INNOVATIVE SONAR TRAINING DESIGN: LINKING SONAR CONCEPTS WITH FAMILIAR HUMAN CONCEPTS

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ABSTRACT. An instructional approach was developed for training applied sonar skills. The approach allows a student to effectively apply concepts learned in a classroom to problems presented on a training simulator. Instruction is in the form of visualizations integrated with the training simulation. These visualizations of environmental, tactical, and acoustic variables facilitate training by providing links from simulation elements to their more abstract representations on the tactical console. Information which addresses the procedural aspects of operating the tactical console is included in the training approach. This approach was presented to submarine sonar instructors and students, as a series of static display snap-shots in the context of specific training scenarios. Evaluation was based on their judgments, obtained with a structured-interview questionnaire, addressing the overall instructional approach and prototype display/control design features. The value of this type of instructional assistance was found to be very high.

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INTRODUCTION

Traditional DoD training strategies have focused on face validity to maximize the transfer of training, based on research that has shown such designs as often positively related to transfer (Osgood, 1949; Roscoe, 1980). Recent research has shown significant instructional enhancement results from use of strategies which present information corresponding to student internal cognitive representations, as summarized by Moxey, Scopatz, Madden & Ahlers (1993). These findings foster creative instructional media designs which key on fundamental human cognitive thought structures to provide a link between familiar concepts and difficult-to-comprehend operational system characteristics. The findings suggest that applied training strategies, such as for sonar employment training, should include media with good operational face validity supplemented by instructional information familiar to student cognitive representations.

Effective employment of modern submarine sonar systems is exceptionally complex. The sonar employment process is confronted by increasing equipment sophistication, quiet adversaries, changing roles of the submarine force, and ever-changing tactics and operational techniques. This complexity is further compounded by submarine operations' growing reliance on environmentally dependent information. The modern sonar system, including its operators, is continually challenged to extract increasing amounts and quality of information from a complicated environment. The concepts of sonar operation and the environment are often abstruse, with sophisticated and involved operating procedures. Achievement of the requisite operating precision requires exceptional levels of operator proficiency to compliment the advanced sensing and processing equipment. Effective operator skills and knowledge require the development of sophisticated, and often abstract, cognitive structures pertaining to the acoustic medium and operational system. It is postulated that the process of learning these will benefit from instructional strategies that augment the operational system displays with information enhancing student understanding and visualization of sonar concepts.

The training process could link new sonar concepts with already-developed familiar student cognitive representations, and then with operational sonar system displays and controls. This congruence, together with imaginative information presentation and visualization approaches, is expected to greatly enhance the student's grasping of fundamental sonar concepts and their application.

To assist in student acquisition of robust cognitive representations of sonar employment concepts, an instructional approach was developed to provide the student with alternative views of task-relevant sonar information, emphasizing visualization imagery, to augment information normally available from the operational equipment. The alternative view information, presented on a student-controlled instructional display placed alongside the operational sonar console trainer, would present a stylistic characterization of sonar system physical phenomena in graphical formats familiar to the student. This linkage of relevant applied information in the operational format with similar information in a more cognitively-familiar format is postulated to assist in student learning and understanding of sonar concepts and their applications, building cognitive representations and strengthening their association with the operational sonar equipment/information.

BACKGROUND

The broad learning/training research literature provides a wealth of guidance to support the design of the postulated alternative view instructional strategy in an applied setting. Certain issues of direct relevance to the postulated strategy are identified below.

Student Cognitive Representations

A common theme is emerging from the literature of perception, decision-making, expert vs. novice problem solving, performance under stress, team functioning, and training -- centered on the importance of well-developed cognitive structures and representations to human performance (Hammell and Ewalt, 1994). For example, cognitive representations have been described as fundamental to human decision making (e.g., Klein, 1989), and expert performance (e.g., Means, Salas, Crandall, and Jacobs, 1993); shared mental models have been identified as conducive to improved team performance (e.g., Cannon-Bowers, Salas, and Grossman, 1993). Individuals are believed to posses internal cognitive representations of objects, events and time-sequenced processes (e.g., Weiten, 1992) that are fundamental to human thinking and thought processes. These representations can have various forms, such as a mental image of an object (e.g., towed array conical beam pattern); or a mental image of the TMA process to calculate target range and course, in the form of a template; or a mental image of a time-line sequence of events for resolving sonar bearing ambiguity, in the form of a script. Individuals are believed to have many overlapping representations, learned from and corresponding to their many and varied experiences through life.

Visual Imagery

One of the primary goals of sonar operator employment training is to provide an understanding of the complex relationships among acoustic signals, the underwater environment, and the acoustic processing equipment. This understanding is necessary to allow an operator to effectively deal with novel tactical situations. Robust, appropriate cognitive representations are necessary to enable an operator to most accurately perceive the sonar-tactical situation as it exists, and to conduct effective decision making and problem solving activities. Since the perceptual process is dependent on past experience, the training strategy should start with, and build on, a student's existing cognitive representations to achieve an efficient learning process. That is, sonar training should begin with cognitive representations of familiar experiences and build to those of the sonar system and its employment. Furthermore, the training system should provide substantial instructional information in a visual format, since visual imagery has a beneficial effect on memory and information processing of complex information (e.g., Pavio, Smythe and Yuille, 1968). For example, representation of sonar beams (an abstract quantity not seen) can be accomplished in a visual manner that can be easily seen and understood by the student. A 3-D beam image, similar to a light beam, is an example of an initial familiar context that can be expanded into appropriate sonar beam mental images. To assist in forming a strong cognitive representation, the student would be able to rotate his viewpoint of the own ship-target-beam imagery in the 3-dimensional environment to provide a better understanding and visualization of the complex beam characteristics. Information in this abstract visualization should in-turn be linked with pertinent information available on the operational sonar console.

Instructional Principles

The research literature is replete with findings pertinent to the design of instructional strategies for applied training applications. Maxey et al (1993) provides a summary of many relevant principles, such as learner centered control of instructional information (i.e., provision of assistance only when requested by the student). Examples of principles considered to have direct relevance to development of cognitive representations for applied sonar operator training, during hands-on exercises using operational-like sonar consoles, are:

Instructional process:

- Student free-exploration, within a guidance structure;
- Procedural and non-procedural tasks supported with aiding information;
- Self-paced, student-selected assistance;
- Aiding information to student to reduce errors during early stages of basic training;
- Reduced aiding during later stages of training, or at any time.
- Positive guidance when student requests help;
- Immediate and delayed reinforcement, tailored to student progress;

Instructional Information:

- Augment operational displays;
- Address fundamental relationships and operational processes;
- Functional information content, specific to operational function and task;
- Hierarchical information organization, essential/minimal information at each level;
- Link with prior classroom instruction and operational manuals;
- Provide alternative views of problem situation;
- Visual/graphical information emphasis, using textual information as necessary.

These were incorporated into the instructional strategy design process under the alternative view approach.

Objective

The objective of the study was to design and evaluate an instructional approach for sonar employment training that provides alternative information to the student, during hands-on sonar trainer exercises, augmenting the information available on the trainer's operational sonar console. The information presentation emphasis was to accentuate the use of visualization imagery, to better-assist the student in acquiring robust cognitive representations.

METHODOLOGY

The research was conducted in the context of applied training for the AN/BQQ-5 submarine sonar system. Difficult-to-comprehend sonar concepts were identified with the assistance of the staff at the U.S. Naval Submarine School. Instructional aiding display concepts were developed to assist in teaching the understanding of two sonar procedures: 1) towed array bearing ambiguity resolution, and 2) relative motion/target motion analysis (TMA). The display concepts were developed to present information in formats believed to correspond with already-developed student internal cognitive representations (i.e., present complex sonar information in a visual manner that would be easily recognizable by the students). The design approach combined applied instructional principles with computer-based visualization techniques, to address applied problems.

The potential value of the alternative view approach was assessed at the Submarine School based on judgments of eight sonar instructors and students, all of whom were experienced sonar operators. The alternative view instructional features were illustrated in the context of two applied sonar training scenarios, one each for the towed array and relative motion/TMA display designs. The scenarios were presented as a series of events and student actions, using a sequence of static display images representing time slices during the scenarios. Judgments were elicited immediately following each scenario presentation, using a structured interview technique with a questionnaire. Likert-type ratings were used to assess the potential merit of the alternative view approach and specific features; questions with open-ended responses were used to identify issues, concerns and recommendations.

FINDINGS

The results of the research occurred in two parts: 1) instructional strategy and alternative view display designs, and 2) evaluation of the designs. Each are addressed separately below.

Display Design

The instructional strategy and aiding displays were designed around a hierarchical information structure, providing increasingly detailed information in successive layers under student control. The specific content was tailored to selected sonar training objectives under each of the two subject areas. The displays were configured around a "windows" format (i.e., assumed most readily familiar computer display format), and included several types of windows for information presentation, data entry and feedback. Elements of the training process strategy included:

- Alternative views of sonar console information, emphasizing graphics.
- Student control of aiding information access.
- Student had to actively request for increasing information details.
- Guidance information to help direct student actions.
- Information content was directed towards:
  - Identification of sonar/tactical parameters;
  - Parameter definitions and abbreviations;
  - Where-to-find data on sonar console;
  - Detailed guidance for procedures and processes;
  - Graphical representation of parameters;
  - Graphical representation of tactical aids;
  - Comparison of student-determined versus actual parameters;

Visualization of sonar phenomena.
Feedback information available at any point in the problem.
Student control design was for mouse-type of interface, or similar (e.g., joystick).

A representative frame of the Towed Array display is presented in Figure 1, showing the primary tactical display area and several nested information windows (both are noted in the figure).

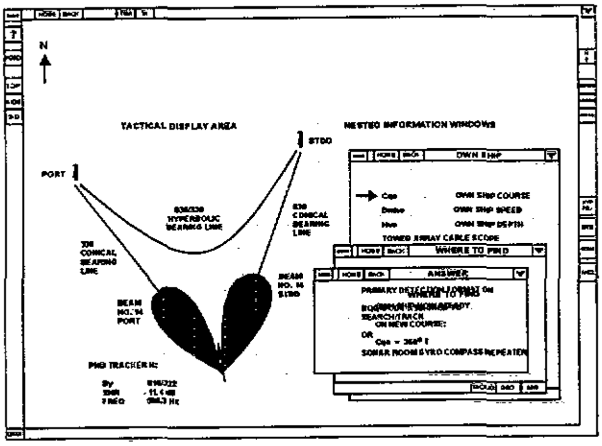

Figure 1. Towed array display example, including the Own Ship Information window, and Where-To-Find and Answer windows.

A second display example is presented in Figure 2, showing a Relative Motion/TMA instructional display with the Target information window open.

Both graphical and textual information is presented, as appropriate. When the student desires assistance as he progresses through the exercise, he would activate the normally blank aiding display located alongside the operational sonar console by moving the mouse. A bare-bones graphical display would be presented in the primary display area, organizing minimal problem-relevant information. The own ship-target information in the primary display area of Figure 2, without the Target information window overlay, is representative of the initial information detail.

The student would obtain additional information by selecting major elements on the display (e.g., clicking on the target icon). An information window overlay would open, such as the Target information window, presenting the next level of information. This next level of information would also be minimal, requiring student request for additional detail.

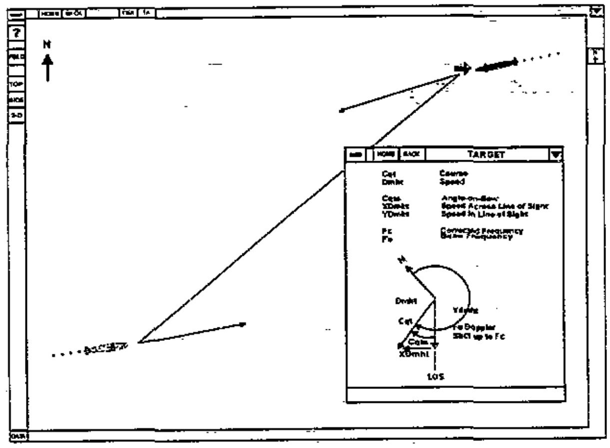

Figure 2. Relative motion/TMA display example, including the Own Ship Information window.

The student could descend to successively deeper, and more complete, levels of information by making successive requests. Additional information would be presented in the open windows, or additional windows would open, as appropriate to the problem and requests. The successive levels of information were designed in correspondence with the sonar problem solving process. For example: the hierarchical order of available information may be: identification of relevant sonar/tactical parameters, definition of acronyms, location of needed information (i.e., relevant parameters) on the sonar console displays, functional steps to calculate needed sonar/tactical quantities, representation of manual Tactical Aid computations, and resulting calculation answers.

The student could display additional information detail in any window when desired, by selecting displayed information and designating its destination (e.g., select target speed to be displayed as a vector in the primary display or in an information window). As the student manually calculates the sonar/tactical parameter quantities for the particular problem, as he normally would using grease pencil, he could enter them into the system, and enable comparative feedback information of calculated versus actual values.

The training process is envisioned to be tailored by the instructor, controlling availability of features and information. For example, access to answers may be allowed at any time early in the course, but constrained later in the course until all student calculations have been entered. Furthermore, the emphasis is to encourage student reliance on the operational sonar console for information, using the alternative view displays only when necessary, or to check on answers and progress. Student use of the assistance features would be automatically monitored, with summary information for the instructor to identify student difficulties.

Display Evaluation

The questionnaire collected data on overall judgments, as well as specific features and characteristics of the instructional approach and display design features.

Overall Potential Effectiveness. The responses to seven questions important to instructor/student judgment of potential overall effectiveness are presented in Figure 3, showing the mean rating for each question on a scale of 1 to 5 (1 = lowest, and 5 = highest rating) (Note, the expected mean was 3.0).

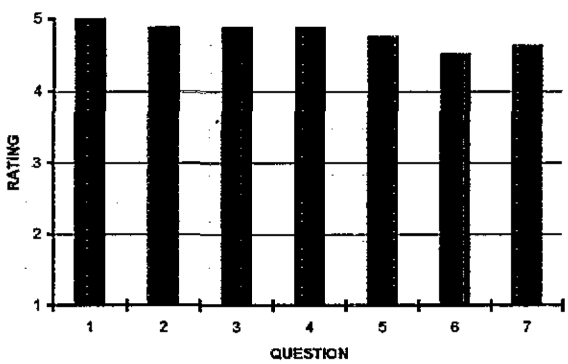

Figure 3. Sonar instructor and student overall judgments of the alternative view instructional approach.

The questions are:

1. Rate the overall effectiveness of the instructional aiding displays. (mean = 5.0, 95% Confidence Interval: 5.0 – 5.0).

2. Rate effectiveness of the displays for providing instructional assistance alongside an operational sonar console for individual training in the lab. (mean = 4.875, 95% Confidence Interval: 4.63 – 5.0).

3. Rate effectiveness of the displays for allowing the student to control access to instructional information -- when he wants it, and which information he wants. (mean = 4.875, 95% Confidence Interval: 4.63 – 5.0)

4. How does this type of display compare with the traditional trainer instructional methods, media and aids? (mean = 4.875, 95% Confidence Interval: 4.63 – 5.0)

5. How does this type of display compare with the traditional classroom instructional methods, media and aids? (mean = 4.75, 95% Confidence Interval: 4.43 – 5.0).

6. Rate the overall effectiveness of the relative motion/TMA instructional aid for assisting student learning and application of relative motion/TMA to sonar employment. (mean = 4.5, 95% Confidence Interval: 3.98 – 5.0).

7. Rate the overall effectiveness of the relative motion/TMA instructional aid for assisting student learning of bearing ambiguity resolution, and calculation of D/E angle. (mean = 4.625, 95% Confidence Interval: 4.11 – 5.0).

As evidenced by the data in Figure 3, the sonar instructors and students judged the potential value of the alternative view instructional aiding approach as very high, with the mean ratings all above 4.0. (Note, the lower confidence limits for 5 of the 6 means were also above 4.0, in comparison with the expected mean of 3.0). These high ratings express the need for instructional media that can assist in addressing the complex sonar concepts, as well as confirm the potential effectiveness of the alternative view approach.

Effectiveness of Specific Characteristics. The high approval ratings were due to characteristics of the media tailored to meet specific needs of sonar training, albeit in concert with guidance obtained from the research literature and the alternative view instructional approach. Examples of the instructor/student judgments of specific characteristics, also providing insight into display design features, are presented in Figure 4, addressing the following questions:

Questions 8 – 11. Rate the potential training effectiveness of this training aid in...

8. ...assisting the student to locate relevant information on the AN/BQQ-5 console. (mean = 4.63, 95% Confidence Interval: 4.11 - 5.0).

9. ...guiding the student to learn and perform sonar tactical calculations. (mean = 4.88, 95% Confidence Interval: 4.63 - 5.0).

10. ...guiding the student to learn and perform sonar tactical problems using the Tactical Aids. (mean = 4.88, 95% Confidence Interval: 4.63 - 5.0).

11. ...understanding sonar employment concepts and tasks. (mean = 4.63, 95% Confidence Interval: 4.11 - 5.0).

12. Rate effectiveness of top-down information access approach, providing increasing information detail with successive student requests. (mean = 5.0, 95% Confidence Interval: 5.0 - 5.0).

13. How important is the student entry of generated data? (mean = 5.0, 95% Confidence Interval: 5.0 - 5.0).

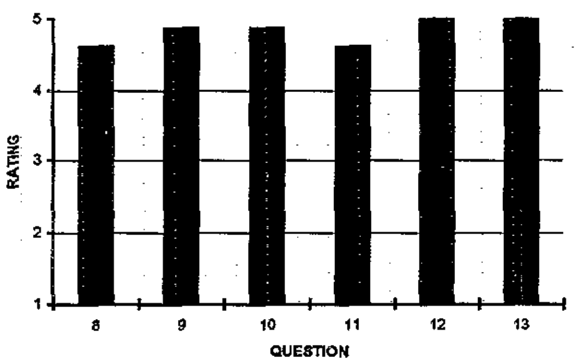

Figure 4. Judged effectiveness of example display characteristics.

The data presented in Figure 4 directly address several of the training process design elements identified earlier in this paper. The very positive instructor/student judgments emphasize the potential viability of these for sonar training, and approval for the implementation approach.

Certain features were not rated highly. For example, the mouse interface received widely varying judgments. Some instructors/students rated it highly, while others preferred another type of control, such as a trackball or joystick. Nevertheless, most features illustrated received high judgment ratings. This finding reflects the tailoring of instructional features designs to the identified needs of submarine sonar training.

Graphical Representation. The importance of providing visual representations of the underlying tactical representation along with procedural information was underscored by the large percentage of responses identifying visualization imagery (graphics) as the most important feature (i.e., 60% of responses). Improvements suggested by the instructors/students also emphasized visual imagery, with 36% of the suggestions pertaining to display design.

Other Findings. Other responses cited the instructional aiding approach as effectively addressing student needs by providing assistance information to students at the time they need it, and to the extent they desire. This approach would augment the instructor in a multi-student station laboratory, enabling applied individual student training using operational sonar consoles, and also providing instructional assistance to the level needed for each student.

The instructors/students were asked to judge the overall effectiveness of the strategy and displays for Basic, Advanced and LCPO sonar courses. High mean ratings were found for all courses (i.e., mean of 4.5 and above). They were highest for the Basic course, and decreasing in order for the Advanced course and the LCPO course. This suggests the training assistance is most needed when learning, or re-learning the sonar concepts and their applications. Once the concepts are well understood and the operators are proficient in their use, this type of assistance during training sessions is of less importance. This coincides with the training emphasis to use the operational displays as the primary information sources, and use the instructional displays only when necessary.

CONCLUSIONS AND RECOMMENDATIONS

The consistently high judgment ratings given to the overall training approach, and major and minor elements of the prototype displays, indicate the alternative view instructional approach has strong potential to enhance sonar employment training. The generic strategy and individual displays are appropriate in each of the sonar employment courses: Basic, Advanced and Leading Chief Petty Officer (LCPO). The implemented example features would, however, be most applicable to Basic sonar training.

The towed array and relative motion/TMA instructional displays appear to be reasonable prototypes for further development and dynamic evaluation during applied sonar training. Over three quarters of the features questioned received high judgment ratings, with the remainder receiving average to above average ratings.

Three features of the prototype displays stand out as having distinctive potential effectiveness for enhancing sonar employment training using the approach under development:

- Visualization imagery of the difficult-to-perceive sonar concepts;
- Emphasis on addressing and meeting student needs during the training process;
- An intuitive learning process tailored to the student, and sonar employment training.

The methodology of the alternative view approach (i.e., augmenting operational console displays, composed around major information windows, and keyed to the particular sonar problem) is expected to be an effective information access and presentation model for sonar employment training in the applied sonar laboratory context. The top-down information access structure, with nested widows for presenting the student-selected hierarchical levels of information, should be an effective strategy. The information presentation formats, combining graphical and textual information as appropriate to the exercise and student problem solving techniques in concert with the instructional strategy, should facilitate student use of the instructional assistance information.

The requirement for, and allowance of, direct student control over the training information access is an important component of the training approach, having received high approval. This results in the student as an active participant in the instructional process, and assists in focusing instructional assistance when and where needed.

The findings of this study demonstrate a need for incorporation of advanced instructional technologies into the applied training context, such as sonar employment training with operational consoles, to augment information provided on the operational equipment. This is emphasized for courses in which complex concepts and their application are being initially learned, and for courses in which they are being re-learned after students/operators had been away for some time.

The instructional strategy and displays, keying on familiar student cognitive representations and visualization imagery to assist in developing robust cognitive representations of the operational system, was found to have strong potential to improve the effectiveness of applied training dealing with difficult concepts. Implementation of a dynamic prototype of this instructional approach in applied sonar training is recommended to evaluate its training effectiveness.

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