TACTICAL ACTION OFFICER INTELLIGENT TUTORING SYSTEM (TAO ITS)

Richard H. Stottler
Stottler Henke Associates, Inc.
1660 So. Amphlett Blvd., Suite 350
San Mateo, CA 94402
(650) 655-7249

LCDR Michael Vinkavich
Surface Warfare Officers School Command
446 Cushing Road
Newport, RI 02841
(401) 841-4963

Abstract

The U.S. Navy's Surface Warfare Officers School (SWOS) in Rhode Island is pioneering the use of a low-cost simulation-based intelligent tutoring system (ITS) as part of its Tactical Action Officer (TAO) training program to train Navy officers in high-level tactical skills. This software was designed and built for SWOS for use on standard PCs, was introduced to the School in early 1999, and the Navy has a royalty-free license to use it. The software can be used both as a classroom aid and by individual students. A key objective of the software is to increase the active training that officers receive to improve their ability to apply their conceptual knowledge of tactics. Early results from its use with two classes are encouraging and indicate that the software will succeed in this goal by enabling as much as a ten-fold increase in hands-on training.

The software has three parts. First, there is a scenario generator, with which instructors, with limited assistance from a programmer, can create any number of simulated scenarios. These can be set in any part of the world, and populated with different surface and air platforms. Each individual platform is implemented as an "intelligent agent" and can be given its own performance characteristics and behaviors so it will act realistically. For example, a hostile plane will have its own mission (which the student can only surmise) but will react to challenges from the student's friendly platforms. Second, there is the intelligent tutoring system, which presents selected scenarios to the student to practice different tactical concepts. The software will adaptively select scenarios for individual students, that practice concepts he or she hasn't yet practiced or has recently failed, or enable a student to pick any scenario. As well as the intrinsic feedback that free-play simulations naturally provide a student, the TAO ITS provides detailed, useful extrinsic feedback to the student once a scenario is finished, which reviews all the concepts attempted and whether they were passed or failed. At this point, the student can review multimedia material about any concept, or see a replay of the scenario to review errors. The third part of the software is an instructor interface tool for instructor to review all the students' work with the tutoring system to assess their progress in detail.

This paper describes the Tactical Action Officer Intelligent Tutoring System as an example of what ITSs can do and the benefits they can provide. It also includes an explanation of why the case-based reasoning technique was used in the software to reduce three problems commonly associated with intelligent tutoring systems: effective incorporation of subject expert knowledge in the software, cost, and development time. It also reviews SWOS's experience with the software since its introduction, students' opinions of the software, and suggests ways in which future simulation-based intelligent tutoring systems might be improved based on SWOS's experience.

Bibliographic Sketches:

Dick Stottler co-founded Stottler Henke Associates, Inc. (SHAI), an artificial intelligence consulting firm in San Mateo California, in 1988 and has been the president and CEO of the company since then. He has been principal investigator on a number of intelligent tutoring system projects conducted by SHAI including the Tactical Action Officer Intelligent Tutoring System. Currently, amongst his numerous projects, he is working on an intelligent tutoring system to teach armored company commander decision-making for STRICOM, as well as continuing to upgrade the TAO ITS. He has a masters in computer science with a concentration in artificial intelligence from Stanford University.

LCDR Mike Vinkavich is currently Instructor at Department Head Officer School in Newport, RI. He has also been an instructor at the SWOS Division Officer Course. He enlisted in the Navy in 1977, after Machinists Mate 'A' School, Nuclear Power School and Nuclear Power Prototype, and served on USS LONG BEACH CGN-9 until 1983. He left the Navy to pursue his education and graduated with a B.S. in Mathematics (education) from the University of Nebraska in 1988. His sea duties consisted of Damage Control Assistant and Combat Information Center Officer in USS KNOX; Communications Officer on Amphibious Squadron Eight Staff; Combat Systems Officer in USS DAVID R RAY and Combat Systems Officer in USS LAKE ERIE.

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Richard H. Stottler
Stottler Henke Associates, Inc.
San Mateo, California

LCDR Michael Vinkavich
Surface Warfare Officers School Command
Newport, Rhode Island

INTRODUCTION

The mission of the Surface Warfare Officers[1] School (SWOS) in Newport, Rhode Island is to provide professional education and training to prepare officers of the U.S. Surface Navy to serve at sea. The importance of this mission was succinctly emphasized by ADM Arleigh Burke who said, "This ship is built to fight. You had better know how."

As part of his training at SWOS, each Surface Warfare Officer learns how to "fight" his ship as a Tactical Action Officer. The TAO training consists of three months of classroom and simulator time wherein students are exposed to all elements of surface warfare; air, surface, subsurface, and amphibious operation as well as electronic and other support mechanisms. One major responsibility of a TAO is to be able to be able to exercise command over the major systems of his ship (weapons, support platforms, radar and sonar, and navigation) during potentially hostile situations. The tactical decisions he makes during such situations can easily affect the outcome of the ship's mission, as well as have life or death consequences.

The U.S. Navy is continually reviewing and improving its training program to prepare its young surface warfare officers for this considerable responsibility so that they will perform effectively the first time when they are put to the test in action. Such training is very expensive (one recent estimate[2] of the total cost to train a surface warfare officer is over $80,000), requires a high instructor/student ratio, and the cost is exacerbated by loss of SWOs from the Navy.

The Navy has been using desktop training software to improve training through more active simulations without increasing the instructor to student ratio, thereby reducing overall cost without reducing training effectiveness. Such software might also prove invaluable at times of emergency when the U.S. needs to rapidly expand its fleet. During a period of rapid expansion, this program would maintain the same training standards throughout a wide range of instructional sources; that is, if such an expansion were to occur, SWOS could not accommodate the increased throughput and other instructional resources would have to offer this type of training.

A promising piece of software introduced to SWOS in early 1999 has been the Tactical Action Officer Intelligent Tutoring System, designed and built to SWOS specifications.

TACTICS TRAINING FOR TAOs

The first formalized tactical training any Surface Warfare Officer receives begins with the Department Head TAO course. (Some students are more proficient in tactics due to billets held as division officers.)

Currently, TAO students spend approximately forty (40) hours in simulators designed to allow practical application of classroom instruction. The future of the navy requires fully qualified individuals when they report to their ship, requiring longer periods of effective realistic training. TAO ITS is a step in the right direction to help fill the gap.

INTELLIGENT TUTORING SYSTEMS

Purpose and Nature of Intelligent Tutoring Systems

Intelligent tutoring systems (ITS) can best be defined as advanced training software that mimics a human tutor by adapting its instructional approach to each individual student. They are particularly valuable for teaching complex cognitive tasks such as trouble shooting, problem solving, and resolving critical situations. As a human tutor does, an ITS continually monitors and assesses each student's actions, infers the student's state of knowledge, and decides on the next instructional event to maximize the student's learning. To do this in a significant and cost-effective way, intelligent tutoring systems use artificial intelligence.

One-on-one tutoring by skilled human tutors is widely regarded as the single best mode of instruction. A study[3] by Benjamin S. Bloom of the University of Chicago and Northwestern University concluded that, under the best learning conditions they could devise (tutoring one-on-one), the average student was 2 Sigma above the average control student taught under conventional group methods of instruction. That is, the average tutored student was above 98% of the students in the control class.

Conventional computer-based training (CBT) software is not designed to provide such a high level of adaptive response to each individual student as an individual human tutor or ITS can. In fact, most CBT software more closely resembles an "electronic textbook" rather than an "electronic teacher." Just as a book implicitly encourages a student to start at the front and move to the back, such CBT software usually encourages a student to move linearly through a set of multimedia material, with the occasional multichoice questions to test the student's retention of the information. Such tests do not assess the student's ability to apply the information; and it is the ability to apply information in a job that training should be really about.

Also, conventional computer-based training is not able to meaningfully incorporate use of free-play simulators into their curriculum, affordably. This is a major shortcoming of conventional CBT as student manipulation of sophisticated simulators that realistically replicate issues that they will encounter on the job is widely recognized to be a highly effective training technique. The catch has been that simulators without instructors are virtually useless for training, and their unsupervised use can even result in students learning misinformation. Students working on simulators need instructors to point out their correct and incorrect actions, to brief them in context on the underlying concepts that are being taught, and to decide on the next appropriate simulated scenario for the student to run.

Intelligent tutoring systems are ideal for incorporating desktop free-play simulators into computer-based training since the software can stand in for a human tutor in all his roles. Existing CBT course material can often be integrated with ITS-enabled simulator and other active training. In this way, ITS technology can greatly leverage the training value of existing CBT and desktop simulators. As shown in the Figure 1, the ITS can monitor a student's interaction with both simulation and other training content in the CBT, create and update the student model and decide on the next instructional event (e.g., provide a hint, ask a question, run a new scenario, display multimedia to explain a concept, alert a human instructor that the student needs special help, etc.).

To keep track of each student, the intelligent tutoring system creates and maintains a "student model" for each individual from the first time he or she logs onto the software. Depending on the sophistication of a particular intelligent tutoring system, the student model keeps different amounts of information on the student. The most basic information includes those tasks the student has performed, and his or her performance on those tasks, but not just a record of their actions. From this information, the software might estimate the student's mastery of relevant skills and knowledge, and the student's ability to apply them when appropriate. For example, a student may be able to apply a concept in one set of circumstances, but not under other circumstances, so it is important that the software tests the student's knowledge of each concept under different circumstances.

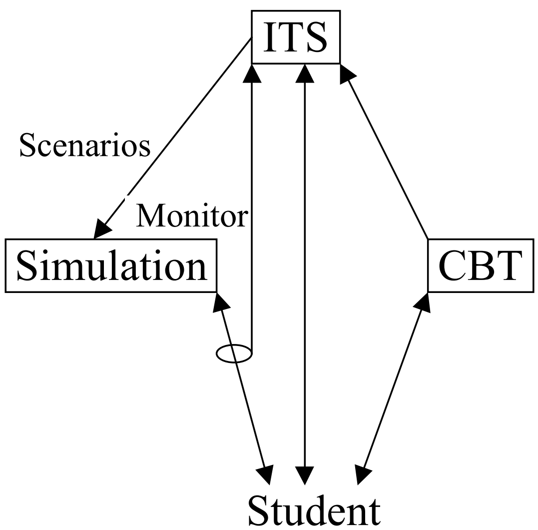

Figure 1. ITS can integrate free-play simulators and multimedia course material

Design of Intelligent Tutoring Systems

As well as a student model, intelligent tutoring systems usually have a number of other functional parts.

There is an instructor or pedagogical module, which contains the knowledge of "how to teach." Decisions about timing of instructional events are originated here in response to input from the student model

A domain knowledge or expert module contains the knowledge that is being taught. Effective representation of this knowledge, particularly concepts and mental models, is a challenging job for the ITS designer. In the case of the Tactical Action Officer Intelligent Tutoring System, much of this knowledge is embedded in the rules driving the simulation and underlying finite state machines that recognize when a student's actions indicate observance or non-observance of a concept that is being taught or tested in a particular scenario.

There is also a communications module, which controls the interactions with the user, and is responsible for presenting the information to the student in the most effective way.

There are different ways of representing the various forms of knowledge that are needed for an ITS, and the software designer is responsible for selecting a way that best suits the knowledge to be taught, the pedagogical methods to be implemented, and the goals of the ITS, not least of which is to enable a cost-effective software product. Designing an ITS is still a complex process and depends on the skill and experience of the designers.

One approach to designing intelligent tutoring systems is to use case-based reasoning (CBR)[4]. The first advantage of this approach is that students learn best from examples (e.g., scenarios simulating realistic situations), and their abilities are best tested in the realistic contexts provided by these scenarios. A case-based approach also reduces the costly and timely activity of developing an explicit expert model that can perform at the required level of expertise, which is a problem in developing a rule-based intelligent tutoring system. A related benefit of the approach is that it reduces the effort of eliciting the knowledge from the subject expert. It is usually much easier for an expert, an experienced tactical action officer for example, to convey his knowledge and reasoning via cases rather than rules. He is usually more responsive if asked to describe an actual specific problem and its solution, with an explanation of the steps required to produce the solution rather than express the same knowledge in a set of consistent and complete rules.

History and Effectiveness of Intelligent Tutoring Systems

Although the history of intelligent tutoring systems goes back around 30 years, the first commercial ITSs, which teach high-school algebra and geometry, were introduced by Carnegie Learning[5] around 1998. They have been extensively tested in schools with extremely good results. For example, students taught using their Algebra I product:

- Score 50-100% higher on problem solving and multiple representation tests than a control group;

- Perform 15-25% better than control classes on standardized tests;
- Are twice as likely to complete Geometry and enroll in Algebra II; and
- Are more likely to attend class.

A high school teacher [6] who helped develop the software and continues to use it, has observed a phenomenon of possibly greater relevance to the needs of the military. One of the best consequences of using the software is that students who pass algebra tests are now more likely to be able to put algebra to work in solving their practical problems. Before using the software, a smaller proportion of passing students were inclined or able to actually use what they had learned, indicating that conventional classroom teaching resulted in more inert knowledge.

Although intelligent tutoring systems are only now being commercialized, there have been a number of systems either prototyped or fully developed for the U.S. government[7], including the Tactical Action Officer Intelligent Tutoring System. Unfortunately, there have been few performance assessments of ITSs in service, though the few that have been done have been very positive. Dr. Wes Regian and co-authors[8] analyzed the effectiveness of 233 conventional computer-based training courses and 3 intelligent tutoring systems. Student learning when using the courseware was compared with student learning under similar circumstances but without the courseware. The conventional software produced a significant positive effect, but the impact of the ITSs was more than twice as positive.

TACTICAL ACTION OFFICER INTELLIGENT TUTORING SYSTEM

Description of the TAO ITS

The TAO ITS is a good example of a "general class" of useful training systems - simulation-based intelligent tutoring systems designed to run on a PC. It has been used at the Navy's Surface Warfare Officer's School (SWOS) in Rhode Island since early 1999. As well as being a powerful assistant to the classroom instructor, the TAO ITS's advanced capabilities as an "electronic teacher" enable a student to use simulations for learning on his own, anytime, anyplace.

The TAO ITS was designed to provide tactical action officer students at SWOS with realistic, practice-based instruction and individualized feedback. A tactical action officer controls his ship's sensors and weapons and directs the movements of the ship and other support vessels and aircraft. The TAO also monitors the movements and actions of friendly and enemy ships, planes, missiles, and submarines in the region. The TAO integrates this information in real time to form a dynamic tactical picture, selects appropriate responses, and issues orders.

The TAO ITS allows students to use information presented in class and receive individual feedback as to their performance in tactical decision-making, use of ship's sensors and weapon systems, and reporting procedures. It allows instructors to review these student runs and tailor scenarios to help overcome any observed deficiencies in their understanding thereby ensuring classroom training is adequate. ITSs can allow the student to provide feedback to the instructor in the scenario itself. For example, if the ITS stated that the student failed a principle that differed from one that he had been taught, he would be able to imbed this information within the scenario for instructor review.

When the TAO ITS is sent to the fleet, the ships will be able to create/tailor scenarios specific to each ship's mission. This will give the commanding officers another tool to help fine tune skills and procedures required for the ship's missions.

The TAO ITS software enables students to act as TAOs in simulations of tactical scenarios, as a conventional training simulator might do. Unlike conventional training simulators, after a student completes each scenario, the TAO ITS also automatically evaluates the student's actions to determine tactical principles that the student has correctly applied or failed to apply. These detailed assessments of student performance are available to both the student and his instructor.

This evaluation is carried out using sophisticated pattern-matching algorithms defined by tactical experts via graphical user interface, without programming. The student can then learn how to correct his problems by either selecting multimedia training material associated with any principle, or by replaying relevant parts of the last scenario he worked to review his mistakes.

The TAO ITS also helps the student choose the next scenario to practice on. The student can allow the software to choose a scenario that contains untested principles, other scenarios that test principles recently failed by the student, or simply pick his or her own preferred scenario. The instructor can use a scenario generator included in the software package to create any number of additional scenarios, defining complex behaviors for each friendly and enemy ship and aircraft to create realistic, multi-agent tactical simulations.

The software has three parts: the scenario generator with which instructors, with limited assistance from a programmer, can create any number of simulated scenarios; the student interface, which presents selected scenarios to the student to practice different tactical concepts; and the instructor interface tool for the instructor to review all the students' work with the tutoring system and to assess their progress in detail.

Scenario Generator

The scenarios created with the scenario generator can be set in any part of the world, and populated with different surface, air and underwater platforms (i.e., ships, planes, helicopters, missiles, submarines). See Figure 2 for the main interface of the Scenario Generator. Each individual platform is implemented as an "intelligent agent" and can be given its own performance characteristics and behaviors (see Figures 3 and 4). For example, a hostile plane will have its own mission such as flying various patterns to search out enemy vessels, and when one is found to attack it. The student can not see these defined behaviors and therefore can only surmise the goals of hostile platforms and their likely reactions to challenges from the student's forces.

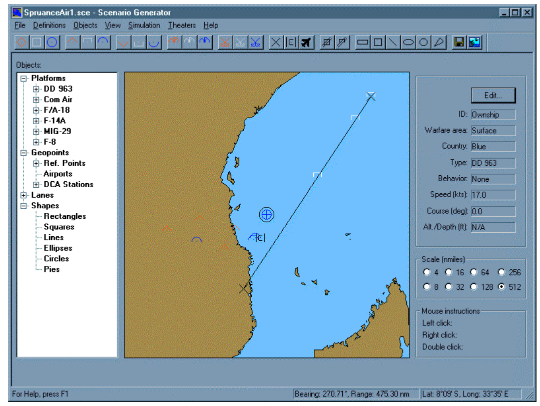

Figure 2. Scenario Generator

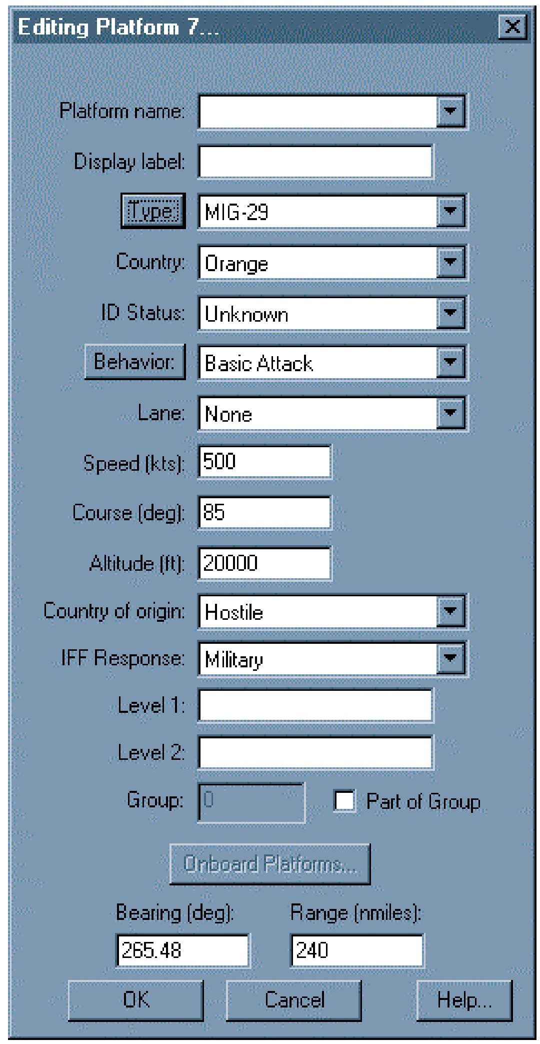

Figure 3. Tool to edit a platform, in this case a MIG-29

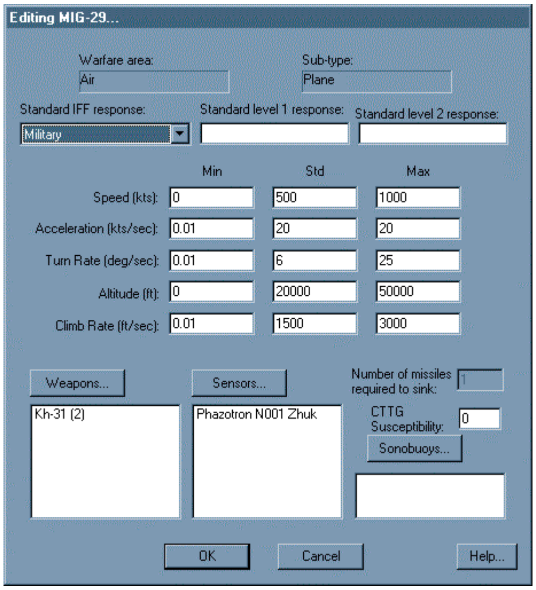

Figure 4. By pressing "Type" button in Figure 3, this second-level tool to set the basic performance characteristics of the chosen platform is made available.

Key to the training effectiveness of a scenario is the instructor's ability to select concepts (also know as principles) from a set of available concepts in order to associate with a particular scenario. (This association is done using the Instructor Interface Tool, see below). The selected concepts are those in which the instructor intends the student to test his or her mastery in the specific scenario. Since the simulator is free-play, there is no guarantee that any particular concept will actually be tested when a student runs a scenario. For example, if the student orders his ship to head away from an enemy plane and remains concealed from it, an entirely different set of events may play out than those that would if the ship were discovered by the plane. To deal with this aspect of free-play simulators, the TAO ITS has "evaluators" associated with the concepts. An evaluator is designed to look for prescribed sequences of events and actions during a scenario. For example, if a missile is fired at the student's ship, there may be a range of appropriate actions he or she could take in response. A number of evaluators could be set up to examine the chosen actions, and depending on what they observe, the software may recognize that different principles are observed or not. There is not a one-to-one correspondence between evaluators and principles, and a combination of evaluated sequences may need to happen to trigger recognition of observance of one principle, or that one evaluated sequence may indicate that several principles were breached.

Student Interface

The heart of the intelligent tutoring system is the student interface that presents selected scenarios to the student in order to practice different tactical concepts. The software was designed to adaptively select scenarios for individual students, who need to practice concepts (principles) he or she has not yet practiced or ones he has recently failed. It enables a student or instructor to pick any scenario from all of the ones available. As well as the intrinsic feedback that free-play simulations naturally provide, the TAO ITS provides detailed, useful, extrinsic feedback to the student once a scenario is finished. This feedback reviews all the concepts attempted and whether they were passed or failed. At this point, the student can review multimedia material about any concept or see a replay of the scenario to review errors.

The student (or instructor) starts a session by logging on. Once logged on, the student can choose to review his or her previous performance, review multimedia instructional material, or run scenarios. This is initiated by picking an appropriate scenario from those available using the window shown in Figure 5.

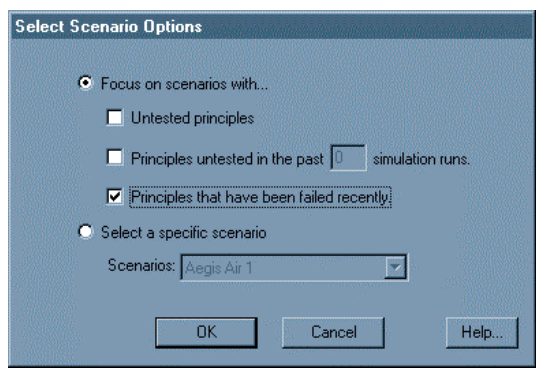

Figure 5. Screen providing assistance to student to decide which scenario to run next.

Pressing "OK" in the "Select Scenario Options" window launches the scenario as shown in Figure 6. The software is set to run a scenario for up to 60 minutes however the student can terminate the scenario at any time.

While there is a basic physical simulation driving all the platforms in a scenario, the simulator in the TAO ITS is inherently conceptual. For example, a tactical action officer on an AEGIS cruiser works in the Command Information Center (CIC), and is supported by a large number of individuals who provide him with information and respond to the TAO's orders. To simulate all of the commands, the TAO ITS provides the means to implement them. Thus, the left uppermost section of the screen operates all the ship's weapon systems, the lower left section issues commands to any supporting aircraft, the upper right section provides control over the ship's navigation, and the lower right section operates the radar and sonar equipment and displays numerical responses to this equipment. The lower middle panel displays communications from crew members, for example, reports of incoming missiles, and these communications can also be heard with the voice synthesizer. The central display panel is a reasonable physical simulation of display in the CIC, and it displays only the information that would be realistically available to the TAO at any time.

An open question for advanced training systems is to what extent physical realism in the simulator is important to meeting the training objectives. The higher the degree of physical realism that is used, the greater the expense of creating the hardware and software and in updating it as the platform changes. The TAO ITS was designed primarily to teach cognitive skills. The reaction of students and instructors to it indicate strongly that lack of physical realism did not negatively impact meeting its training objectives.

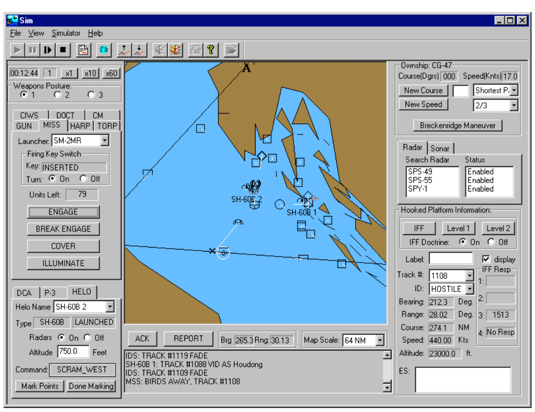

Figure 6. Main Student Interface.

Once terminated, the software evaluates the student's actions by comparing his actions and the circumstances under which he made those actions against the "evaluations," and prepares an Evaluation Summary (see Figure 7). Doing the evaluation for the whole scenario session was a design choice. For other ITS applications, it may be more appropriate to do an on-going evaluation that could generate hints, provide hints, or alter the course of the session in some other chosen way.

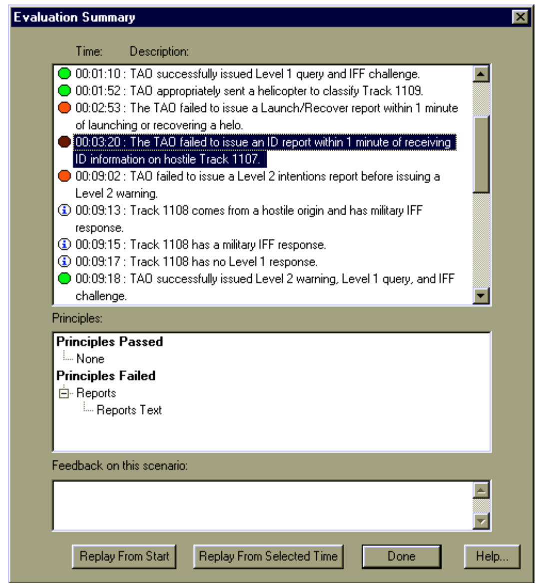

Figure 7. Evaluation Summary

The Evaluation Summary lists the situations in which the student demonstrates understanding of concepts (principles) by their correct application. Correct decisions are marked by a green circle, and situations where understanding of concepts was not observed (either by incorrect or omitted actions) are marked by red circles. Also provided are the time and description of the action. It also provides additional information that an instructor might mention to a student in regular one-on-one tutoring. The exact principles observed or not observed for any of these situations can be found by clicking on the particular situation. By clicking on any noted principle the student will be taken to multimedia information that explains the principle. The Evaluation Summary form also allows the student to replay the recent scenario from the start or from a selected time.

Instructor Interface Tool

The instructor can manage the activities of all students using this tool (see Figure 8). It provides the instructor with tools to manage the hierarchy of instructional principles and the set of multimedia review content; to link specific multimedia review content to principles so that when a student's actions endanger friends the review text covers that topic; and to associate principles and evaluations with specific scenarios.

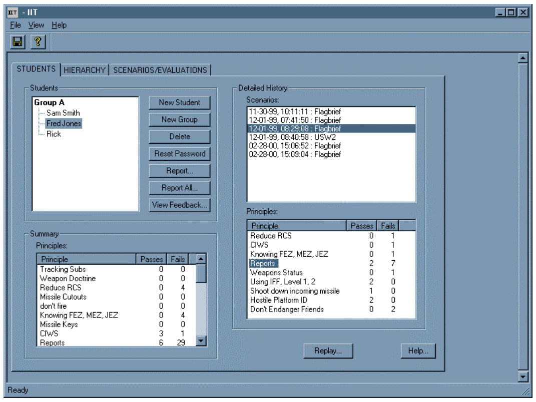

Figure 8. Instructor Interface Tool

Ongoing improvements being made to the TAO ITS

Work continues on additional improvements to the current TAO ITS to enable trainers to implement a wider range of teaching strategies. An ITS authoring tool is being built that works with the TAO ITS or other similar training simulators. With the authoring tool, a trainer will be able to specify a hierarchy of principles to be taught, identifying prerequisite and dependent principles, so that the software can determine their order of presentation. Alternatively the instructor can specify the desired order in which to deliver instruction. He will also be able to instruct the software to implement a wide range of teaching strategies to be used with beginner through advanced students, as appropriate. In addition, a trainer will be able to instruct the software how he wishes it to perform initial expertise and ongoing expertise assessments of students at different levels of performance. Based on these assessments, the software will continually regrade students so they always are taught the appropriate material in an instructionally effective way, based on past performance and the system's estimates of their knowledge, ability and learning style. The authoring tool will also give the trainer more control over the way scenarios will be selected. For example, a beginner may have scenarios selected for him according to a trainer-specified criterion, while an advanced student may be able to continue selecting the scenarios he prefers to run.

With these improvements, an ITS can deliver an even greater one-on-one learning experience for each student, enabling the power of simulation-based training to be provided, without requiring the presence of a human instructor.

EARLY REACTION TO TAO ITS BY SWOS INSTRUCTORS AND STUDENTS

Overview of Dr. Joan Johnston's survey

A survey of student reaction to the TAO ITS was conducted at SWOS in June 1999. The survey was designed by Dr. Joan H. Johnston of the Naval Air Warfare Center Training Systems Division (NAWCTSD) in Orlando, Florida. Dr. Johnston also evaluated its results.

SWOS department head students in one of LCDR Black's classes participated in a demonstration of the TAO-ITS. Following the classroom demonstration, LCDR Black distributed the survey. Twelve students responded.

(LCDR Black was integral to the development of TAO-ITS and its introduction into the curriculum at SWOS. Additionally, TAO-ITS was used more often than just for the survey. It has been an integral portion of the AEGIS Tactical Employment Training portion of the TAO curriculum for several classes.)

The survey was designed to gauge student reaction to the TAO ITS in two prospective roles—first, as a classroom aid; and second, in its more demanding role as an intelligent tutor to support the individual in learning and practicing tactical decision-making tasks.

Results of survey

Nine of the 12 students had an extremely favorable overall reaction to the TAO ITS as a classroom aid, two had a favorable reaction, and only one student was neutral. All of the responding students had an overall favorable reaction to the TAO ITS as a stand-alone training tool, and 80% of these students' reactions were extremely favorable. LCDR Gene Black, Lead AEGIS Instructor at the Surface Warfare Officers School (SWOS) shared their enthusiasm: "TAO ITS gives a student tactical action officer ten times the tactical decision-making opportunity [compared with that provided by] existing training systems."

CONCLUSIONS

The initial reaction from students to this simulation-based intelligent tutoring system has been very good and is indicative of a strong positive effect it has on learning. By making desktop simulator-based ITSs more available to students in and out of the classroom, cognitive skills training can be greatly improved at a reasonable (or even reduced) cost. The intelligent tutoring system capability removes the greatest current limitation on simulator training, that they are virtually useless without an instructor present for evaluation, debriefing, remediation, and scenario selection. An ITS can be useful to instructors, as the assessments it makes about the skills gained by students can help an instructor plan appropriate classroom activities, and interventions with individual students. This ITS study also provides strong support to the viewpoint that a high degree of physical realism in a simulator, which is expensive to attain, is not necessary to teach cognitive skills.

ACKNOWLEDGEMENT

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[1] See http://www.colorado.edu/NROTC /career/career-SWO.html or http://depts.washington.edu/uwnrotc/swo.htm for a description of the role of a Surface Warfare Officer.

[2] http://web.nps.navy.mil/~code36/ Makeemd.html

[3] Benjamin S. Bloom (June/July 1984), The 2 Sigma Problem: The Search for Methods of Group Instruction as Effective as One-to-One Tutoring, Educational Researcher, Vol. 13, No. 6, pps 4-16.

[4] R. Stottler, S. Ramachandran, "A Case-Based Approach to Internet Intelligent Tutoring Systems (ITS) and ITS Authoring," Proceedings of the Twelfth International Florida AI Research Society Conference, Orlando, FL, 3-5 May, 1999.

[5] http://www.carnegielearning.com/ home_fs.html. While not a simulation-based ITS, this software successfully demonstrates how this software can adjust to the needs of individual students while doing math exercises on a computer.

[6] Private conversation with Jackie Snyder, Department Chair of Mathematics at Langley High School, Pittsburgh, PA, November 1999.

[7] Christine Youngblut, "Government-Sponsored Research and Development Efforts in the Area of Intelligent Tutoring Systems," IDA Paper P-3003, Institute for Defense Analysis, September 1994.

[8] Dr. Wes Regian, Dr. Robert Seidel, John Schuler, Paul Radtke, "Functional Area Analysis of Intelligent Computer-Aided Instruction," http://train.galaxyscientific.com/icaipage/litlfaa/litlfaa.htm, last modified June 11, 1999.