INSTRUCTIONAL DISPLAY DESIGN FOR SUBMARINE TACTICS TRAINING

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ABSTRACT

Instructional features, such as performance measurement and feedback, are widely accepted as integral elements of instructional systems, although their effectiveness is often compromised by inadequate use. This investigation focused on the design of feedback displays used to convey information to students during debriefing following a team tactics training exercise. Such feedback displays are essential components of tactics training but must be designed to motivate use. Operational system displays and capabilities, which are familiar to instructors and students, were evaluated to determine if they could provide the basic mental model foundation on which to build instructional enhancements. Feedback displays designed in accordance with instructor and student operational system mental models were found to facilitate user acceptance and ease of use. The results of questionnaires administered to, and information retrieval tasks performed by, twenty-one active duty submarine tactics instructors showed strong approval of the mental model feedback display design approach and superior information processing performance.

INTRODUCTION

Instructional technology features are today widely accepted as integral parts of a computer-based training system, crucial to the enhancement of training effectiveness. Examples include system-generated measures *of effectiveness (MOEs)* and performance feedback displays for identifying student performance strengths and weaknesses. These features are designed for use primarily during post-scenario debriefings.

The effectiveness of instructional features is dependent on several factors, including their regular and proper use by instructors. The design of instructional features should encourage regular use as well as provide effective instructional assistance. Their design should be tailored for the instructor and students with the same care espoused for user-interface design in operational systems, albeit following principles appropriate to the design and operation of instructional systems.

Recent research suggests the relevancy of a mental model concept to computer display design, workplace design,[5] and[4] to the learning/training process.[2 3 5 6 4] The preponderance of decision making tasks in military operations, such as submarine tactics, suggests the importance and existence of strong cognitive mental models by operational personnel. These factors are being carefully considered in the design of operational combat system human interfaces.[1] Training systems should likewise carefully consider the use of operational personnel (instructors and students) mental models in the design of instructional features.

It was with the goals of improving the usability and acceptance of instructional technology features, specifically feedback displays, that this study was conducted. The study hypothesized that feedback displays should be designed in accordance with instructor and student operational system mental models to facilitate user acceptance and ease of use. A mental model, for purposes of this study, can be viewed as an individual's internal cognitive representation of a physical system and its functioning. Instructional enhancements should be added to the operational displays in a form as close as possible to that of operational system/display information and features, so as to maintain a good mental model. User acceptance and usability will be high to the extent that the resultant feedback display exhibits information characteristics similar to those of the operational system. Where instructional features are unique to the trainer, they should be modeled as close as possible to good operational system characteristics.

STUDY OBJECTIVE

The objective of the study was to evaluate an approach to the design of instructional displays, specifically feedback displays, that focuses on design in accordance with instructor and student operational system mental models. This approach further relies on the adaptation of operational system displays, as the mental model framework, for the initial foundation onto which the instructional feature enhancements should be built. Certain operational system displays are believed to represent fundamental mental model narrow menus along each of the four display margins. An upper horizontal display menu was suggested for presentation of a scenario time bar, enabling the instructor to conveniently move to desired time points during the debriefing replay. A narrow vertical menu on the left side was suggested for display selection, while that on the right was suggested for overlay selection.

Instructional enhancements to the displays included:

1) Actual target-related graphical information was overlaid on geographic and other plot windows. For example, the actual target track (as known by the simulation) was overlaid on the geographic plot, along with the combat system's target track (as known by the students).

2) Actual target-related alphanumeric information was presented next to the corresponding system-generated information. Examples include target bearing, range, course, and speed.

3) MOEs were displayed. These included MOEs to be available on the operational combat system (e.g., probability of counterdetection), and MOEs available only in the trainer (e.g., target range, course and speed error).

4) Windows and specific overlays of relevant combat system-generated tactical information, such as a target escape envelope, were used.

5) Theoretical doctrine values, such as for weapon presets, were presented adjacent to the normally displayed list of system-generated presets.

6) Projected outcome situations, both graphical and alphanumeric, were provided so they could be compared with those actually achieved. For example, weapon search coverage was projected at an early stage prior to firing; its actual coverage was shown as a weapon deployed.

7) Historical system-generated data distributions were displayed along with the actual target information. For example, the system-generated target range error estimates formed an envelope over time, illustrating the changing nature of the TMA solution accuracy as a function of the situation, target and ownship actions.

8) Several feedback display control functions were provided to facilitate instructor use during the debriefing. These included functions common to a windows/mouse interface, as well as functions more unique to the debriefing application. Examples are enlarged windows to permit focusing on particular graphical information, selection and removal of overlays, rapid jumping between different displays, and rapid jumping to time points in the scenario.

An illustration of the adaptation of a hypothetical operational display for instructional purposes is shown in Figure 1. Instructional features include the actual target track history (in bold) and current position overlaid on the combat system-generated track history (thinner lines); comparison of the system-generated and actual target parameters in the data area on the right; measures of effectiveness in the same area; and various mouse-activated features. A horizontal slider control is included at the top to select replay time position in the scenario, instructional overlay selection icons are placed on the right vertical margin, and icons for selecting another display are located on the left margin. These modifications were made to an operational display as necessary to support the instructional process (in this case, post scenario debriefing).

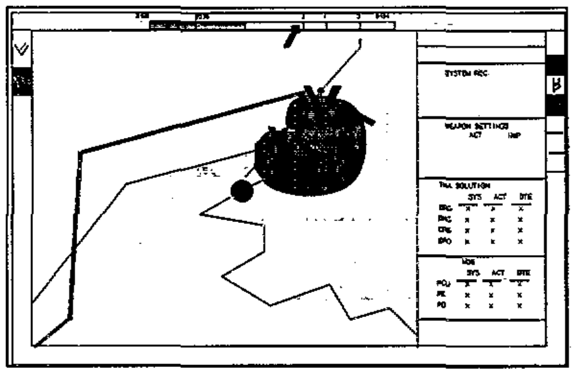

Figure 1. An illustration of a hypothetical operational display adapted for instructional purposes.

Subjects

Twenty-two active duty submarine tactics instructors at three training sites, including Atlantic and Pacific fleets, served as subjects.

The instructors/subjects were not directly familiar with the operational displays since the advanced combat system is still under development. However, they were familiar with many of the individual elements contained in the displays and with the general format of the information.

Apparatus

The two new feedback displays were generated by a drawing program in color on structures of operational personnel, the population from whom the instructors and students come.

APPROACH

The empirical research was conducted in the context of tactical team training for an advanced submarine combat system, with two newly designed feedback displays to support the post-scenario debriefing session. Two submarine combat system operational displays, representing good submarine tactics mental models, were selected as the foundation for the two new feedback displays. Instructional enhancements were added to the operational displays to create the new feedback displays designed for use in the context of post-scenario team training debriefings.

Evaluation of the design hypothesis was achieved using two types of empirical data: 1) questionnaire data investigating *instructor acceptance of the new displays* and the hypothesized display design approach; and 2) reaction time and accuracy data measuring instructor information retrieval performance comparing the newly designed displays with currently available feedback displays.

Each of the two new feedback displays was presented as a series of photographs, *representing sequential time slices and* information overlay options, during a hypothetical post-scenario debriefing. Each subject answered tactical questions using information presented on each of the new displays, and on corresponding versions of the currently available feedback displays. Response time and accuracy data were collected. Each subject answered a detailed questionnaire immediately following the display presentation.

Display Selection

Tacticians, including instructors and experienced students, were hypothesized to develop mental models corresponding to the graphical operational combat system displays with which they regularly work. Displays of this type, therefore, were hypothesized to provide good baseline designs, the foundation platforms, to which necessary instructional information could be added to achieve effective and user friendly instructional displays. This approach used operational displays selected for conformance to the experimenter-perceived instructor and student mental models, in addition to other criteria, as the foundation onto which the instructional displays would be built.

Instructional features, such as the actual target track history overlaid on the combat system generated target track history, were added to a simulation of an operational display to achieve an instructional display which was then suitable for debriefing purposes. Elements from multiple operational displays were integrated into the simulated instructional display as appropriate for training.

Two operational combat system displays two operational combat system displays were selected from twenty-five candidates, which had been identified on the basis of *providing* a comprehensive view of the combat situation. Selection of the two operational displays was accomplished on the basis of: 1) tactics training application, for which an instructional process strategy was hypothesized; and 2) specific display selection criteria, described below. A comprehensive submarine tactics training strategy was hypothesized for the next generation combat system. A subset of the strategy was assumed for this experimental application, constraining the set of candidate displays.

Each of the twenty-five displays was assessed on a 3-level Likert-type scale for each of nineteen characteristics. These criteria addressed the potential of an operational display to be adapted for instructional feedback. The information *content*, *relevancy*, and presentation to provide an image of the tactical situation (in essence, a good mental model) was also addressed. The displays were then rank-ordered on the basis of their assessment score, and the highest ranking display in each of two tactical application areas was selected.

A Weapons Status display, showing a *geographical picture of the engagement* and associated alphanumeric information, with overlays in both the geographic and alphanumeric areas, was selected as providing a comprehensive overview of the tactical situation. It provides a good summary of the overall tactical situation in a form familiar to submarine tacticians. A Target Motion Analysis (TMA) Summary display was also selected. It presents a mosaic of TMA-relevant graphical *information windows* and an alphanumeric window. This TMA display was believed to provide a more in-depth set of information in one particular area of submarine tactics, target motion analysis. These two operational displays formed the foundation for development of the new feedback displays.

Feedback Display Design

Instructional enhancements were integrated with the operational displays. These enhancements were of two types: 1) other characteristics of the operational combat system which have relevancy to the instructional process, and 2) features which are indigenous to the training situation only. These consisted of actual target and situation information, transformations of selected tactical information, and manipulation of presented information (e.g., enlarging windows) that were presented as overlays for comparison with the similar information generated by the combat system. Variations of enhancements were presented during the evaluation of each display.

The instructor control interface, which is of direct importance to user acceptance, was considered in the design of the feedback displays, although to a lessor degree. A mouse-type interface was suggested, with a PC/AT computer display system. Approximately twenty display frames were developed for each display. These represented time slices and overlay options appropriate to the debriefing sessions of the respective hypothetical tactical training exercises. The resultant series of display frames were printed on 5"x8" photographs for serial presentation.

In addition to the two modified operational displays, feedback displays from a current submarine combat system trainer were evaluated. These displays (called "trigraphs") simultaneously display three linegraphs of selected parameters (y) as a function of scenario time (x). Each trigraph presented three parameters, for a total of nine curves.

Three trigraph displays were developed to correspond with the three new feedback display frames (two different time-slice versions of a Weapons Status display and one TMA display). The new feedback displays and corresponding trigraphs were the display frames used for the information retrieval tasks, directly comparing the new and current designs.

A questionnaire was developed to obtain subjects' opinions regarding the design approach, quality, and content of each display. Each questionnaire included questions with a five-category Likert-type response (31 and 25 questions for the Weapons Status and TMA displays, respectively), and open-ended comments (8 questions each). Additionally, the TMA display questionnaire included questions of a more general nature pertaining to the design and use of training systems.

A set of tactical questions was developed for each of the three trigraph-new display combinations (8 or 9 questions), comprising the information retrieval tasks. All of these questions were tactically relevant for the situation, and would be expected to occur during a normal debriefing.

<u>Procedure</u>

The data collection sessions were individually conducted with each subject, spanning a period of 1 1/2 to 2 hours each. Each subject, at the start of each session, received a brief overview of the advanced combat system capabilities and the two operational displays which formed the foundation of the new feedback displays. The subsequent steps are explained below.

<u>Information Retrieval</u>. Each subject initially performed the information retrieval task. A photograph of a Weapons Status, TMA, or trigraph feedback display was presented and its content explained. After studying the photograph for about a minute, the series of tactical questions was asked, one at a time, with responses and times recorded by the experimenter. This information retrieval process was carried out for two pairs of displays, with the presentation order first alternating between the Weapons Status and corresponding trigraph displays, and then the TMA and its corresponding trigraph display. The Weapons Status/trigraph combination was presented first. This would be expected to occur in a training situation because the Weapons Status display provides a tactical situation overview, while the TMA display provides a more detailed view of a tactical subset. The order of new and corresponding trigraph displays was balanced across subjects.

<u>Instructor Acceptance</u>. A submarine tactical training scenario engagement, with assumed team actions and outcome, was summarized for each instructor. It was immediately followed by a debriefing session using the new feedback displays, as might be conducted by an instructor. The debriefing, explained by the experimenter, was accomplished using the series of about twenty feedback display photographs. They simulated a replay of the scenario, along with providing insight into the various instructional technology enhancements available. The questionnaire was administered immediately following completion of the debriefing. This process was first conducted for the Weapons Status display, and then for the TMA display in the context of a different training exercise.

FINDINGS

The analysis addresses the findings separately below for user acceptance of the displays (questionnaire data), and information processing performance (information retrieval).

<u>User Acceptance of Feedback Displays</u>

Of greatest importance to the study was the acceptance of the new feedback displays by the experienced instructors. Six questionnaire items directly pertain to this issue:

A. Rate the overall quality of this display for assisting the instructor in presenting the debriefing.

B. How does this type of display compare with the traditional debriefing methods for providing feedback?

C. Rate this type of display for the ease of recognizing and understanding information.

D. How often would you expect to use this display, or a similarly designed display, during the debriefing?

E. Rate the effectiveness of designing debriefing displays based on operational system displays, such as these. (TMA questionnaire only)

F. Will this display design approach foster its use during the debriefing? (TMA questionnaire only)

The opinions of the experienced submarine tactical instructors on these questions are summarized in Figure 2. A score of one indicates a negative response; a five is highly positive; three indicates a neutral response. The consistently high user acceptance of these feedback displays shows the efficacy of using a good operational display foundation. Of substantially greater interest, these results strongly support the importance of designing feedback displays in accordance with instructor/student mental models, the hypothesized design approach investigated by this study. The inherent mental model characteristics of good operational displays facilitate the design of effective feedback displays.

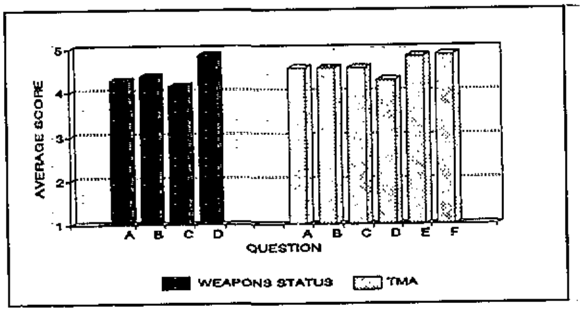

Figure 2. Average opinion ratings of new display formats (5 is highest possible rating).

The questionnaire responses provided additional information supporting this design approach, and a variety of other information addressing specific characteristics of the two newly designed feedback displays. These included characteristics that were rated high and others that were rated low. The overall feedback display design approach, however, was viewed very positively by the operational submarine tactics instructors.

<u>Information Processing Performance</u>

The information processing performance achieved using the newly designed feedback displays is of considerable importance in the applied training environment. A display design, even a generic design approach, might be ineffective even though it shows a high degree of user acceptance. If the design approach of exploiting already formed mental models is valid, however, information processing performance would be expected to correlate with display acceptability.

<u>Response Accuracy</u>. The subjects responded to the tactical questions with significantly higher accuracy for the newly designed feedback displays, in comparison to the currently available trigraph displays (see Figure 3). While using the newly designed feedback displays instructors achieved greater accuracy on 24 of 28 responses (86%), less on only 2 (7%), and the same on 2. This result would be expected to occur by chance in only 1 of 10,000 similar tests ($p<.0001$, non-parametric Sign Test), a highly significant finding.

The tactical questions posed to the instructors were comprised of: 1) procedural questions that required the rapid location of alphanumeric information on the display; and 2) interpretive questions for which the answer was not immediately available, requiring analysis of displayed information. Although the interpretive questions imposed a greater cognitive burden on the subjects, both interpretive and procedural questions resulted in significantly better performance using the new displays (see Figure 3). On interpretive questions, instructors achieved significantly higher accuracy on 11 of 15 responses (73%) while using the newly designed displays, less on 2 (13%), and the same on 2 ($p<.02$). Instructors were more accurate on all 13 procedural responses (100%) ($p<.0004$, Sign Test).

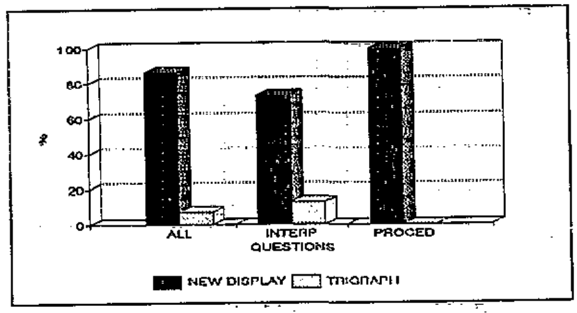

Figure 3. Percentage of questions that resulted in a greater number of correct answers.

<u>Reaction Time</u>. The times taken to answer each question were similarly found to differ between the new display designs and the currently available trigraph displays (see Figure 4). Note that two of the questions had two responses each; hence, there were more accuracy responses than reaction times. The average reaction times to answer the tactical questions using the newly designed displays were faster on 21 of the 26 questions (81%), less on 2 (12%), and the same on 2 ($p<.0004$, Sign Test). Also similar to the response accuracy findings, the reaction times were significantly faster on interpretive questions when using the new displays, with 12 of 13 questions yielding faster average responses (92%), and slower on only 1 question (8%) ($p<.003$, Sign Test); and on the procedural questions, with 9 of 13 questions yielding faster average responses (69%), slower on 2 questions (15%), and the same on 2 questions ($p<.03$, Sign Test).

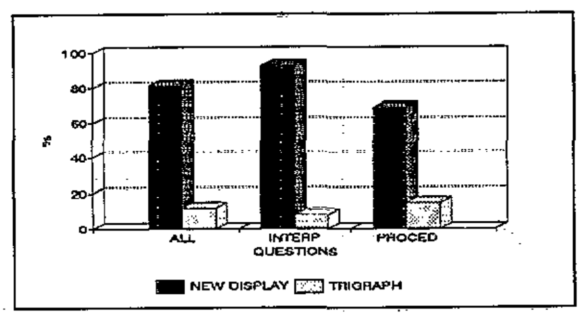

Figure 4. Percentage of questions that resulted in faster reaction times.

The response accuracy and reaction time results strongly demonstrate superior information processing characteristics of the Weapons Status and TMA displays, in comparison with the trigraph displays currently on the submarine combat system trainers. Subjects were better able to locate, retrieve, and process information from those displays which were more similar to their own mental models. Although the newly designed displays are certainly less familiar to the instructors than the trigraph displays which exist on the trainers, elements of these new displays are also obviously more familiar to the instructors -- more like their mental models of the submarine tactical engagement.

CONCLUSIONS

The user acceptance and performance results consistently support the effectiveness of display design approach used to achieve the new feedback displays. Carefully chosen operational displays can provide a good mental model foundation on which to build instructional assistance displays. The subjects' enthusiastic acceptance of the newly designed feedback displays, coupled with superior performance using these unfamiliar displays, demonstrate the importance of designing information displays in accordance with the user's mental model, not only to achieve user acceptance, but also to achieve enhanced performance.

The methodology used in this study was conducted in a submarine tactics context. The principles employed, however, should apply in many application contexts. The specific aspects of instructional technology used, and the resultant display/control designs would need to tailored to the particular application.

The use of a mental-model-based display design approach is believed particularly important in instructional systems since the instructors and students do not generally have much time for the learning of instructional system displays and their operation. Hence, the information presented on displays for feedback should be in an easily recognized and usable form for instructors and students -- as similar as possible to the operational system mental models they already possess.

REFERENCES

[1] Kanter, M. F., O'Brien, F. J. "Submarine Combat System Configuration Modeling Methodology". Technical Memorandum TM No. 89-2032, Naval Underwater Systems Center, January 3, 1989.

[2] Norman, D. A., and Babrow, D. G. "On the Role of Active Memory Processes in Perception and Cognition". In "The Structure of Human Memory", Cofer (Ed.). W. H. Freeman, San Francisco, 1976.

[3] Rasmussen,J. "Information Processing and Human-Machine Interaction". Amsterdam: North-Holland, 1986.

[4] Veldhuyzen, W., and Stassen, H. G. "The Internal Model: What Does it Mean in Human Control?" In T. Sheridan and G. Johannsen, (Eds.), "Monitoring Behavior and Supervisory Control". Plenum, New York, 1976.

[5] Williams, K. E., Hamel, C. J., and Shrestha, L. B. "An Evaluation of Characteristics contributing Towards Ease of User-Computer Interface in a Computer-Aided Instruction Exercise". Technical Report TR87-030, Naval Training systems Center, Orlando, FL, 1987.

[6] Wilson, J. R., and Rutherford, A. "Mental Models: Theory and Application in Human Factors". The Journal of the Human Factors Society, 31(6), 617-634, 1989.

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