ADVANCED EMBEDDED TRAINING CONCEPTS FOR SHIPBOARD SYSTEMS

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ABSTRACT

The requirement to achieve and maintain higher and more complex skill levels with fewer dollars faces all modern military systems. One way to accomplish these seemingly incompatible goals is through advanced training concepts, particularly those that move training to the operational platforms. Besides having the obvious advantage of being more accessible than traditional (classroom-based) training, embedded training has the potential to result in better operational performance if developed and implemented properly. The purpose of this paper is to describe a series of research projects aimed at improving the state-of-the-art in embedded training systems. This will be accomplished through a description of a research system exemplifying the latest vision and concepts for embedded training. The system links experiential learning via realistic workstation-embedded problem simulations, with intelligent tutoring via multiple levels of real-time instructional guidance and performance diagnosis. Trainee operator performance is measured against both fixed and adaptive criteria generated from executable cognitive models of expert operators. Cognitive and behavioral diagnosis is dynamically performed based on the differences between trainee behavior and the model-generated criteria. Additional diagnostic inputs from human instructors, via mobile pen-based interfaces, are added to the automated diagnoses. The result is guided practice, in which trainees gain problem-solving practice while receiving real-time and post-problem guidance from both automated and human instructor sources.

BIOGRAPHICAL SKETCHES

Wayne Zachary is an internationally recognized leader in the design and analysis of human-computer interfaces, cognitive modeling of individuals and organizations, and development of decision training and decision support systems. He led the development of the Cognition as Network of Tasks (COGNET) framework for cognitive task analysis of real time, multi-tasking domains, and applied COGNET to diverse domains, ranging from military command and control to patient-physician clinical encounters. He received Ph.D. and M.A. degrees in Anthropology and Computer Science from Temple University. Prior to founding CHI Systems, he was Associate Professor of Information Systems at Drexel University and was Director of Human Systems Research for Analytics Incorporated.

Peter Bilazarian is currently the Industry Technical Director for the Navy Advanced Embedded Training Advanced Technology Demonstration program. Dr. Bilazarian has led and contributed to numerous R&D programs involved with advanced Navy simulation and training systems, advanced technologies for human-computer interaction, real-time military tactical planning and decision aids, and the modeling of complex environmental influences on ocean sensor systems. He received Ph.D. and M.A. degrees in Mathematics from Rensselaer Polytechnic Institute and Duke University and a BA degree from Harvard University.

John J. Burns received his Ph.D. in psychology from the University of Massachusetts-Amherst. His professional interests include cognitive approaches to training people who work with complex systems, and developing and implementing technologies that support people in learning about complex systems as they use them. His interest in team training began while he was a Post-Doctoral Fellow at the Naval Air Warfare Center Training Systems Division, where he was responsible for conducting behavioral research to develop training and simulation principles for the Tactical Decision Making Under Stress (TADMUS) exploratory research program. He is currently working on the development and implementation of an electronic performance support system for Navy personnel tasked with conducting shipboard training.

Janis Cannon-Bowers holds a Ph.D. degree in Industrial/Organizational Psychology from the University of South Florida. As the team leader for Advanced Surface Training Research at NAWCTSD, she has been involved in many research projects directed toward improving training for complex environments. These have included investigation of training needs and design for multi-operator training systems, training effectiveness and transfer of training issues, tactical decision-making under stress, the impact of multi-media training formats on learning and performance, and training for knowledge-rich environments.

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INTRODUCTION

The training of ship crews is currently being driven by many competing demands that simultaneously seem to require both more and less training:

- Complexity of Modern Battle Scenarios and Systems -- after generations of developing systems preparing for large-scale hostilities between super-powers, the Navy is moving, together with all US defense forces, to develop the capability to respond to a much broader range of missions. Many involve limited objective and contingent objective warfare in complex geopolitical settings. At the same time, newer generations of sensors, weapons, and system automation are bringing both increased capability and increased complexity. Together, these factors give ship crews a much broader range of missions and systems for which to train.
- Decreasing Budgets and Affordability Issues -- The end of the cold war has also brought lowered levels of funding for maintaining readiness in this increasingly complex environment. Training costs can no longer be automatically increased to accommodate increased training need. New systems are being designed with explicit criteria for affordability, involving dramatically reduced manning while maintaining or increasing readiness.
- OSD-Level Attention to Embedded Training -- The infrastructure for training, which has historically been shore-based, is under increasing scrutiny. The costs associated with travel to/from shore-based facilities, together with the limited ability of this traditional approach to provide adaptive, just-in-time training, has led to an increased emphasis on embedding training functionality directly into the operational systems used by war fighters.
- Increased Need for Embedded Training -- Ship crews are increasingly being called on to respond quickly to new and unique missions such as projection of force in regional conflicts and support for humanitarian and peacekeeping operations. In these contexts, ship crews need to receive mission-specific training, ideally while en-route to these operations. Such training can only be received via shipboard training means, particularly embedded training systems.

The current model for embedded training is one of scenario-based free-play simulation. In this model, the operational system is placed into a simulation mode and stimulated by realistic information that emulates external inputs and events. The external simulation and internal (mission) simulation are organized into a training scenario, which is designed to present specific mission situations to the system operators, who, in turn, become trainees at their operational work/watchstations. At some time after the scenario is completed, the trainees receive evaluation and feedback on their performance, typically from a human trainer or training team. Although this model is clearly an advance over traditional drill-and-practice computer-based training, there are still substantial problems with this current embedded training model, as shown in Figure 1. A scenario-based free-play simulation approach to embedded training:

- is labor intensive -- the monitoring and evaluation of the trainee's performance are left to human trainers, and this can result in a high ratio of trainers to trainees, approaching 1:1 in many situations.
- is based on ad-hoc performance measures -- performance assessment and monitoring are left to human trainers precisely because they are not done by the embedded training system itself. This leaves each trainer/training team to develop its own way of measuring and diagnosing trainee performance on an ad hoc basis. With no consistent means and standards for measurement and assessment, there can, therefore, be no consistent training across teams, across trainers, and across ships.
- is prone to data loss -- with only manual monitoring of performance, only minimal performance data can be recorded and stored. As a result, there is only very limited ability to capture meaningful data on trainee performance over time, and to analyze it in a timely manner for trends in gain/loss of proficiency and readiness.
- relies on informal diagnostic mechanisms -- there is typically little support for the

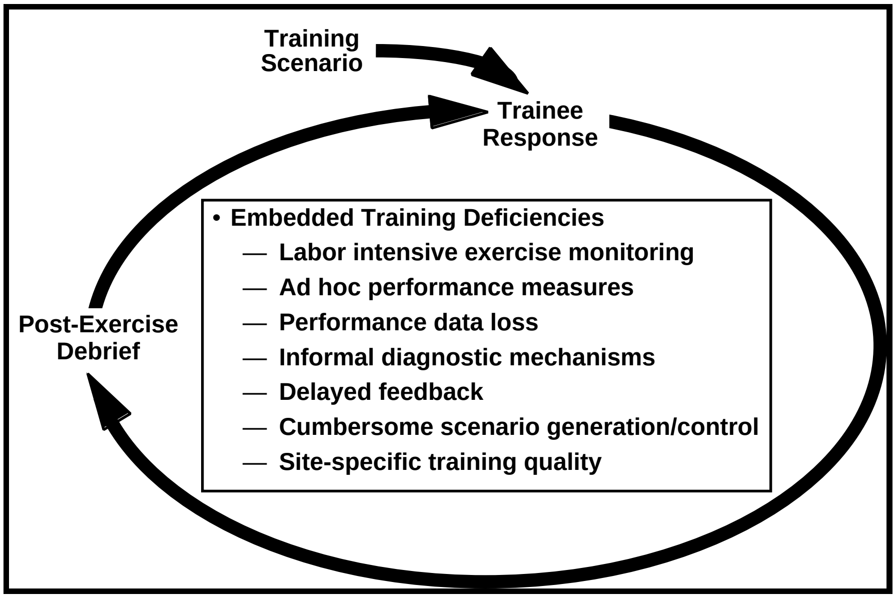


Figure 1. Current Embedded Training Approach and Primary Limitations

provision of feedback to the trainee other than verbal comments from the human trainer/training team. Lacking structured means for evaluation and data recording, the resulting diagnosis tends to be highly idiosyncratic and informal, with many aspects of performance going undiagnosed or diagnosed only intuitively.

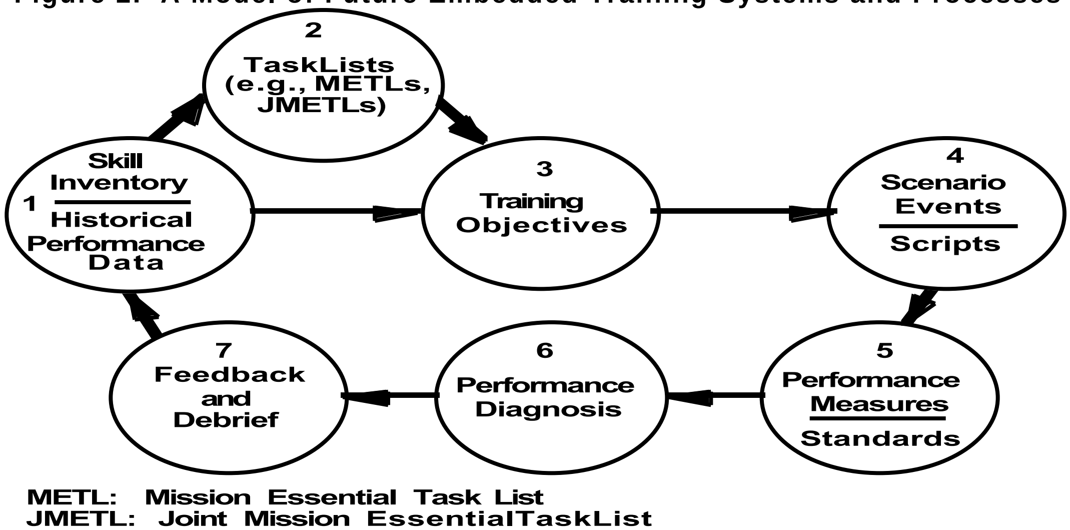
- leads to delayed feedback -- the predominant mode of feedback in embedded training simulations is via post-scenario debriefs. Because the performance data are recorded manually by instructors, who also generally lack tools to analyze these data and organize them, the resulting debrief is often removed from the actual simulation by periods of hours (for simple, single-ship simulation) to days or weeks (for complex, multi-ship exercises).
- involves cumbersome scenario-generation and scenario-control processes -- the embedded training simulators require scenario definitions in precise form, and creation of new scenarios or modification of old ones to meet new needs can, therefore, be a difficult process. Moreover, the scenario input files must be defined in terms of external events, even though trainers may want to design scenarios in terms of decisions or tasks that they want trainees to encounter. As a result, it is difficult and time-consuming to craft a training scenario that will have specific training value to a trainee/team.
- has great site-to-site variability in training impact -- with the performance monitoring, diagnosis, feedback, and new-scenario definition left up to the local human trainer or training team, it is not surprising that scenario-based, free-play, embedded training has varying effectiveness. When the human trainers have the skills, time, and motivation to use it well, the training result can be good. But with unskilled trainers and stressful and busy conditions, the effectiveness of the training can degrade quickly.

This suggests that current embedded training capabilities must be enhanced by capabilities that provide an augmented training vision, one that encompasses support for performance monitoring, diagnosis, feedback, and new problem generation as well as problem simulation. The remainder of this paper presents an enhanced vision for shipboard training, and its embodiment in a specific advanced embedded training system.

A VISION OF FUTURE SHIPBOARD TRAINING

This new vision of shipboard embedded training is pictured in Figure 2. In this vision, embedded training is a multi-step process in which problem simulation is only one part of a larger continuous training cycle. In this vision, each training cycle begins with the development of a set of specific training objectives for the next problem-scenario simulation. These objectives are well-defined specifications of the knowledge and skill elements and mission tasks that each trainee is intended to acquire and practice during the next

Figure 2. A Model of Future Embedded Training Systems and Processes



problem exercise. When a trainer defines these training objectives, he or she must develop them from:

- inventories of abstract skills and knowledge elements that are known to be needed by operators performing each watchstanding role covered by the training simulation, and
- lists of mission-specific tasks that are required for successful accomplishment of various mission types.

In order for these training objectives to be meaningful, they should be based, at least in part, on the past performance and training of the targeted operators. That is, future training should be based on the types of past training received and the results of that past training. Thus, in addition to the skill inventories and tasks lists, the development of training objectives should rely on historical data on the proficiency of the operators to be trained. Currently, the human trainer in shipboard embedded training systems must do this all manually. In the future, this should all be supported by automated tools. Once training objectives have been defined, the trainer must then define or select a specific scenario to be simulated and translate that into an appropriate script or input file to the embedded training subsystem. The trainer's objective is to select a scenario that provides each trainee with the opportunity to employ the skills and knowledge and to practice the tasks targeted in the training objectives. Unfortunately, existing training scenarios are not described in this way (i.e., what they require the operator to do), but rather in terms of the external events that stimulate the system (e.g., the threats, external environmental conditions, neutral and friendly air traffic, etc.). Except as learned through rote experience, the trainer currently has no way of knowing what tasks, knowledge, and skills are required by existing scenarios, and, therefore, has no way to translate training objectives into the selection or modification of an existing scenario to fit the training objectives. In the embedded training vision in Figure 2, this process is supported by computer-based tools that help the trainer map training objectives into the selection, and where needed, modification of a scenario for the next training simulation.

At this point, the embedded training simulation can be executed. Rather than using ad hoc performance measures and ad hoc feedback (as is done in current embedded training systems), the future embedded training system will provide support for these processes as well. The system will employ a standardized set of performance measures that have been defined to help the human trainer assess the trainees' actions in terms of the knowledge, skills, and tasks incorporated in the objectives defined before the scenario was run. These measures, in turn, will be used in a computer-aided diagnostic process which assesses the observed performance against the stated objectives, and identifies the knowledge, skill, and task areas where each trainee:

1) requires specific feedback and/or instruction, or
2) requires further practice in future training problems, and/or
3) shows strong performance.

The items in the first set are used to stimulate the production of feedback to the trainee, either on-the-spot, or in the post-exercise debrief. The second and third items are used to update the base of historical performance data that will help support the next iteration of the embedded training cycle.

The Naval Air Warfare Center Training Systems Division (NAWCTSD) and a contractor team[1] is currently conducting a related set of research projects to implement and demonstrate an embodiment of the embedded training vision in Figure 2 above. These include two main projects:

1) an Advanced Technology Development (ATD) project that is demonstrating an Advanced Embedded Training System (AETS) that augments the existing embedded training facility within the AEGIS Combat System with the capabilities to monitor the behavior of operators in an AEGIS Combat Information Center (CIC) during embedded training exercises, and, using embedded generative or predictive models of operator performance, to diagnose operator performance.
2) a project to develop Shipboard Instructor Training and Support (SITS), as a set of tools to facilitate the selection of training objectives from historical performance data and local training needs, to develop appropriate scenarios from such training objectives, and to develop and maintain the appropriate inventories of general skill and task requirements as well as student-specific performance data as measured in terms of those requirements. The SITS project also focuses on the AEGIS CIC application.

In terms of the training vision set forth in Figure 2, the AETS effort is implementing the lower half of the cycle, while the SITS effort is implementing the upper half of the cycle. Together, they are creating a demonstrable system that implements the potential of future embedded training.

In the remainder of this paper, we will discuss specific aspects of the systems developed under SITS and AETS in terms of the way they implement the broader training vision for future embedded training of shipboard crews.

[1] This team includes Lockheed Martin Corporation's Advanced Technology Laboratories, which is the industry lead on the ATD and participant in the SITS effort, CHI Systems Incorporated and Sonalysts Incorporated, which are participants in the SITS and ATD efforts, and MicroAnalysis and Design Incorporated, which is the contractor lead on the SITS effort.

MANAGING THE TRAINING PROCESS

One major difference between the vision for future embedded training in Figure 2 and the current practice lies in the increased emphasis on active and structured management of embedded training as a delivery mechanism for a continuous training cycle. Each cycle of training must be managed by comparing past trainee performance to the overall job/task requirements, and translating the result of that comparison into the careful selection of immediate training objectives and simulation scenarios that will support those objectives. This training management process is sufficiently complex and data intensive that it requires automated support for the human trainer (or training team) that must do it. To this end, a ship-based Training Management Module, or TMM, is being built (see Stretton et al., 1997). The TMM seeks to provide software support for objective-based training in an embedded system environment by providing a single software tool through which the human trainer can carry out steps 1-4 of the training process in Figure 2.

The key relationship in Figure 2, and in TMM, is that between steps 3 and 4, i.e., the ability to select/generate a scenario to meet specific training objectives. The design of TMM began with a detailed survey and review of current scenario-based training systems (embedded and stand-alone), and the instructional process that they supported (see Stretton et al, 1997; Stretton and Lackie, 1995) This process identified the intermediate steps and functions that a TMM would have to provide for it to be able to broadly support the training vision for current and future Naval shipboard embedded training systems. The TMM functional organization is shown in Figure 3. Given the goal of applying the TMM in a shipboard environment, the key criterion for translating functional requirements into a software tool was that of integrating the functionality into a highly user-friendly, well integrated interface that would itself require little or no training to use.

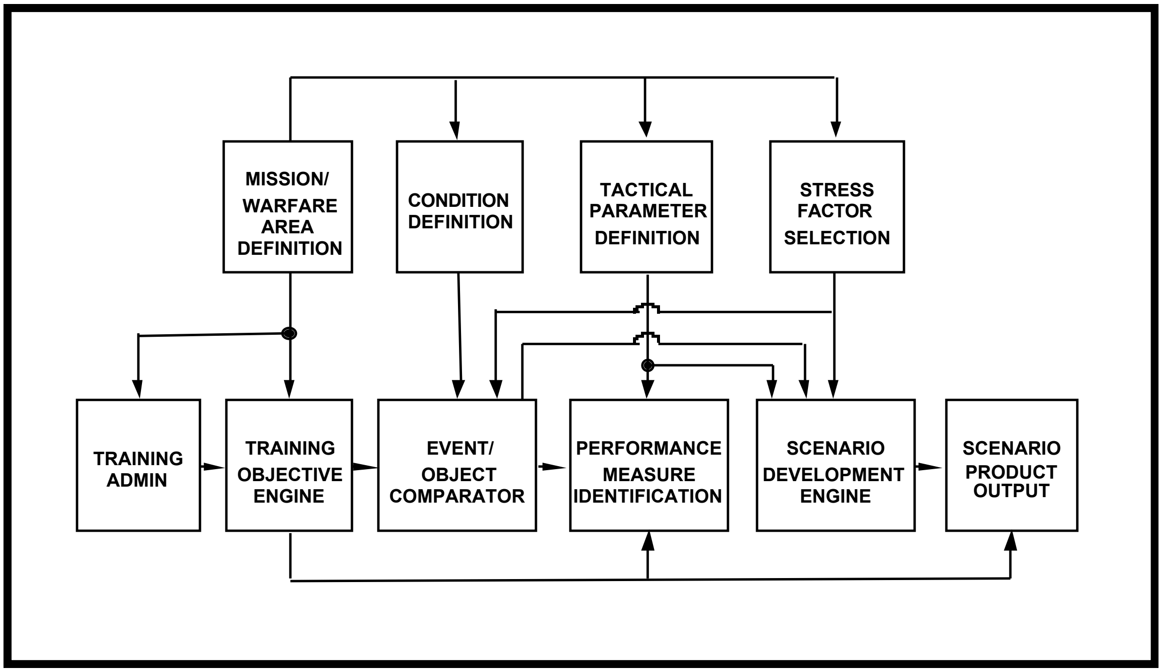


Figure 3. Functional Organization of the TMM

The key to achieving this flexibility was the development of a "learning centered" process that supports the human trainer in the development of scenario-based instructional material. As the trainer/user of TMM develops expertise in both the tool and the objective-based embedded training process, the system will provide a flexible means for the trainer to interact more and more with the scenario building process. Figure 4 illustrates the system functional areas starting with this flexible user-interface shell. The system also tracks historical performance data at the team and individual levels (as these data are received from the embedded training system after each scenario run) to help the trainer tailor future training to areas of greatest need. This hierarchical performance data can be used to annotate the hierarchy of mission related training objectives to support prioritization of scenario elements, or generic event strategies, required for an upcoming training session. Upon selection of an exercise area and antagonist, these strategies can be combined and populated with the appropriate entities and placed within the geographic context. Support materials, such as pre-brief information, can also be produced from templates that are filled in based on prior selections. Scenario difficulty can be tailored based on the trainee/team's past performance and experience with missions of this type. Once events are selected relative to identified objectives, the trainer uses a performance measure identification capability to set goals for measures related to the specified objectives.

CAPTURING AND ANALYZING DATA ON TRAINEE PERFORMANCE

A second major difference between the current embedded training practice and the future vision lies in the bottom half of Figure 2 -- in the augmentation of the embedded training system to provide automated performance measurement, diagnosis, and training feedback. Current scenario based embedded training systems provide only the opportunity for realistic scenario-based practice, and leave assessment and diagnosis to the human trainers who oversee the trainees working the scenarios. The Advanced Embedded Training System, or AETS, represents a system that implements data capture, assessment, diagnosis, and feedback. Figure 5 shows the way in which these processes are automated in the AETS.

The AETS is organized into four separate components, which all work in parallel. The first concerns data capture, which observes the actions of the trainee in multiple modalities. It captures all keystroke level interactions and aggregates them automatically into higher level units that represent the operator's functional interactions with the workstation. In parallel, the system records and processes all speech communication within the team, recognizing and analyzing the utterances

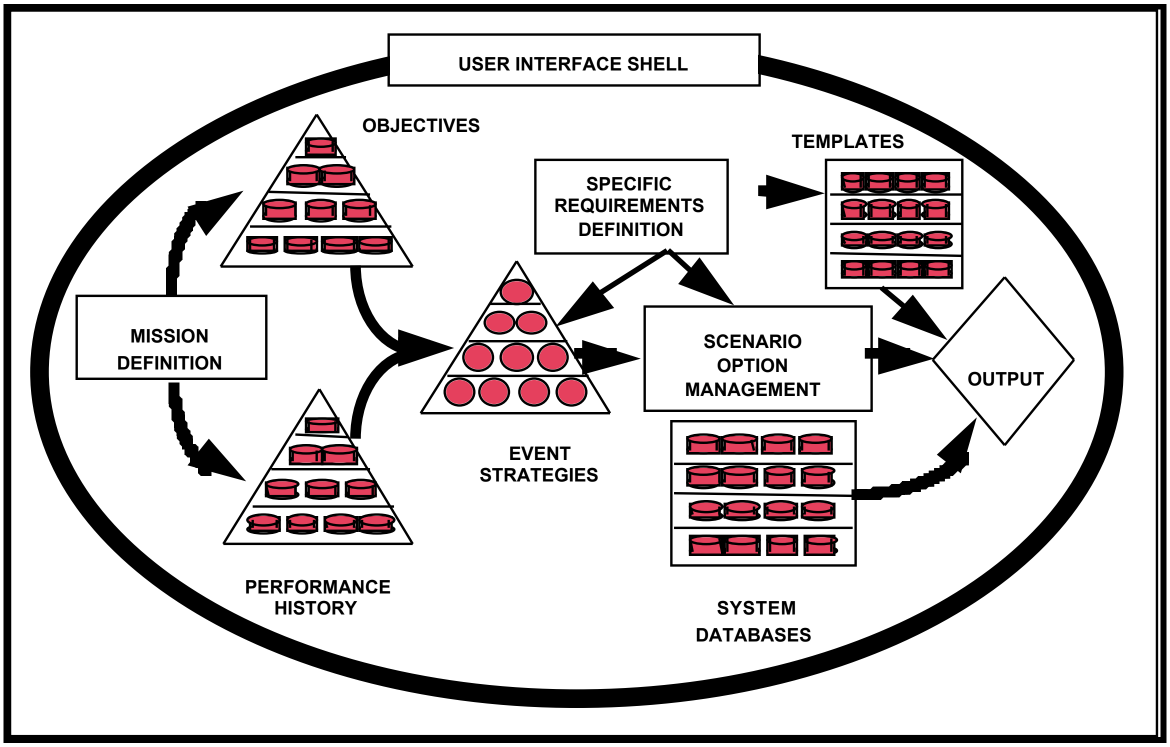


Figure 4. TMM Operating Concept

into semantic components that define, for each utterance, the source, destination, message type, and the objects and relationships mentioned. Also in parallel, each operator's eyes are tracked, and the dynamic eye-movement data are analyzed to assess what objects the operator viewed, when, and for how long. These three data paths are then fused to provide a coherent record of what the trainee is doing during the embedded training exercise.

This picture of what the trainee is doing is dynamically compared with a model-based specification of what the trainee should be doing. An executable cognitive model of each trainee passively observes the information provided to the trainee (voice and visual/screen data), and identifies actions that an experienced operator ought to take at that point in the exercise. The model also identifies the knowledge and skill elements needed to generate the expected behavior. These expert operator models are expressed in the COGNET framework (Zachary et al, 1997; Zachary et al., 1996) for cognitive simulation. The two specifications -- of what the trainee is doing and what the trainee should be doing -- are compared in a two-stage diagnosis process. The first is a behavioral diagnosis stage. The high-level behaviors of the trainee as observed are compared to the high-level behaviors recommended by the model, to determine if the recommended behavior was done, and within the recommended time window. This behavioral diagnosis (both correct actions and deviations) is then input to the calculation of overall performance measures, which are used to determine the trainee's performance relative to the stated training objectives. In the second stage is a cognitive diagnosis, the trainee's actions are processed to determine which knowledge and skill elements are (and are not) being demonstrated in the observed behavior. Using a bayesian inference approach commonly employed in intelligent tutoring systems (Nichols et al, 1995), a model of the trainee's knowledge state is built and maintained over time.

The third component of the AETS is a feedback and instruction component. The results of the behavioral and cognitive diagnosis are used to provide information to the trainee and/or instructor both during the scenario and after the scenario. The former is provided through a limited display window and other means, and is judiciously limited (to avoid intrusion onto task performance) to information that can be immediately used by the trainee to guide and improve their performance during the scenario. The latter information is provided indirectly to the trainee, via the training instructor's post-scenario debrief.

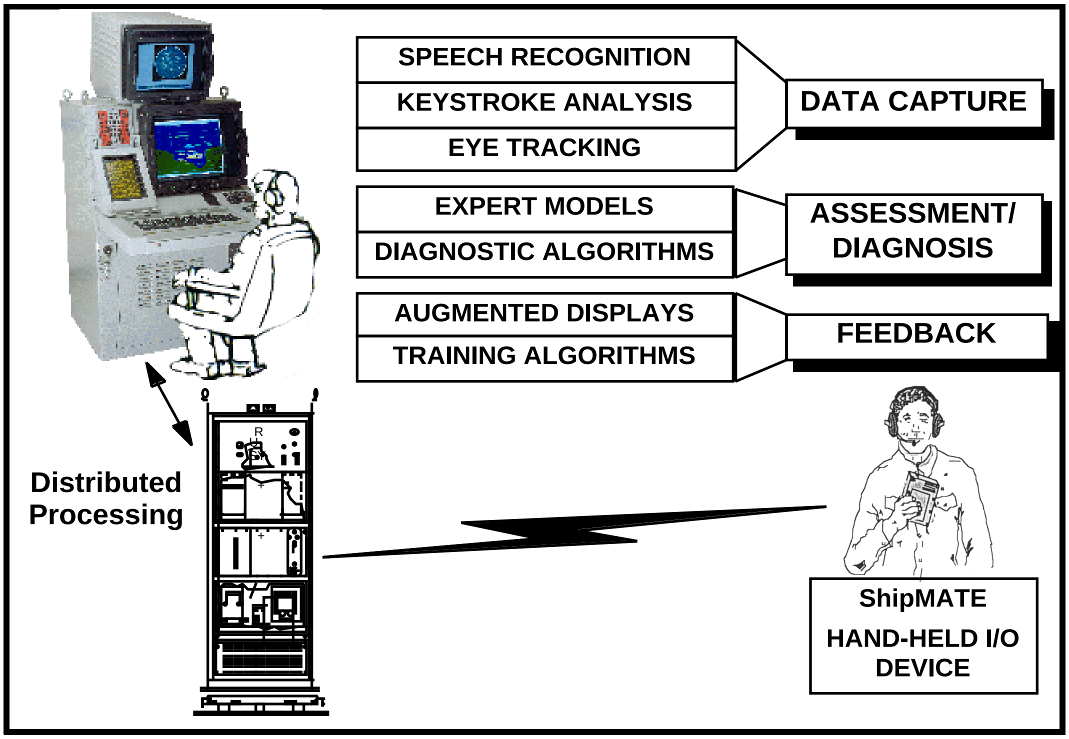


Figure 5. Components of the AETS

ASSESSMENT AND FEEDBACK SUPPORT FOR THE INSTRUCTOR

The first three components of the AETS are themselves ‘embedded' into the embedded training system. Except for the eye-tracking camera (which is only slightly larger than a coffee-cup), the processing of these components is conducted on the same equipment as the embedded simulation processor. Not only do these components have no physical 'footprint', they have no user interface. They operate automatically behind the scenes, providing data for feedback to the trainee, for the post-scenario debrief, and for the historical performance data archives. However, the AETS is not intended to operate as a fully automated training system. The focus of interaction with the trainee (team) remains through the human training instructor who is overseeing the scenario exercise. The AETS provides a mobile, pen-based interface for this human trainer, called the Shipboard Mobile Aid to Training and Evaluation (ShipMATE)[2].

ShipMATE is a prototype software application designed to aid shipboard trainers in the task of preparing for, conducting, and debriefing objective-oriented, scenario-based training. Pictured in Figure 6, ShipMATE runs on a lightweight (approximately 3.5 lbs.), off-the-shelf, pen-centered, hand-held computer (that can potentially serve multiple purposes in addition to hosting ShipMATE). Importantly, this extremely lightweight and portable system has infrared and radio-frequency communications capability that allows the user to move freely about the ship, untethered to any physical equipment.

ShipMATE serves two main functions. First, it provides a medium through which the AETS can communicate information on performance, diagnosis and feedback to the trainer, who can decide how (and if) to use it;. AETS diagnostic data and performance measures are simply transmitted to ShipMATE as data objects, which the instructor can use in any manner she/he feels appropriate. Perhaps more important is the second function, a tool by which the trainer can manage the execution of the training scenario, via construction of the pre-run pre-brief, management of real time data sources during the run, and construction of the post mission debrief.

Team training using embedded systems places enormous demands on trainers to make relevant and memorable interventions to the team

[2]ShipMATE is actually common to both the AETS and SITS projects, and has been developed collaboratively across the two by Lockheed Martin, NAWC-TSD, and Sonalysts.

Figure 6. Data Capture Screen.

in real time, or shortly after performing. Some of these demands include monitoring multiple individuals, diagnosing errors, delivering feedback, and specifying remediation. Even if the trainer's task were limited to overviewing one individual, the difficult tasks of assessing understanding, interpreting misconceptions, and tailoring training to the individual's specific needs would remain. It is clear that trainers are overloaded in team situations where they must simultaneously measure process and performance, detect problems, deliver feedback, and tailor remediation. However, if trainers are not able to do these things, the process of remediation will likely fail.

Currently, four main features enable ShipMATE's ability to support the trainer in preparing the team for the exercise (prebrief support), as a data collection device to be used during the exercise, and as a tool for preparing for and conducting post-exercise debriefs:

- Digital Ink Notes -- the trainer can create notes during the simulation run via the digital pen for storage and later use in preparation of the debrief. These notes are automatically time-stamped (which links them implicitly to the scenario timeline) and associates them with specific operators, as well as with other performance measures
- Voice Annotation -- the trainer also wears a microphone, through which verbal notes can be recorded. These, too, are automatically time-stamped and can be indexed to the same parameters as digital ink notes, thus providing the trainer with multiple modalities though which to record observations and comments on the observed performance of the trainees.
- Team Communications Capture -- through its wireless network, the ShipMATE has access to all communications being transmitted through the local voice-communication networks. The ShipMATE user (i.e., the trainer) can direct ShipMATE to record for later use/analysis any voice communication in this network. These, too, are time-stamped and indexed by any parameter the user wishes. To allows for the fact that the trainer will typically recognize the need to record a conversation after it occurs, ShipMATE can record conversions beginning up to 30 seconds in the past, through use of a built-in delay mechanism.
- Console Screen Capture -- finally, the ShipMATE user can capture a 'snapshot' of the contents of any operator's screen at any point in time. Once again the snapshot is time-stamped and fully indexable.

CONCLUSIONS

This paper has described why embedded training will be increasingly important in the future, and has given a vision of how embedded training will need to be conducted in the future if it is to meet the requirements and expectations that are currently being placed on it. It is important to note, however, that this vision is not just a rhetorical stance, a 'pie in the sky' notion of how things may work someday. We have also presented information on some of the research and development that is actively underway to bring this vision into reality. While there may be other ways of accomplishing the goals of the future training vision, we have endeavored to show that it can be realized with today's technology, and in a way that is fully compatible with existing simulation-based embedded training systems.

REFERENCES:

Nichols, P., Chipman, S., & Brennan, R. (Eds.). (1995). Cognitively Diagnostic Assessment. Hillsdale. NJ: Erlbaum.

Stretton, M. & Lackie, J. (1995). SITS scenario development mission profiles. (SITS program technical report).

Stretton, M., Lackie, J., & Cannon-Bowers, J. (in press). Requirements for Objective- and Performance-based Creation and Modification of Complex Training Materials, in Proceedings of the Human Factors and Ergonomics Society 40th Annual Meeting, Santa Monica, CA: HFES.

Zachary, W., Le Mentec, J.-C., & Ryder, J. (1996). Interface Agents in Complex Systems. In C. A. Ntuen & E. H. Park (Eds.), Human Interaction with Complex Systems: Conceptual Principles and Design Practice, (pp. 35-52). Boston: Kluwer Academic Pub.

Zachary, W., Ryder, J., & Hicinbothom, J. (in press). Cognitive Task Analysis and Modeling of Decision Making in Complex Environments. In J. Cannon-Bower & E. Salas (Eds.), Decision Making Under Stress: Implications for Training and Simulation, Washington, DC: American Psychological Association.