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Research Note 83-3

AN APPROACH TO FIDELITY IN TRAINING SIMULATION

Jon S. Freda and Halim Ozkaptan

MANPOWER AND EDUCATIONAL SYSTEMS TECHNICAL AREA

U. S. Army
Research Institute for the Behavioral and Social Sciences

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JOSEPH ZEIDNER
Technical Director

FRANKLIN A. HART
Colonel, US Army
Commander

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Jon S. Freda and Halim Ozkaptan

Submitted by:
Halim Ozkaptan, Acting Chief
MANPOWER AND EDUCATIONAL SYSTEMS TECHNICAL AREA

Approved by:
James D. Baker, Acting Director
ORGANIZATIONS AND SYSTEMS
RESEARCH LABORATORY

U.S. ARMY RESEARCH INSTITUTE FOR THE BEHAVIORAL AND SOCIAL SCIENCES
5001 Eisenhower Avenue, Alexandria, Virginia 22333

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Training
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FOREWORD

The Manpower and Educational Systems Technical Area of the Army Research Institute for the Behavioral and Social Sciences (ARI) is concerned with improving individual and unit training through research in the design, methodology, and implementation of instructional delivery systems. One aspect of this research is to understand the relationship between media selection and fidelity requirements in training simulation.

This report focuses on guidelines to aid in the determination of fidelity in Army training simulation. Work on this technological base effort was accomplished under Army Project 2Q162717A790, Human Performance Effectiveness and Simulation (FY 80).

JOSEPH ZEIDNER
Technical Director

AN APPROACH TO FIDELITY IN TRAINING SIMULATION

BRIEF

Requirement:

To provide general guidelines for determining fidelity requirements in training simulation.

Procedure:

Army training systems were organized and delimited within a two-dimensional matrix. Fidelity issues and assumptions were discussed within the framework of this matrix. An information-processing approach was then applied to answering fidelity questions as they relate to media selection issues.

Findings:

Media allocation questions (between-media selection) should follow the development of training requirements and instructional strategies but precede the addressing of fidelity issues (within-media selection). Mapping training tasks onto basic learning tasks within an information-processing approach may aid decisionmaking in fidelity requirements for training simulation.

Utilization of Findings:

Applying the information-processing approach to training simulation may provide an initial groundwork for improving determination of fidelity requirements.

AN APPROACH TO FIDELITY IN TRAINING SIMULATION

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AN APPROACH TO FIDELITY IN TRAINING SIMULATION

This paper presents some ideas concerning the development of fidelity recommendations in training simulation. Fidelity is a major issue partly due to an increasing concern that the amount/kind of fidelity incorporated in devices and simulators, as currently requested by the Army training schools, may not result in cost effective transfer of training. The approach of this paper is as follows: first, Army training programs are organized within a two-dimensional matrix within which training simulation is delimited; second, definitions, assumptions, and constraints underlying fidelity are discussed; and finally, a conceptual analysis which distinguishes between-media selection from within-media selection is presented. Within-media selection is viewed as an extension of Block III of Interservice Procedures for Instructional Systems Development (IPISD), 1975, and is discussed in the form of a set of procedures to guide the selection of the appropriate amount of fidelity.

GENERAL ORGANIZATION AND DELIMITATION OF ARMY TRAINING SYSTEMS

Current Army training systems can be organized on a global level in terms of (a) the nature of interactions within the training setting and (b) the predictability of events within the operational setting. That is, the nature of training system interaction can be man ascendant (primarily man-man interface) or machine ascendant (man-machine interface). Predictability of operational events can be described as an emergent situation (low predictability) or as an established situation (high predictability) (Erwin, 1978). The cells within this 2 x 2 matrix represent a starting point from which to focus interest on the fidelity issue in training simulation (see Table 1).

The goal, cost-effective transfer of training, is achieved in part by selecting the appropriate amount of fidelity in training simulation. With this goal as a reference, this paper discusses fidelity as it relates primarily to training in machine ascendant, established situations. Thus, current interest in simulation focuses on man-machine interfaces in training for subsequent transfer to highly predictable operational settings. This focus in training systems lends itself to S-R analysis and CFD (Criticality, Frequency, and Difficulty) analysis of operational settings for developing fidelity recommendations (Cream, Eggemeier, & Klein, 1978; Erwin, 1978).

DEFINITIONS, ASSUMPTIONS, AND CONSTRAINTS UNDERLYING THE FIDELITY ISSUE

Fidelity in training simulation refers to the amount/kind of similarity between the training device (setting) and the operational equipment (setting). Fidelity can be conceptualized in terms of physical fidelity (engineering [hardware] representation of features in the operational equipment) and psychological fidelity (behavioral [functional] representation of the information processing demands of the operational equipment). Within psychological fidelity, the skills and knowledge required in the operational setting can have a peripheral focus (concentrating on sensory input and/or psychomotor output) or a central focus (primarily cognitive skills/strategies). Within physical

Table 1

Matrix Depicting a General Organization of Military Training Programs
(Matrix Cells Contain Appropriate Examples)

Nature of interactions in the training setting		Predictability of operational events[a]: Emergent situation	Predictability of operational events[a]: Established situation
	Man ascendant (man-man interface)	Engagement simulation team (CGTU) training Manual gaming	Classroom lecture
	Machine ascendant (man-machine interface)	Computer adaptive testing (branching; nonlinear approach) Computer gaming	Training devices Simulators[b] CAI with linear approach

[a]Discussed in Erwin (1978).

[b]Equipment capability spectrum: full mission to part-task trainers.

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fidelity, the overall training configuration in which display and control formats are presented to the trainee can be viewed as a between-media selection (also known as media-selection or choosing instructional delivery systems). When the between-media selection is made, then the issue of within-media selection is addressed; cost effective, representative features of the displays and controls are chosen for incorporation in the training media selected. Within-media selection is synonymous with the current use of the term fidelity (see Figure 1).

It is assumed that training requirements should drive device features. That is, psychological fidelity (as a reflection of training requirements) should guide physical fidelity (as a reflection of device features). These statements mean that the behavioral skills and learner strategies displayed or used in the operational setting should be prompted/elicited by the cues or features incorporated in the training setting. Traditionally, the full-mission simulation approach has concentrated on duplication of the appearance and functioning of the operational equipment for training purposes (also referred to as the "Stimulation vs. Simulation" controversy; see Montemerlo, 1977).

"Shotgunning," simulated duplication of operational equipment, provides an array of training device cues/features, some of which are critical for skill acquisition. However, shotgunning, when a high degree of fidelity is included in training devices, is very costly. This shotgun approach, although apparently reliable in the past, has recently come under budgetary scrutiny. Fiscal constraints limit the amount of RDTE money for development of sophisticated training systems. Therefore, the training community asks the question, based primarily on the perspective of physical fidelity and training hardware notions: What is the level of fidelity required to insure cost effective transfer of training? From the behavioral researcher's point of view, however, the question posed is "What are the cues/features that best train the behavioral skills and learner strategies required in the operational setting?" The researcher's perspective views simulation as a continuum of media differing in configurational similarity to the operational equipment, while the training community's perspective views simulation as more closely alined with the operational configuration (see Figure 2).

One major issue underlying the difference between the perspectives of the researcher and of the training community is the influence that the timing and nature of the media selection process has on the development of a training system. It is assumed that between-media selection should follow the development of training requirements and instructional strategies but should precede within-media selection (see IPISD, 1975). Figure 3 presents a conceptual flowchart of the activity sequence leading to fidelity recommendations. Note that this sequence reflects the aforementioned idea that training requirements should guide device features. The IPISD takes one up to and including between-media selection. The next section will discuss how one can structure questions to address the within-media selection (fidelity) issue.

WITHIN-MEDIA SELECTION

This analysis involves an information-processing approach. The steps are as follows:

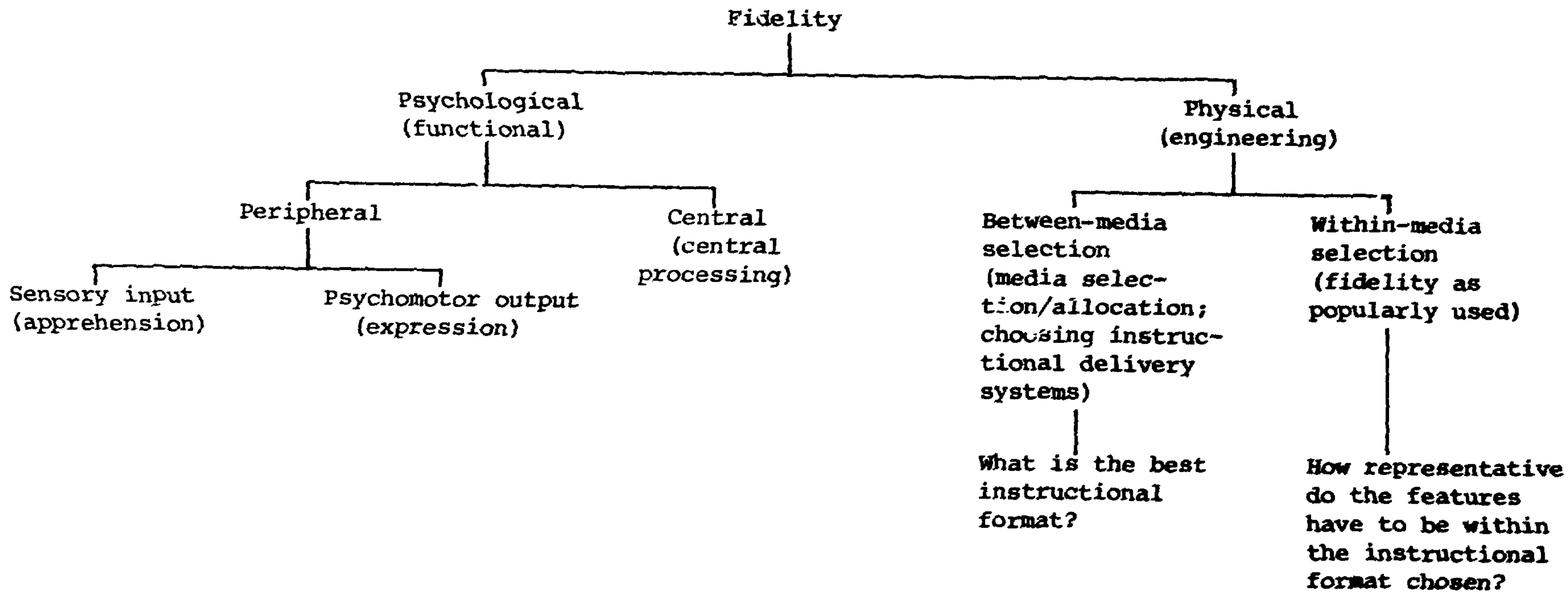

Figure 1. Breakdown of fidelity issues in training simulation.

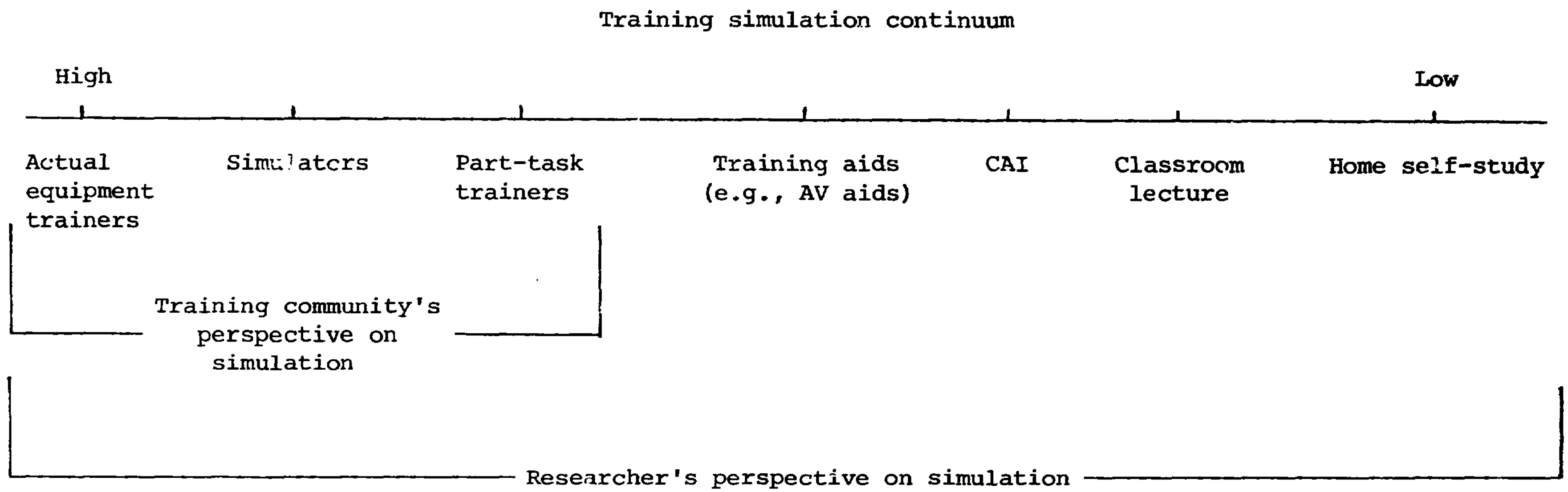

Figure 2: Degrees of physical similarity of device features in the training setting to those in the operational setting.

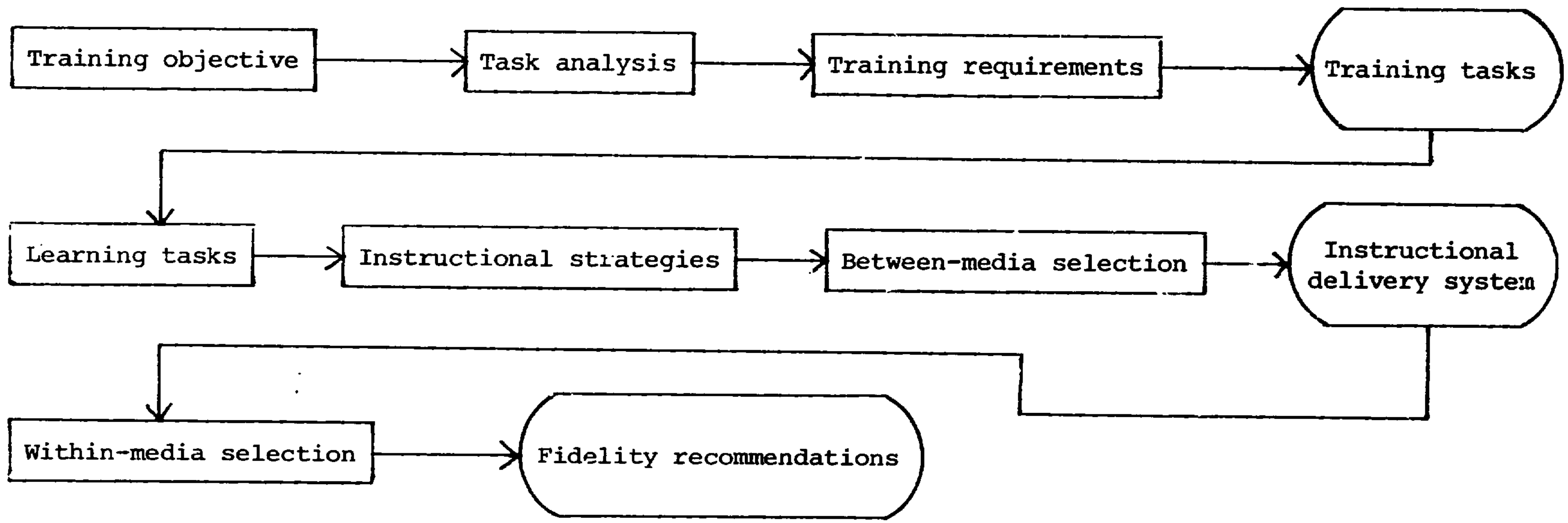

Figure 3. Sequential flow of activities for developing fidelity recommendations.

1. Map the training tasks onto the learning tasks specified in Navy Training Analysis and Evaluation Group (TAEG) Reports 16 and 23, and IPISD, Blocks II and III. Focus on the 11 learning tasks presented in TAEG Report 23 (excluding attitude learning task). Each learning task describes what the individual is required to do in the operational setting.

2. Analyze each learning task in terms of the information-processing demands required of the individual in the operational setting. These information-processing demands can be viewed as a sequential flow of three information-processing stages:

Sensory Input → Central Processing → Psychomotor Output

Sensory input refers to the degree of the Criticality, Frequency, and Difficulty (CFD) involved in the apprehension of operational stimulus parameters for supra-threshold input processing. Central processing refers to the degree of CFD involved in using cognitive skills and strategies to select the appropriate psychomotor output based on the sensory input. Psychomotor output refers to the degree of CFD involved in the expression of the appropriate behavioral response. CFD is a subjective rating system graduated in high, medium, or low values. The sources of authority for completing these fidelity ratings are the users, training psychologists, and design engineers (Cream et al., 1978). The following assumptions underly this approach:

a. Sensory input and psychomotor output reflect peripheral psychological fidelity, and central processing reflects central psychological fidelity.

b. There is an equivalence between training requirements and psychological fidelity, and between device features and within-media selection.

c. CFD ratings of sensory input and psychomotor output are related directly to the physical representativeness of the respective device features; the CFD ratings of central processing are only partially related to the physical representativeness of the respective device features.

The above-mentioned assumptions mean that if there is a large degree of dependency on incoming stimulus parameters in the operational setting and/or on the expression of a behavioral response in the operational setting, then high CFD ratings in sensory input and/or psychomotor output would reflect the need for a higher degree of physical fidelity in the device features than if the CFD ratings were lower. However, CFD ratings for central processing reflect an emphasis on cognition, rather than psychophysical dependencies or environmental manipulation within the operational setting. Thus, functional considerations are only obliquely related to the physical representativeness involved in choosing device features for central processing dependency in the learning tasks. Figure 4 shows how questions pertaining to training requirements (psychological fidelity) and device features (physical fidelity in terms of within-media selection) can be addressed and rated/ranked in a parallel fashion.

3. Rate each learning task selected for training on the degree of CFD in performing within each information-processing stage in the operational setting.

	SENSORY INPUT →	CENTRAL PROCESSING →	PSYCHOMOTOR OUTPUT
Training Requirements (psychological fidelity) ▶	How much CFD is assigned to apprehend the information?	How much CFD is assigned to use the information?	How much CFD is assigned to express the information?
Device Features (within-media selection) ▶	What are the display alternatives that present the relevant sensory input?	What are the feedback/cue alternatives that aid cognitive skills/strategies?	What are the control alternatives that elicit the expression of the appropriate psychomotor output?

Figure 4. An information-processing approach to address questions in training requirements and service features.

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These subjective ratings can be ordered on a high, medium, and low continuum. Table 2 presents a description of each of the learning tasks (TAEG Report 23). Table 3 presents an example of CFD ratings for each information-processing stage by each learning task, based on the author's interpretation of Table 2. Note that the CFD ratings are subject to modification dependent upon the operational setting under study. Interpretation of the CFD ratings in Table 3 is as follows:

a. Learning tasks 1 through 4, 9, and 11 are low in CFD for sensory input. Therefore, the individual's dependency on physical stimulus parameters in the operational setting for supra-threshold information processing may be trained with device features not having a high degree of physical fidelity to the displays in the operational setting. However, learning tasks 5 through 8 and 10 would require a higher degree of physical fidelity for displays since the dependency is greater during sensory input.

b. Similarly, learning tasks 1 through 8 are low in CFD for psychomotor output, and thereby do not require a high degree of physical fidelity to the controls in the operational setting since training would be minimal for expression of the appropriate behavioral response. However, learning tasks 9 through 11 would require a higher degree of physical fidelity for the controls since there is a greater dependency during the expression of the behavioral response.

c. Learning tasks 1 through 11 for the central processing stage represent varying degrees of dependency on cognitive skills and strategies used by the trainee for performing the learning task to criterion. The greater the dependency (the higher the CFD rating), the greater the need for feedback cues that heighten the effectiveness of instructional strategies for training those skills. This dependency is primarily a functional consideration, and thus is only partially related to physical cues in the operational setting (if the cues do exist at all in the operational setting). Thus, CFD ratings on central processing guide instructional strategies rather than physical correspondence to the operational setting.

The subjective CFD ratings for training requirements (psychological fidelity) and the selection of current device features (within-media selection) are but first steps in the development of a systematic procedure to determine fidelity. What has not been discussed in this paper is the major metric underlying fidelity--transfer of training. The within-media selection procedure attempts to provide structure for fidelity questions, which can then be addressed via empirical research--research using transfer of training as the valid measure of success or failure of the training program (see Baker, 1976a, 1976b, for discussion of the validity issue as it pertains to transfer of training and simulation). Table 4 presents a guide into the academic and applied psychological research areas involved in transfer of training. It is hoped that this outline, in conjunction with the within-media selection procedure, will provide starting points for adding empirical validation to theoretical formulation.

Table 2

Eleven Types of Elemental Learning Tasks

Names of learning tasks	Characteristics of training objectives within task categories: Action verbs	Behavioral attributes	Examples
1. Recalling Bodies of Knowledge	Answer Define Express Inform Select	1. Concerns verbal or symbolic learning. 2. Concerns acquisition and long-term maintenance of knowledge so that it can be recalled.	1. Recalling equipment nomenclature or functions. 2. Recalling system functions, such as the complex relations between the system's input and output. 3. Recalling physical laws, such as Ohm's law. 4. Recalling specific radio frequencies and other discrete facts.
2. Using Verbal Information	Apply Arrange Choose Compare Determine	1. Concerns the practical application of information. 2. Generally follows the initial learning of information through the use of the guidelines for recalling Bodies of Knowledge. 3. Limited uncertainty of outcome. 4. Usually little thought of other alternatives.	1. Based on academic knowledge, determine which equipment to use for a specific real world task. 2. Based on an academic knowledge of the system, compare alternative modes of operation of a piece of equipment and determine the appropriate mode for a specific real world situation. 3. Based on memorized knowledge of radio frequencies, choose the correct frequency in a specific real world situation.
3. Rule Learning and Using	Choose Conclude Deduce Predict Propose Select Specify	1. Choosing a course of action based on applying known rules. 2. Frequently involves "If...Then" situations. 3. The rules are not questioned, the decision focuses on whether the correct rule is being applied.	1. Applying the "rules of the road." 2. Solving mathematical equations (both choosing correct equation and the mechanics of solving the equation). 3. Carrying out military protocol. 4. Selecting proper fire extinguisher for different type fires. 5. Using correct grammar in novel situation, covered by rules.
4. Making Decisions	Choose Design Diagnose Develop Evaluate Forecast Formulate Organize Select	1. Choosing a course of action when alternatives are unspecified or unknown. 2. A successful course of action is not readily apparent. 3. The penalties for unsuccessful courses of action are not readily apparent. 4. The relative value of possible decisions must be considered--including possible trade-offs. 5. Frequently involves forced decisions made in a short period of time with soft information.	1. Choosing frequencies to search in an ECM search plan. 2. Choosing torpedo settings during a torpedo attack. 3. Assigning weapons based on threat evaluation. 4. Choosing tactics in combat--wide range of options. 5. Choosing a diagnostic strategy in dealing with a malfunction in a complex piece of equipment. 6. Choosing to abort or commit oneself to land upon reaching the critical point in the glidepath.

Table 2 (Continued)

Names of learning tasks	Characteristics of training objectives within task categories: Action verbs	Behavioral attributes	Examples
5. Detecting	Detect Distinguish Monitor	1. Vigilance--detect a few cues embedded in a large block of time. 2. Low threshold cues; signal to noise ratio may be very low; early awareness of small cues. 3. Scan for a wide range of cues for a given "target" and for different types of "targets."	1. Detecting sonar returns from a submarine target. 2. Visually detecting the periscope of a snorkeling submarine during daytime operations in a sea state of three. 3. Detecting, through a slight change in sound, a bearing starting to burn out in a power generator.
6. Classifying	Identify Recognize Differentiate Classify	1. Pattern recognition approach of identification--not problem solving. 2. Classification by nonverbal characteristics. 3. Status determination--ready to start. 4. Object to be classified can be viewed from many perspectives or in many forms.	1. Classifying a sonar target as "sub" or "non-sub." 2. Visually classifying a flying aircraft as "friend" or "enemy" or as an "F-4." 3. Determining that an identified noise is a wheel bearing failure, not a water pump failure, by rating the quality of the noise--not by the problem solving approach.
7. Identifying Symbols	Identify Read Transcribe	1. Involves the recognition of symbols. 2. Symbols to be identified typically are of low meaningfulness to untrained persons. 3 Identification, not interpretation, is emphasized. 4. Involves storing queues of symbolic information and related meanings.	1. Reading electronic symbols on a schematic drawing. 2. Identifying map symbols. 3. Reading and transcribing symbols on a tactical status board. 4. Identifying symbols on a weather map.
8. Voice Communicating	Advise Answer Communicate Converse Direct Express Instruct Interview List Order Report Speak	1. Speaking and listening in specialized terse language. 2. Often involves the use of a specific message model. Standard vocabulary and format. 3. Also concerns clarity of voice, enunciation, speed. 4. Timing of verbalization is usually critical--when to pass information. 5. Typically characterized by redundancy in terms of information content. 6. Involves extensive use of previously overlearned verbal skills, or overcoming overlearned interfering patterns. 7. Task may be difficult due to presence of background noise.	1. Officer giving oral orders and receiving reports. 2. Sonar operator passing oral information over communication net. 3. Instructions by GCA operator to pilot in landing aircraft.

Table 3 (Continued)

Names of learning tasks	Characteristics of training objectives within task categories		
	Action verbs	Behavioral attributes	Examples
9. Recalling Procedures, Positioning Movement	Activate Adjust Aline Assemble Calibrate Disassemble Inspect Operate Service	1. Concerns the chaining or sequencing of events. 2. Includes both the cognitive and motor aspects of equipment set-up and operating procedures. 3. Procedural check lists are frequently used as job aids.	1. Recalling equipment assembly and disassembly procedures. 2. Recalling the operation and check out procedures for a piece of equipment (cockpit check lists). 3. Following equipment turn-on procedures--emphasis on motor behavior.
10. Guiding and Steering, Continuous Movement	Control Guide Maneuver Regulate Steer Track	1. Tracking, dynamic control: a perceptual-motor skill involving continuous pursuit of a target or keeping dials at a certain reading such as maintaining constant turn rates, etc. 2. Compensatory movements based on feedback from displays. 3. Skill in tracking requires smooth muscle coordination patterns--lack of overcontrol. 4. Involves estimating changes in positions, velocities, accelerations, etc. 5. Involves knowledge of display-control relationships.	1. Submarine bow and stern plane operators maintaining a constant course, or making changes in course or depth. 2. Tank driver following a road. 3. Sonar operator keeping the cursor on a sonar target. 4. Air-to-air gunnery--target tracking. 5. Aircraft piloting such as visually following a ground path. 6. Helmsman holding a course with gyro or magnetic compass.
11. Performing Gross Motor Skills	Carry Creep Fall Jump Lift Run Swim Throw	1. Perceptual-motor behavior--emphasis on motor. Premium on manual dexterity, occasionally strength and endurance. 2. Repetitive mechanical skill. 3. Standardized behavior, little room for variation or innovation. 4. Automatic behavior--low level of attention is required in skilled operator. Kinesthetic cues dominate control of behavior. 5. Fatigue or boredom may become a factor when skills is performed over an extended period of time or at a rapid rate. 6. Fine tolerances.	1. From a kneeling position, throw an M67 Fragmentation hand grenade 40 meters on target within effective casualty radius (ECR) using acceptable technique. 2. Wearing a utility jacket, utility trousers, combat boots, and armed with M16 rifle, traverse 75 meters in deep water using correct form. 3. Demonstrate the proper technique for a parachute landing fall (PLF) in open terrain. 4. Demonstrate the proper technique of creeping at night across open terrain with a rifle. 5. Demonstrate the proper technique of chin-ups starting from "dead" hang, palms toward face position.

Table 3

CFD Ratings for Each Information-Processing Stage by Learning Task

Learning task	Sensory input	Central processing	Psychomotor output
1. Recalling bodies of knowledge	Low	Med	Low
2. Using verbal information	Low	Med	Low
3. Rule learning and using	Low	High	Low
4. Making decisions	Low	High	Low
5. Detecting	High	High	Low
6. Classifying	High	High	Low
7. Identifying symbols	Med	Med	Low
8. Voice communicating	High	High	Low
9. Recalling procedures, positioning movement	Low	Med	Med
10. Guiding and steering, continuous movement	High	Med	High
11. Performing gross motor skills	Low	Low	High

Table 4

Transfer Perspectives

Topic	Academic psychology	Applied psychology
Goal	Transfer of learning	Transfer of training
Processes	Learning and memory	Training and retention
Source of study	Human experimental psychology	Human performance in Army materiel systems
Type of research	Controlled experimentation	Evaluation
Subject population	College students	Army trainees/experts
Nature of tasks	Experimental (synthetic)	Operational and simulated
Units of analysis	Skills and knowledge	Jobs/tasks/subtasks
Conditioning parameters	Context	Device features
	Sequence of events	Instructional strategies
	Learner deficit: baseline vs. optimum performance differences	Training requirements: difference between current and required skills
Testing parameters	Savings in time, trials or errors, based on performance observed in learning or testing conditions	Initial and later transfer
Internal validity	Acquisition (learning) rate	Training efficiency
External validity	Transfer of learning	Training effectiveness (transfer of training)
Economic parameters		Cost effectiveness (for given level of cost, choose alternative with best performance, or for given performance level, choose least expensive alternative)

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