more than 3 or 4 boxes per page. Use additional pages if necessary.

Figure 3. Procedure format information page.

Use this page format immediately following each use of the page 1 format.

The purpose of this page format is to:
- provide students exercise in the recall of key words in the procedure.
- direct the students to practice the step on the paper mock-up.

Copy the previous page. Then drop out key words that were underlined on the previous page.



Add directions requiring students to go to the paper mock-up to practice the step.

Figure 4. Procedure format paraphrase page.

regarding the display of ship's lights and practice applying the rules. Section Three of the module is based on the page formats for Classifying. Students learn to recognize ship's lights in various real-life situations and to classify the activity, direction, and general characteristics of vessels at sea by the lights they display.

Formative testing during development indicates a probable high degree of success for the Nomenclature and Classifying formats. Since the validation studies are currently in progress, no definitive results are available.

Production Algorithms For Page Layouts

While the format models provide instructional strategy algorithms for teaching the learning tasks, the quasi-algorithmic nature of the *Format Model Handbook* is not considered to be a sufficient guide to authors to assure the production of training aids which follow the learning algorithms. The *Guide for the Preparation of Procedure Training Aids* (Terrell, 1982) is a production algorithm for the manual production of page layouts for the procedure learning format. The Procedure Training Aid author who precisely follows the algorithm for page layouts will always arrive at an outcome which looks like a Procedure Training Aid and which requires students to perform the steps of the procedure learning algorithm. The quality and accuracy of the Procedure Training Aid is determined by the appropriateness of the author's data base which was built through application of the quasi-algorithm for analysis, design, and procedure learning (NAVEDTRA 110A).

The *Guide for the Preparation of Procedure Training Aids* was developed as a test to determine whether production algorithms for each of the format models was feasible and acceptable to authors of training materials. The Guide was tested in the development of the *Initial Control Setting Procedure Training Aid* for the AQS-13E SONAR in the SH3-D/H Helicopter. A subject matter expert with no previous training in the design of production of instructional materials, was able to prepare the training aid following the production algorithm presented in the Guide. Though it has not been formally evaluated, instructors report that prior to use of the Procedure Training Aid, beginning students required twenty minutes to perform the forty-one item checklist. With use of the Procedure Training Aid the same procedure is performed in less than one minute. Though apparently successful in producing an effective training aid, the novice designer reported that the page layout process required by the Guide was tedious and time consuming. The format model for procedure learning resulted in more efficient instructional design in the sense that an SME, untrained in instructional design, could produce an effective procedure training aid. However, the labor involved in the design and actual production of the page layouts would discourage preparation of Procedure Training Aids by anyone except the most dedicated instructional designers.

A computer automated page layout system for Procedure Training Aids (Terrell, 1982) was developed to minimize the labor involved in the preparation of Procedure Training Aids. Machine production includes the actual page layout, printing of boxes, and printing of text. An advantage in using computer automation is the greater compliance of the outcome to the procedure learning format because the computer requires precise adherence to the algorithm. Figure 8 illustrates the comparison between manual and computer automated preparation of a page layout. The computer automated Page Layout (PLA) program is currently being tested for effectiveness in field situations and for acceptance by SMEs and instructional designers preparing procedure training aids.

Studies have already been conducted which have established the effectiveness of the symbol learning format model and a computer automated authoring system for symbol learning (Braby & Ainsworth, 1979). Studies are currently underway to test the effectiveness of the format models for recall of bodies of knowledge, rule learning, and classifying (Thomas, Terrell, & Braby, 1982; Braby & Brown, 1982).

Authoring Aids

TAEG has also developed the Computer Readability Editing System (CRES) and the Text and Illustration Processing System (TIPS) as part of the total effort to increase the efficiency of instructional design. CRES (Kincaid, Aagard, & O'Hara, 1980) is a set of machine-performed algorithms which analyze the reading level and suggest editing changes as a method of improving the readability of instructional materials. The CRES contributions to increasing the efficiency of instructional design are more comprehensive editing, reduction of time, and elimination of drudgery by replacing the human search for text problems with a machine search. The human role is reserved for intuitive application of the creative editing skills required to improve text readability.

The *Text and Illustration Processing System* (v.1, Brown & Cox, 1982; v.2, Cox & Braby, 1982) is part of the TAEG effort to increase the efficiency of instructional design. The intent is that text and graphic data bases will be built and drawn upon for the production of a variety of instructional materials including training aids based on the learning algorithms.

Graphics represent a particularly high cost and time consuming element in the production of heavily illustrated printed instructional materials. In many cases, local production of highly illustrated materials as training aids by SMEs is nearly impossible because graphic art support is not available. The TIPS graphic processing system is still under development though some elements are currently operational. If proven successful, the computer generation, storage, and reproduction of line art and half-tone graphics will make a significant contribution toward increasing the efficiency of instructional design.

Summary

The effort to increase the efficiency of instructional design included strategies to provide maximum use of the professional skills of designers, reduce the time required for design, reduce the cost of design products, and maximize the effectiveness of design products.

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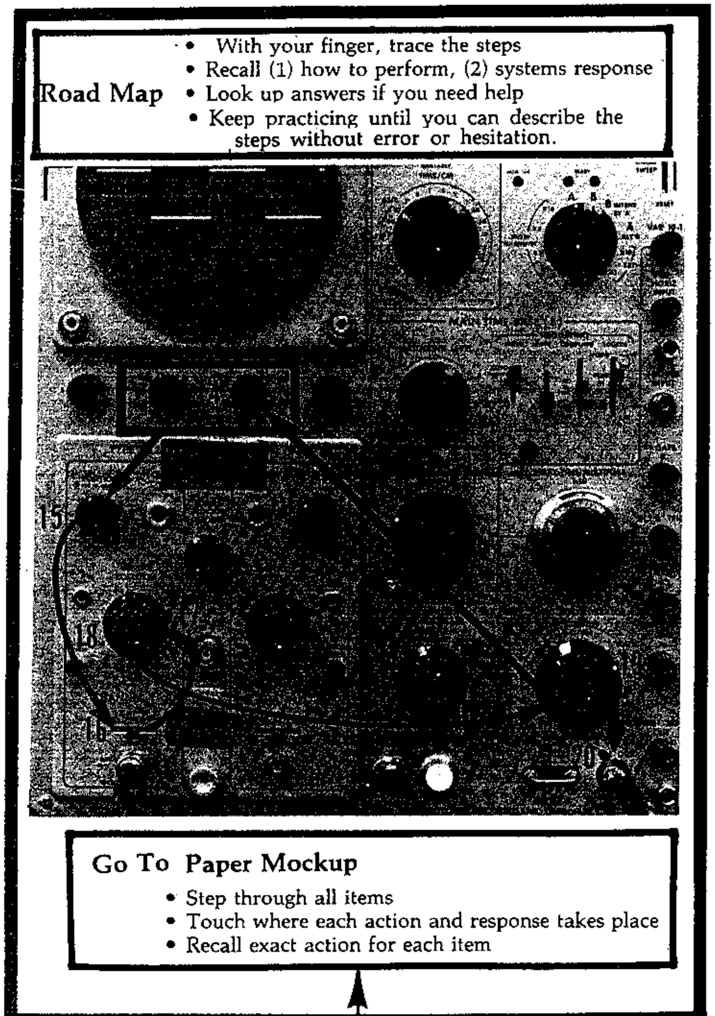
Use this page after presenting each set of 3 to 7 steps in a procedure.

The purpose of this page format is to provide a finger-tracing exercise to aid students in recalling a sequence of steps.

For each cluster of 3 to 7 steps, present a Road Map showing how the steps are chained together.



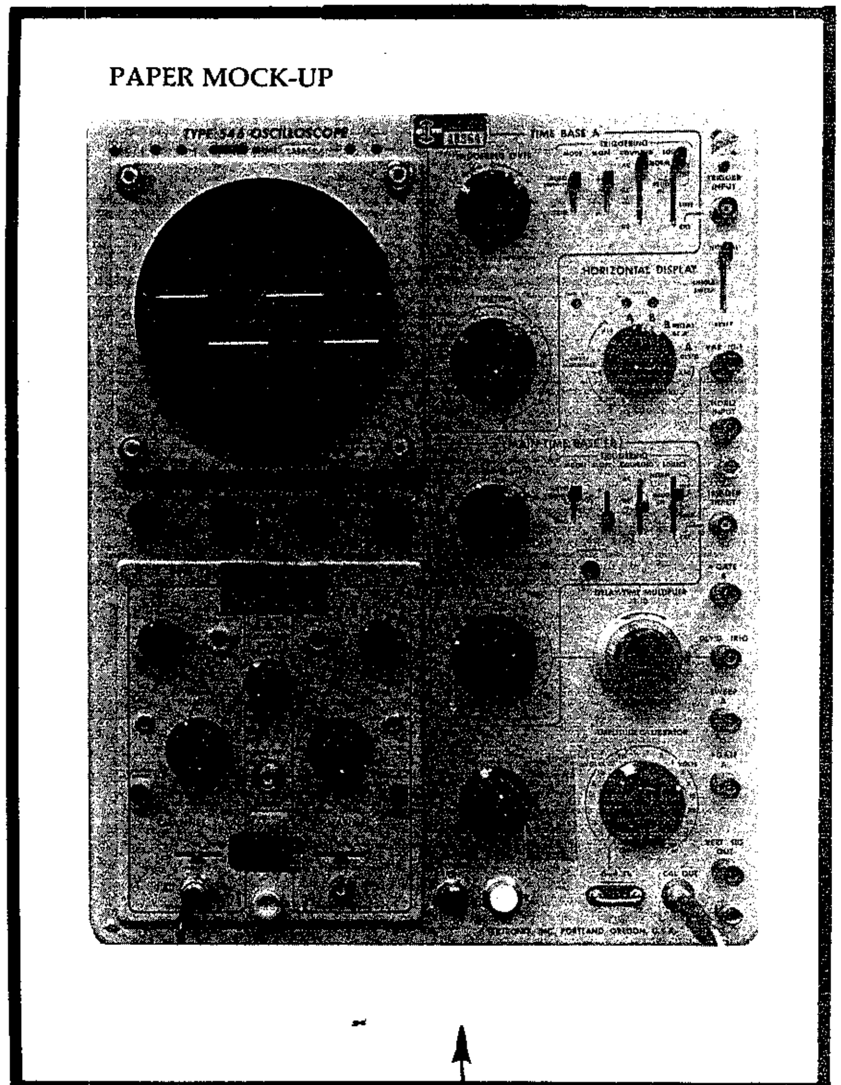
Present last step from previous cluster.

If the procedure is to be performed on the job with a checklist, present the checklist items here.

Figure 5. **Procedure format finger tracing page.**

Use this type of page at the end of the learning module.

The purpose of this page format is to provide students with a way to practice one step, a set of steps, or all the steps in a procedure without the use of guides and prompts.



Make sure this page is a foldout that can be used at any time.

If the procedure is to be performed on the job with a checklist, present the entire checklist here, or on the opposite page where it can be easily seen while viewing this page.

Figure 6. **Procedure format paper mock-up.**

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NORMAL START CHECKLIST ITEM NO. 28. No. 1 Overspeed System . . . . CHECK.

Purpose: To simulate an overspeed condition for checking the electrical overspeed system.

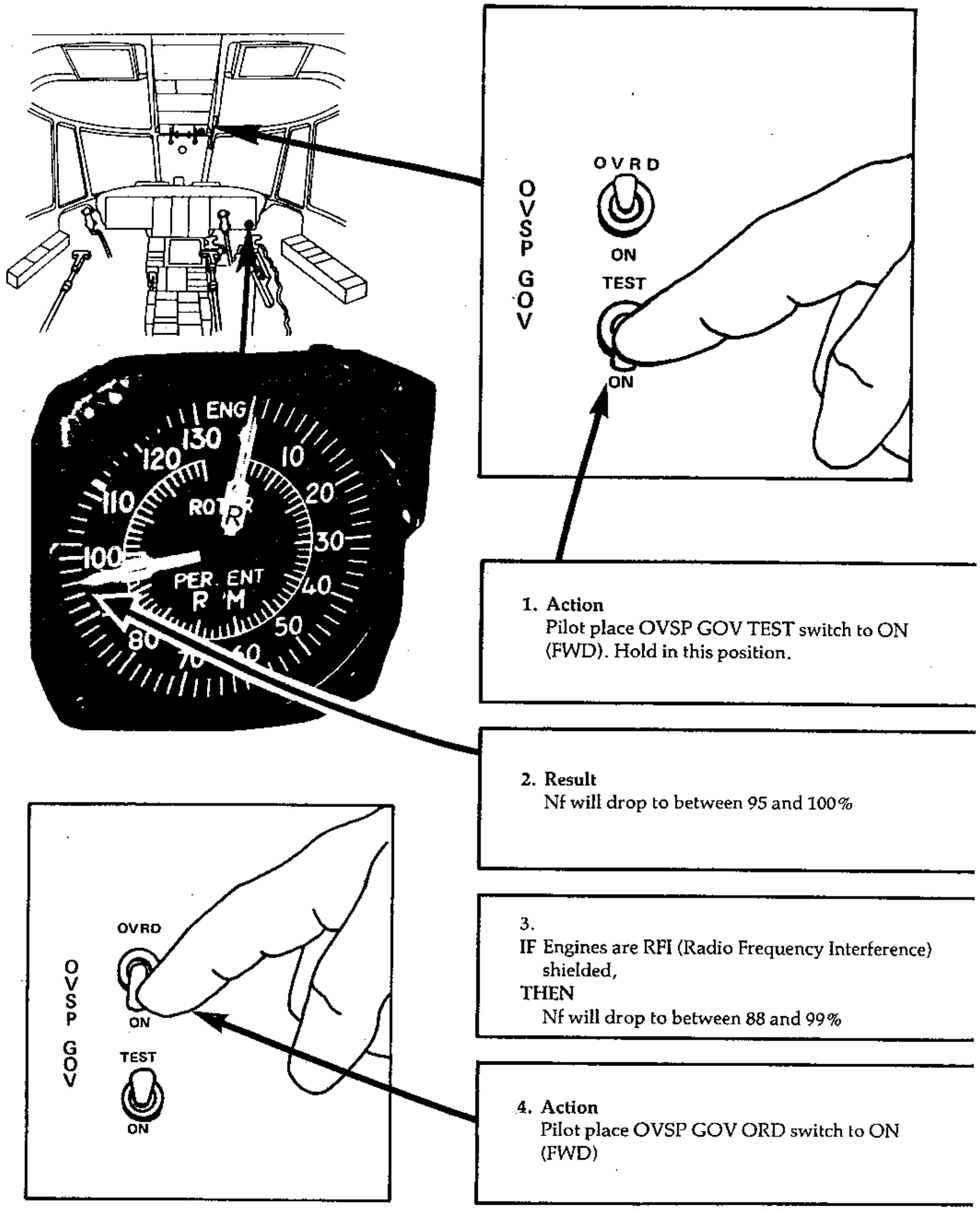

Figure 7. Normal start checklist procedure training aid.

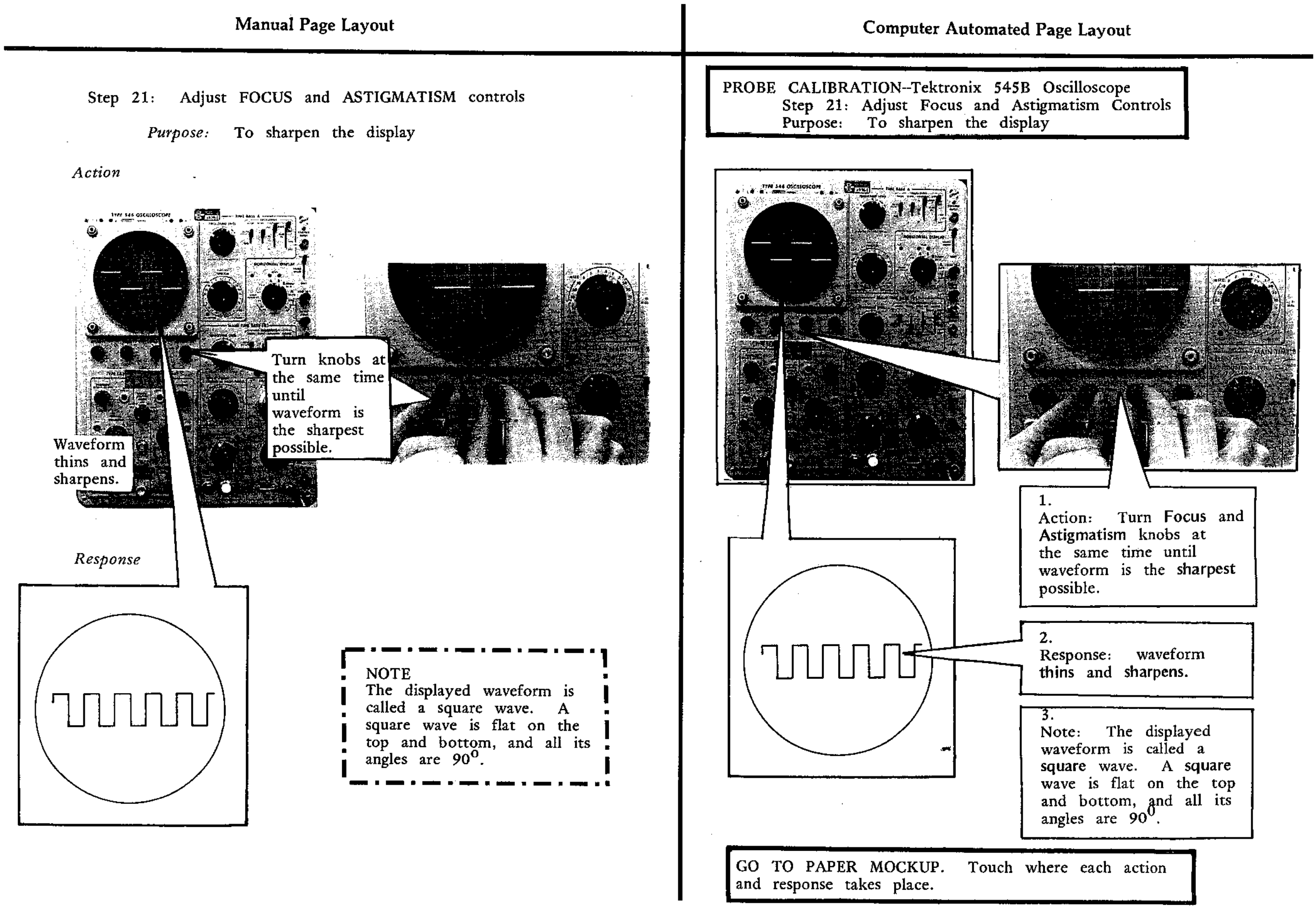

Figure 8. Page layout algorithm for procedure training aids.