RECOMMENDED PROCEDURES FOR IMPLEMENTING COST-EFFECTIVE EMBEDDED TRAINING INTO OPERATIONAL EQUIPMENT

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ABSTRACT

With the increased sophistication of weapons systems and the reduced funds for operating these systems, the military is experiencing significant skill degradation, leading to degraded combat readiness. Embedded Training has been proposed as a solution to this problem and substantial research is underway to develop efficient Embedded Training design principles. However, large numbers of weapons systems are currently in development and the designers need guidance now on how to design Embedded Training into those systems.

This paper presents an approach for determining the most cost-effective training capabilities to embed into the operational equipment. This approach is based on the consolidation of research in the areas of Embedded Training and skill degradation.

INTRODUCTION

Modern weapon systems are increasingly using electronic sensors, processing the information with computers, displaying the information on electronic displays, and accepting operator inputs via keyboard entry. This increasing reliance on computer technology simplifies the introduction of computer-based training and makes it feasible to embed training into the weapon system. In addition, the plummeting cost of memory has led to systems with enough excess capacity to support training functions. Finally, microminiaturization has produced tremendous computing power in a small, ruggedized package. Embedded Training not only provides a training capability that can accompany placement in the operational environment, it also supports mobilization. Moreover, the characteristics of Embedded Training are such that it can be used to retrain individuals that have experienced a break in service, as well as provide additional training in order to prevent skill decay.

Unfortunately, the increases in technology that have fostered the development of Embedded Training have not been accompanied by a set of generalizable guidelines for efficiently implementing Embedded Training. More specifically, there is no standard task selection method to aid designers in determining which tasks are the most critical to embed into the operational equipment. Since financial constraints, as well as the memory constraints of the equipment, prevent the inclusion of all possible tasks, the most critical ones need to be identified. The processes that are now used are time-consuming and costly. While substantial research is underway to develop efficient and effective Embedded Training principles of design, a large number of systems (i.e., weapon and sensor) are currently in development and the designers need immediate guidance on how to design Embedded Training into those systems.

This paper presents an approach for determining cost-effective training capabilities to embed into the operational equipment. This approach is a refinement of previous work [18] that has since been modified to concur with the existing literature. This approach develops Embedded Training guidelines that are based on the literature on skill retention and degradation. Since one of the main uses of Embedded Training is to alleviate skill degradation, it seems only reasonable to implement Embedded Training based upon the characteristics of that degradation.

SKILL DEGRADATION

Skill retention after periods of nonuse is a topic that has been the focus of a wide body of military research [e.g., 5; 8; 10; 11; 12; 13; 22; 25; 32]. One fact that has emerged from this research is that discrete tasks, such as those contained in a procedure, are the most susceptible to decay. This fact has broad implications for the military where the most critical tasks tend to be procedural in nature. Moreover, within the military environment, periods of nonuse frequently develop as a result of an assignment outside of one's field of specialty or a break in service. The increased sophistication of weapons systems coupled with the reduced funds for training on those systems, has caused the military to experience significant skill degradation between training exercises. This results in degraded combat readiness.

Embedded Training is a viable technology for solving the skill degradation problems for two main reasons. First, Embedded Training can be used to prevent skill decay by providing additional practice. There has been substantial evidence to show that providing additional training beyond just mastery training (i.e., one errorless trial) is the most effective way to combat skill decay [3; 7; 10; 13; 22; 25]. However, financial and time constraints within the military training pipeline usually make any additional training infeasible. Embedded Training has the potential to provide additional training within the operational environment. Military personnel can be placed in their respective positions and at the same time continue to receive practice on the skills necessary to perform their jobs. The second reason for the viability of Embedded Training is in retraining individuals that have experienced a gap between school training and the operational use of their skills.

The Institute for Simulation and Training at the University of Central Florida conducted a literature review to consolidate the existing literature regarding skill degradation. The outcome of this effort was two scales for rating the benefit and cost of incorporating Embedded Training into a system. The first scale is an Embedded Training Benefit Rating Form which is a task selection method based on empirical research on skill degradation and Embedded Training research. The second scale is an Embedded Training Cost Rating Form. These forms are geared toward design engineers who are currently developing Embedded Training systems and have no guidelines to follow in their development.

Naturally, not all systems are ideal candidates for the use of Embedded Training. For that reason, these forms also help assess the systems in which the implementation of Embedded Training would produce the greatest benefit at the lowest cost (a high benefit-cost ratio). However, the benefit and cost of Embedded Training are not simple things to determine. The benefit of Embedded Training comes from the increased performance of the operator on the job using Embedded Training, relative to performance without it. Those tasks that are most critical to mission success and most likely to degrade between training and mission performance are the ones that should be given a high priority for Embedded Training. The cost of Embedded Training is the increased procurement costs attributed to incorporating Embedded Training into the system procurement. Tasks with a high benefit rating and low cost rating should receive the highest priority for Embedded Training.

EMBEDDED TRAINING BENEFIT RATING

The approach presented in this paper emphasizes refresher training for individuals who have received school house training before being assigned to an operational unit. The benefits of Embedded Training meant for initial skill acquisition would be determined using a technique closer to the standard Instructional System Development (ISD) methodology.

Figure 1 contains the Embedded Training Benefit Rating Form. While some of the categories and associated rating scales included in this Embedded Training Benefit Rating Form are based on the consolidation of evidence obtained through an analytical review of the existing literature on skill degradation and Embedded Training, others were directly extracted from more applied research. More specifically, the categories of Quality of Job Aids, Number of Steps in Task, Built-in Logic Within Tasks, and Task Time Limit were extracted from Rose, Czarnolewski, Gragg, Ford, Doyle, and Hagman [23]. The categories of Task Criticality and Task Performance Frequency were extracted from Lenzycki and Finley [15]. The importance of the User Interface was taken from Schendel and Hagman [24]. Slight modifications were made to some of the scales obtained from the above sources in order to increase the useability of this rating form by equipment design personnel. A brief description of and justification for the inclusion of each of the categories follows the scale.

Category Justification

Training-To-Performance Lag

The length of the interval between school training and operational performance of a task is one of the most influential variables affecting skill retention. As the retention interval increases without using a learned skill, decay also increases [25].

User Interface

One aspect of this category is the existent compatibility between the display and the associated controls. That is, how closely the movement of the controls coincides with the subsequent effect on the display. If the control/display relationships agree with population stereotypes (e.g. clockwise to increase value) or the dialogue is computer initiated (with prompts and menus), then the user has a reduced need to remember how to operate the system.

Training-To-Performance Lag Rating ______

1. None
2. One Week
3. One Month
4. Three Months
5. Six Months or More

User Interface Rating ______

1. Very Good
2. Good
3. Fair
4. Poor
5. Very Poor

Learning Subcategory of Tasks ______

1. Attitude Learning
1. Gross Motor Skills
1. Steering & Guiding Continuous Movement
2. Positioning Movement
2. Detecting
3. Making Decisions
4. Recalling Bodies of Knowledge
4. Classifying-Recognizing Patterns
5. Recalling Procedures
5. Voice Communicating

Quality of Job Aids Rating ______

1. Excellent. Using the job aid, a soldier can do the task correctly with no additional information or help.
2. Very Good. With the job aid, a soldier would need only a little additional information to complete the task.
3. Good. Even with the job aid, a soldier would need some additional information to complete the task.
4. Poor. Even with the job aid, a soldier would need a great deal of additional information in order to complete the task.
5. No job aids available.

Number of Steps in Task ______

1. One Step
2. Two to Four Steps
3. Five to Nine Steps
4. Nine to Twelve Steps

Built-in Logic Within Tasks Rating ______

1. All steps are sequentially related (e.g., a group of switches that are organized sequentially).
2. Most steps are sequentially related but there are some breaks (e.g., multiple groups of switches with few breaks in between).
3. Most steps are sequentially related but there are many breaks (e.g., multiple groups of switches with many breaks in between).
4. Few steps are sequentially related.
5. The steps have no built-in logic.

Task Critically Rating ______

1. Non Critical: No effect on mission success.
2. No important effect is evident; mission is slightly degraded.
3. Mission is compromised or degraded significantly; equipment is damaged.
4. Mission is aborted; equipment is damaged significantly but personnel safety is not jeopardized.
5. Mission is aborted; equipment is damaged significantly; personnel safety is jeopardized or personnel can be injured or killed.

Task Time Limit Rating ______

1. No Time Limit
2. There is a time limit, but it is very easy to meet under operational conditions (i.e., will meet the time limit more than 95% of the time).
3. There is a time limit, but it is fairly easy to meet under operational conditions (i.e., will meet the time limit between 85% and 95% of the time).
4. There is a time limit and it is fairly difficult to meet under operational conditions (i.e., will meet the time limit between 75% and 85% of the time).
5. There is a time limit and it is very difficult to meet under operational conditions (i.e., will meet the time limit less than 75% of the time).

Task Performance Frequency ______

1. Hourly - One or more times an hour.
2. Daily - One to four times a day.
3. Weekly - One to four times a week.
4. Monthly - One to four times a month.
5. Yearly - One to four times a year.

TOTAL BENEFIT RATING SCORE ______

Figure 1.
Embedded Training Benefit Rating Form

While this variable obviously affects the ease of motor learning [1; 6], it also affects performance after a retention interval [19].

Learning Subcategory of Tasks

The tasks included in the scale are derived from NAVEDTRA 106A [21], Procedures for Instructional Systems Development. The low end of the scale contains skills that have been found to be very resistant to decay over periods of nonuse. At this end are attitude learning, gross motor skills, continuous and positioning movements, and target detection. Attitude learning refers to the attitudes that are fostered in the military personnel such as the importance of their mission. The gross motor skills category refers to tasks that require more strength than fine motor coordination, such as pressing brakes or operating levers. It seems obvious that little or no degradation would occur in these types of tasks with very low cognitive content.

Regarding continuous movements, there is considerable evidence to support the hypothesis that continuous movements, such as steering, guiding, or tracking, are impervious to decay [e.g., 2; 20; 28]. Hence the old saying that "you never forget how to ride a bicycle."

The category of positioning movement refers to the action that is made on a control to activate that control, or to change its value. Although this task is a discrete movement (which tends to be highly degradable), in this context the positioning movement refers to the operator's memory of how to manipulate a control, NOT which control to manipulate. Ammons et al. [2] found that while manipulative errors (i.e., manipulating an item incorrectly) are prevalent in the initial stages of learning, they do not occur after a retention interval.

Success in detecting a target or signal is based more on the laws of perception than on learning. Although scan patterns will undoubtedly affect target detection probability, these tasks are more properly categorized as procedures. If the operator remembers the scanning procedure, the actual probability of detection will degrade very little over time without practice. The category of making decisions refers to "if X occurs then do Y". The operator must remember these rules or principles and apply them when certain conditions are observed. Evidence suggests that simple rules such as these tend to be hard to forget [31].

Regarding the ability to recall bodies of knowledge, Wetzel, Konoske, and Montague [32] found a significant amount of degradation in the knowledge factors associated with acoustic analysis after a 1 month retention interval. Similarly, Johnson [14], in a review of maintenance training, found that the theory learned in training is particularly vulnerable to forgetting.

The category of classifying and recognizing patterns subsumes tasks such as target identification or classification. In an analysis of sonar skills obtained through a series of interviews with passive acoustic analysis operators, supervisors, and instructors within the surface, subsurface, and aviation communities, McDonald [17] found that target classification skills tend to be lost very rapidly in all three communities.

At the highest end of the rapidly forgetting scale, are voice communicating and recalling procedures. McDonald [17] found that within the air and subsurface communities, sonar team interaction was quickly lost. Further, Shields, Goldberg, and Dressel [26] broke 20 basic soldiering skills down into their component steps and evaluated the retention of those components after a 12 month retention interval. Three of the tasks required some type of verbal communication. These verbal communication steps had a relatively low Percent Go (i.e., low percentage of soldiers that performed the step to criterion). Finally, Billings and Reynard [4] found that over 70% of reported aircraft incidents contained evidence of ineffective communication. Although this is not directly related to the retention of verbal communication skills, it does have some implications of the importance and fallibility of those skills.

Referring to the recollection of procedures, McDonald [17], in his evaluation of sonar skills, also found that procedural skills required by a sonar operator (e.g., signature analysis procedures and aural acoustic analysis procedures) tended to degrade quickly. It seems that the main problem with the retention of procedural skills is in deciding what response to make in what sequence, as opposed to how to make the response. The fact that procedural skills decay over short retention intervals has been well documented [e.g., 7; 27; 29; 30].

Quality of Job Aids

Hagman [8] analyzed the types of errors that occurred on a maintenance task when a guidebook or job aid was constantly available. He found that the majority of the errors were associated with a soldiers inability to retrieve a complex procedure from memory as opposed to remembering to execute individual steps. These results show the value of good quality job aids for reducing the memory requirements placed on personnel.

Number of Steps in Task

Shields, Goldberg, and Dressel [26] found that the best predictor of long term retention of soldiering skills was the number of steps involved in the task. Their results indicated that 12 months after training, more than half the Army trainees could correctly perform tasks with fewer than nine steps. However, fewer than 10% could perform tasks with 15 steps. Hurlock and Montague [13] also found that as the number of steps within a task increases, forgetting increases.

Built-in Logic Within Tasks

This category refers to the existent sequential information that leads a soldier from one step in a task to the next step in that same task (e.g., a series of switches that need to be activated in sequence are placed in that sequence on a panel). Both Shields, Goldberg, and Dressel [26] and McCluskey, Hiller, Bloom, and Whitmarsh [16] found a greater amount of forgetting on tasks with steps that did not follow from preceding steps.

Task Criticality

This category refers to the effect that inadequate operator performance of the task would have on the probability of mission success. Obviously, if the incorrect performance of a particular skill (or components) would result in injuries to the operator or other personnel, then frequent refreshment of that skill is imperative. Due to the importance of this factor to mission success, this rating is given a double weighting.

Task Time Limit

This variable was included because the speed required to perform a task in a given period of time has been found to deteriorate quite rapidly. This ability tends to degrade more rapidly than performance accuracy [7].

Task Performance Frequency

This category refers to the regularity with which a task is performed between training and mission performance. If the operator can conduct this task frequently, then skill degradation will be minimal. In general, the more that operational vehicles must be operated (e.g. friendly and bogey aircraft) in order to produce a realistic task environment, the less often the task can be practiced.

Overall Benefit Score

Once the task has been rated on each benefit factor, the ratings are summed to produce an overall benefit score for that task.

COST OF EMBEDDED TRAINING

Figure 2 contains the Embedded Training Cost Form. There are eight factors that affect the cost of incorporating Embedded Training into a system: target display type, user control type, user communication type, target recognition level, target sophistication, number of targets, similarity to test signal, and workplace type. Following is a proposed form for estimating the cost of Embedded Training on a particular system.

Cost Category Explanation

Following is a description of and justification for the inclusion of each of the categories included in the Cost Rating Form.

Target Display Type and Entry Device Type

Since Embedded Training generally consists of software resident on a tactical or strap-on computer, the least expensive means of communication between this software and the user is through electronic displays and keyboards. Operational systems in which the user has a direct view of the target will require the addition of video or graphics displays for Embedded Training. Systems that use mechanical linkages to make user inputs will require that sensors be attached to the equipment to sense user inputs. These extensive modifications would drive up the cost of Embedded Training.

User Communication Type

If successful completion of a task in the operational environment requires communication between the user and other crew members, the cost of providing this Embedded Training capability will depend on the required user communication type. If other crew members can be trained at the same time, this capability will not be overly expensive. However, if the other members of the crew are normally in a separate moving platform (i.e., Air Intercept Controller communicating with pilot), then speech generation and understanding systems would be required at substantial expense.

Target Recognition Level

Target recognition level refers to whether a user must detect, recognize, or identify the target. As the Embedded Training moves up the scale from detection to identification, the required fidelity of target representation increases and the cost of creating and controlling the target increases.

Target Display Type Rating ______ 1. Electronic Display (Alphanumerics) 2. Electronic Display (Graphics) 3. Electronic Display (High Fidelity Targets) 4. Electronic Display (Visual Image) 5. Direct View **User Control Type Rating ______** 1. Keyboard (ASCII Signal) 2. Joystick (Electronic Signal) 3. Mechanical With Electronic Position Feedback 4. Mechanical Linkage 5. Hand Held **Target Recognition Level Rating ______** 1. Detect 2. 3. Recognize 4. 5. Identify **Target Sophistication Level Rating ______** 1. Stationary Target 2. Moving Target	3. Pre-Programmed Maneuvers 4. Some Reaction To User Inputs 5. Knowledgeable Opponent **Number of Targets Rating ______** 1. One Target 2. 25% of Saturation 3. Pre-Programmed Maneuvers 4. Some Reaction To User Inputs 5. Knowledgeable Opponent **Similarity to Test Signal Rating ______** 1. Identical 2. Similar 3. Somewhat Similar 4. Slightly Similar 5. No Test Signal **Workplace Type Rating ______** 1. Building 2. Ship 3. Large Vehicle 4. Small Vehicle 5. On Foot **TOTAL COST RATING SCORE ______**

Figure 2.
Embedded Training Cost Rating Form

Target Sophistication Level

Target sophistication level refers to whether the target blunders in on a preset course or exhibits the characteristics of a knowledgeable opponent. Increasing target sophistication complicates the software and increases the cost of Embedded Training. Since target sophistication will have a tremendous impact on software costs, this factor is given a double weighting.

Number of Targets

As the number of targets under computer control increases, the complexity of the software and the size of computer increases and the cost of Embedded Training increases.

Similarity to Test Signal

Most modern weapon systems incorporate test signals (injected near the sensors and observed on the display) that are used to detect failures and assist in calibration. If the targets required for effective training are similar to those used for testing, the cost of implementing Embedded Training will be relatively low.

Workplace Type

User workplace refers to the area surrounding the user and the system. If the user is on foot, incorporating Embedded Training will require extremely light, compact and rugged hardware. If the user is in a building, the packaging requirements are much less severe and less expensive. Since workplace type has a tremendous impact on hardware costs, this factor is given a double weighting.

BENEFIT COST RATIO MATRIX

The above rating forms are scales for rating the benefit and cost of incorporating Embedded Training for a task into a system. The decision maker should rate the system on each factor and determine the total benefit score and cost score for each task. Figure 3 is a Benefit-Cost Ratio Matrix to assist design teams in determining whether Embedded Training on a given task will be cost-effective in the operational system. For example, a task with a benefit rating of 23 and a cost rating of 35 would be a poor candidate for embedded training. The intent of the above procedure is to make the process of predicting which tasks would benefit most from Embedded Training simpler and more consistent.

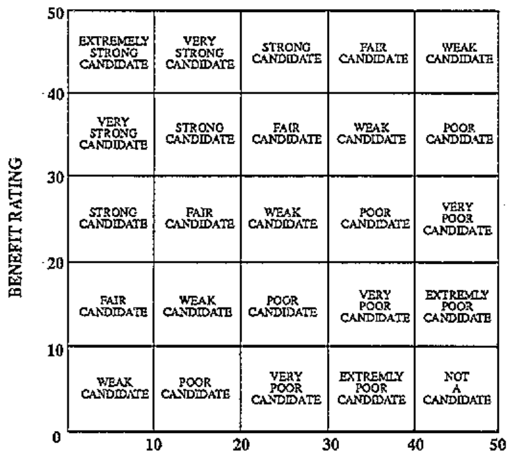

FIGURE 3
Matrix for Selecting Candidate Tasks to be Implemented in Embedded Training

DETERMINATION OF REQUIRED CAPABILITIES

The final step in the process is to determine the cues the operational equipment must generate and the student responses that must be sensed in order to provide embedded training on the selected tasks. This process consists of returning to the Embedded Training Cost Rating Forms for the selected tasks and listing the sophistication, target saturation, and test signal similarity selections. The design engineer will then compare this list of capabilities to those already available in the operational equipment and decide what additional capabilities must be added to the equipment in order to implement Embedded Training on the selected tasks. For example, the analysis may show that the following capabilities are required:

Electronic display OK as is
Additional joystick required
Speech generation system required
Sufficient fidelity level for target recognition required
Pre-programmed maneuvers of targets required
X simultaneous targets required to achieve 75% saturation
Use of test signal inadequate

CONCLUSIONS

Embedded Training has tremendous potential for alleviating the skill degradation between school training and on-the-job performance. However, the candidate tasks for implementation in Embedded Training must be chosen initially to provide the maximum benefit at the lowest cost to the operational unit. This approach is proposed to assist equipment design teams in selecting these candidate tasks and the cues and responses that are required of the operational equipment in order to promote the Embedded Training.

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