# Learning Anti-Submarine Warfare with a Game-Like Tactical Planner

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## ABSTRACT

A large body of research indicates that authentic problem-solving experiences are crucial in achieving mastery of complex subject matter. It is relatively rare, however, that problem-solving environments for serious applications are instrumented in a way that makes it possible to record and automatically categorize every meaningful action in the problem-solving context. We have developed such a tool and have begun to use it to study complex learning and problem solving.

The *ASW Sandbox*, a tool for learning about anti-submarine warfare (ASW) in the context of tactical planning was developed for a course taught at the U.S. Navy Surface Warfare Officers School (SWOS). The tool offers two modes: an Instructor Mode for rapidly developing tactical scenarios and problems, and a simpler Problem Mode for delivering interactive scenarios and recording learner actions. Instructors and students have chosen to utilize the tool in five ways. (1) Instructors develop simple scenarios to illustrate particular tactics in ideal contexts. They then record their own solutions to these problems. In class, they play back a recorded solution while describing processes and procedures and explaining the reasons for actions and effects. (2) Instructors develop more complex and/or realistic scenarios that test different types of tactical knowledge. Students are divided into groups and given these problems in class. Their recorded actions are played back through the simulator as they debrief the other members of the class. (3) On an experimental as-needed basis, ASW problems are used to evaluate students, when conventional paper-and-pencil tests are suspected of not reflecting actual competence at the task. (4) Some individual students voluntarily work with additional instructor-authored problems to expand their understanding of ASW. (5) Some students also utilize a version of Instructor Mode to author new problems, so that they can test the limits of tactics.

## ABOUT THE AUTHORS

**Allen Munro** is Professor of Research at the Rossier School of Education, University of Southern California, and co-director of USC's Center for Cognitive Technology. He leads the development of computer-based authoring systems and for developing graphical simulations and instruction in the context of such simulations. Such systems can provide controlled environments for research on complex learning and problem solving.

**Quentin Pizzini** is Senior Research Associate at the Center for Cognitive Technology, University of Southern California. He has played a lead roll in the development of the RIDES, VIVIDS, and iRides authoring and delivery systems, as well as in the development of the ASW Sandbox.

**William Bewley** is Assistant Director at the Center for Research in Evaluation, Standards, and Student Testing at UCLA. He leads a multi-institution research effort sponsored by the Office of Naval Research that includes the work described here. He is interested in the application of advanced technology to the development and validation of effective assessment methods in game and simulation contexts.

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## BACKGROUND

A significant body of research shows that applying new knowledge to problems is an essential part of training people to perform complex tasks. Merrill (2002) analyzes the results of many controlled studies of instructional designs and concludes that effective instruction is almost always problem-centered. Instruction typically also relates the learners' prior knowledge to new concepts, and introduces facts and methods that are required to solve problems or perform the tasks in the learning domain. Such instruction includes demonstrations, and it gives learners the opportunity to practice in problem contexts that support realistic decision-making. Finally, learners are given opportunities to integrate the new knowledge by extending it to novel problems and by demonstrating solutions to others.

### Effective Problem Based Instruction

Clark, Yates, Early, and Moulton (in press) extended and systematized Merrill's approach after reviewing additional research results. Effective instruction begins with motivating learners by explaining what they will be able to do in the real world using the knowledge that they will acquire. It includes didactic/declarative materials that explain the *what*, *how*, and *why* of the problem-solving approach that will be adopted. It also includes demonstrations of how problems are solved, with explanations of the conditions for various actions and steps in the procedures that are used. Very importantly, students are given opportunities to practice what they have learned by solving problems themselves. A variety of techniques may be used to support initial learner practice, including worked examples, instructor hints or help, and post-task analysis and feedback. In the ideal case, motivated students can continue to practice the problem-solving task on their own.

Clark, Bewley, and O'Neil (2006) developed a heuristic for selecting media to support learning of complex problem-solving domains. Their process requires that one determine whether senses such as taste, smell, or touch are needed to effectively practice the procedure. (If one is teaching cooking, it may be necessary to use taste, smell, and tactile senses, for example.) If so, special environments will be required to provide effective practice (such as a kitchen, in the case of teaching cooking).

If the senses of touch, taste, and smell are not necessary for practicing a problem-centered task, instructional designers can evaluate several types of environments (or media) that support demonstration and practice of problem-solving skills. These typically include both real work environments and simulations or games and with varying degrees of fidelity. Two types of fidelity can be distinguished, pictorial (or image-) fidelity and behavioral fidelity. Pictorial fidelity is particularly important for certain types of tasks, such as training sailors to recognize the class of a ship on the horizon from its shape. When teaching problem-solving skills, behavioral fidelity is ordinarily more important.

If there is more than one environment that can support effective practice and instruction, then the less expensive one should be preferred. For example, tactical action officers (TAOs) can practice surface anti-submarine warfare (ASW) by conducting at-sea exercises using red and blue teams of surface ships and submarines. Each such exercise would have to play out in real time and would require the utilization of hundreds or thousands of sailor-hours for each exercise and for each TAO trainee. Alternatively, a computer-based simulation environment that captured the essential behavioral fidelity required for ASW surface warfare tactics practice would be much less expensive. Many TAOs could train at the same time. By accelerating simulated time, it would be possible to present each learner with many more problems than could possibly be given in a real surface fleet training exercise.

### Rapid Development of Tactics Training Visualizations

Under funding from the Office of Naval Research, the Center for Cognitive Technology at USC has developed software tools for the rapid development of interactive graphical simulations and training that is delivered in the context of such simulations. Rivets (Munro and Pizzini, 2004) and iRides Author (Munro, 2003) are recent versions of these tools. Thanks to these tools, it is possible to rapidly build simple interactive visualizations in response to an expressed need. In conversations with surface ASW instructors in the Department Head Course at the Surface Warfare Officer's School, we were able to prototype simple visualizations to help the instructors convey geometric concepts that were difficult for some students to quickly grasp when they were presented with static line drawings on a white board. For example, passive sonar detection at intervals can generate lines of sound (LOSs), lines that pass through the positions of the submarine and the detecting ship. A series of such lines can be seen to form a pattern, and the shape of the pattern (fanning out, fanning in, crossing, etc) will depend on the relative locations, speeds, and bearings of the submarine and the detecting ship. To help students understand why this should be so, we built, over the course of a few days, the simple visualization tool depicted in Figure 1.

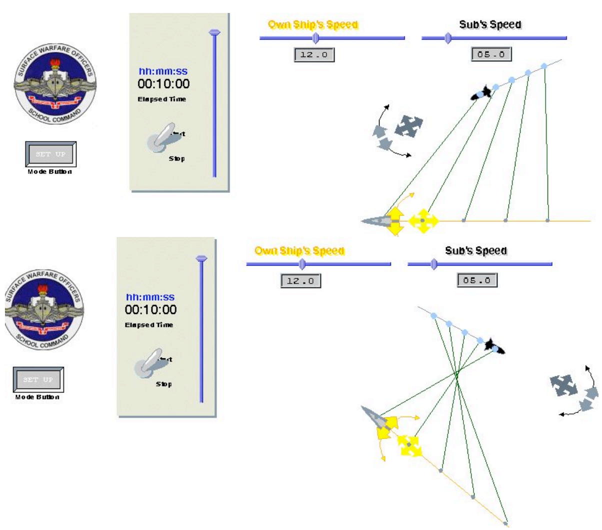


**Figure 1. Visualization Prototype: Patterns of Lines of Sound**

This tool gives the user independent control over the speed and bearing of a submarine and a surface ship with passive sonar that is generating lines of sound. In the upper part of Figure 1, the user has arranged the ship and sub on roughly parallel (slightly converging) courses. In the lower part of the figure, the ship and sub are travelling in opposite directions on parallel courses, which results in a crossing pattern in the lines of sound. ASW instructors found it useful to use this visualization tool to present patterns in lines of sound, and made use of it in lectures. They also made the tool available to the students on their classroom computers, so that the students could experiment with the patterns that result from a number of different relative courses and speeds.

Rivets and iRides were used to build several other interactive visualizations, including one that helps students understand a concept called *Limiting Lines of Approach*. The size and shape of the area of ocean that could contain an underwater threat to a surface force varies, depending on six factors: the speed and bearing of the surface force, the silent speed of the submarine, the range and speed of its torpedoes, and the planned duration of the mission.

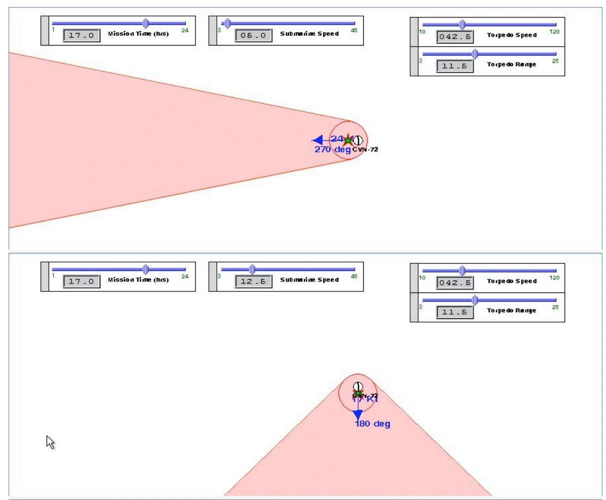


**Figure 2. Visualization Prototype: Lines of Limiting Approach**

In this interactive visualization, the user is given slider controls for setting the estimated silent speed of a hostile submarine, that submarine's torpedo speed and range, and the length of the mission that is to be performed. The user sets the speed and direction of the mission essential unit by dragging the end of its bearing line. In addition to seeing the effects of these factors on the limiting lines of approach, users can see how they affect the Torpedo Danger Zone (the area enclosed by a circle that marks the boundary at which a submarine could launch a successful torpedo attack against the surface force at the present time, and how they affect the Advance Position, the point on the surface unit's course where the unit would be hit by a torpedo fired from the edge of the TDZ.

**Assessing Air Defense Planning**

We had previously used Rivets and iRides Author to build a more complex application for automatically assessing a TAO's Air Defense planning skills (Bewley, Chung, Delacruz and Munro, 2006; Bewley, Leew, Munro, and Chung, 2007). Students would be presented with a static situation that required the development of a plan for the defense of the MEU from air attack. Students constructed a plan by dragging units into positions and assigning them roles to play in the defense of the MEU. They could add visualization elements such as the Vital Area and the Surveillance Area, and could set the size of these areas by dragging handles on their perimeters. A Threat Axis, bounding lines, and possible air attack vector objects could also be used to help develop a plan. When the student finished a planning problem, the simulation checked that ships were in areas that required the roles assigned to the ships.

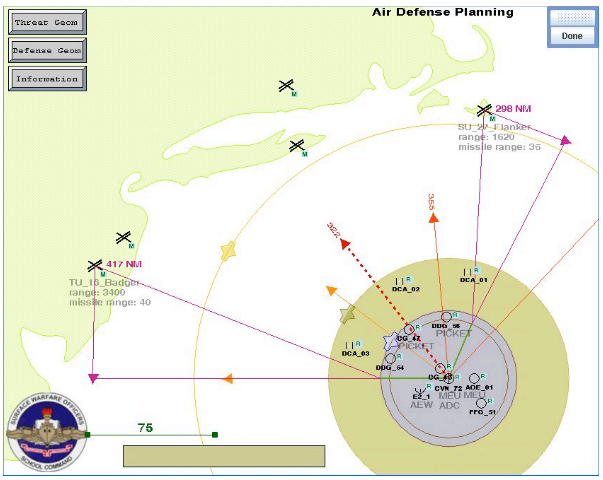


**Figure 3. Assessment Tool for Air Defense Planning**

Instructors have control over the scoring mechanism in the Air Defense Planning tool. They can position and shape sector areas and specify the roles for those areas.

A static positioning-and-duty-assignment approach was deemed insufficient for evaluating or training TAOs in surface ASW tactics, because such tactics involve a complex set of responses to the actions of opponents and to the vagaries of the acoustic environment, the mission, the capabilities of the target submarine, and so on. What was needed was a robust practice environment for ASW tactics, one in which scenarios could be played out, and whole sequences of adaptive decisions could be made and observed.

## THE ASW SANDBOX

Using iRides Author, we rapidly developed an initial approach to authoring scenarios and delivering tactical decision-making practice in the context of those scenarios. Feedback from the SWOS instructional staff guided the development of revised versions of this training and practice environment, the ASW Sandbox.

The Sandbox has two modes: Instructor Mode and Problem Mode. Instructor Mode is used for building scenarios and for conducting in-class demonstrations. Problem mode is used for solving ASW problems in the context of scenarios authored by the instructors.

**Solving Tactical Problems in the Sandbox**

In Problem Mode, users can select problems that have previously been authored by instructors. Each problem has a map on which all action takes place. Typically the scenario has a mission briefing that explains the situation, including the commander's intent and intelligence on potential hostile units. Users solve the problem by running the scenario, ordinarily at some high multiple of real time, utilizing resources to try to avoid or to detect and attack hostile units, if required.

When using the Sandbox for tactics practice, users can pause scenarios, and they can speed up and slow down virtual time. They can deploy assets such as helicopters, sonobuoys of several types, the active and passive sonars of surface ships, and datums. The helicopters can be directed to utilize dipping sonars or to drop torpedoes.

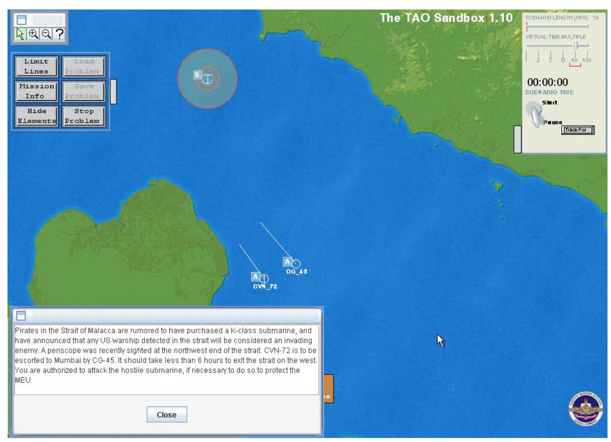


**Figure 4. Beginning a Tactics Problem**

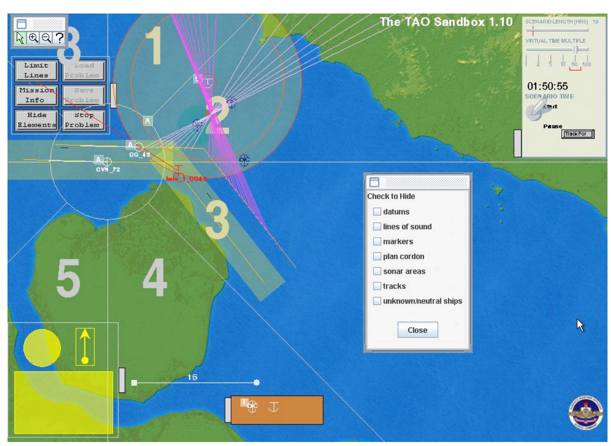

**Figure 5. On Completion of the Tactics Problem**

Several visualization tools are provided, including the Torpedo Danger Zone (TDZ), Advance Position, Limiting Lines of Approach, Air Defense Sectors, Cordon (shown in Figure 5, above), Major Threat Axis, Vital Area, CIEA, and general purpose markers, including arrows and transparent shapes, which can be labeled.

When in Problem Mode, the Sandbox records all actions and independent events in a lightweight text format. Later, the Sandbox can be used to replay these recordings, so that after-action-reviews can be conducted.

Users can choose to solve problems again to explore tactical alternatives. They can also replay automatic recordings of the actions that they took during a session. It is possible to interrupt a playback and continue the problem in a different way at any point. These features make it possible to use the Sandbox as a kind of "what-if" planning tool.

### Authoring Scenarios

Instructors create new tactics problems. This is done by selecting maps, entering a mission briefing, positioning units (including enemy forces), and specifying environmental conditions. The environmental conditions determine sonar, radar, and visual ranges. The authoring interface is only slightly more complex than the scenario-playing interface.

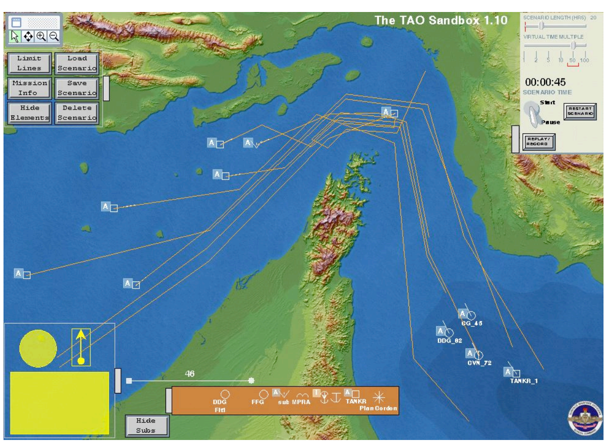


**Figure 6. Authoring a Scenario**

The instructional staff at SWOS has found it very practical to build the scenarios that they want to illustrate in class presentations or that they want their students to solve. Little time is required to set up a scenario and save it with a descriptive name. It then takes not much more time to test the scenario by playing through it.

## ASW SANDBOX UTILIZATION AT SWOS

The ASW instructors have used the Sandbox in a number of ways throughout the spiral development process. They have found five major ways to use this product to improve instruction and learning.

### Demonstrations

One of Merrill's (2005) principles is that knowledge about procedures needs to be demonstrated. In fact, there is evidence that practice alone is less effective than a combination of viewing correct demonstrations plus practicing. Sweller and Cooper (1985) found that errors in an assessment were reduced by half if 12 math practice problems were replaced by 6 worked-out examples, each followed by a related practice problem.

The ASW instructors apparently appreciate the importance of demonstrating solutions in the problem context. To illustrate a concept or a type of tactic, they create one or more scenarios that help to explicate the concept or that are suited to the use of the tactic. Then they demonstrate a solution to the problem in class. They have experimented with two ways of doing this. First, they have simply started the scenario and demonstrated the solution as the students watched, commenting on relevant features as the problem unfolds. The second approach is to perform the solution in advance with recording turned on. By playing back their recorded solution in class, they are able to attend more closely to the class, looking for questions or signs of confusion, rather than focusing on what must next be done with the mouse pointer. Instructors typically narrate the action. If a question arises, they can pause the playback in order to answer it. This second approach, using recorded demonstrations, has found favor with the instructors.

### Practice and Remediation

Clark and Mayer (2008) recently reviewed the cognitive processing evidence for the importance of problem-solving practice, concluding that

> *Generative cognitive processing* occurs when a learner engages in deep processing in working memory in service of the learning goal…. For example an effective practice exercise can foster generative processing. (p. 6)

For a given class session, the instructor may prepare three problems, each of which requires some common knowledge and/or tactics, but each of which also has unique features that illustrate situations or tactical requirements that are not present in the others. The classroom is divided into three groups of students, and each group works on a different problem, discussing the issues and testing possible solutions. Ordinarily, students have enough time to attempt two or three different approaches. During this problem-solving time, the instructor is available to help groups that encounter thorny issues, providing an expert help system. In general, however, students take these problems as a challenge and do their best to find their own solutions.

As the students practice solving these surface ASW problems, their actions are recorded. One to three students from each group then come to the head of the classroom and present their solution as the recording is played back. This gives the students who worked on different problems a chance to see this particular problem from another student's viewpoint. Finally, the instructor comments on the problem and the solution presented, pointing out issues that were not addressed and opportunities that were or were not exploited.

**Student Assessment**

Merrill's (2002) work and that of Clark, *et al* (in press) shows that assessment in conceptually realistic problem-based environments is more likely to predict post-training performance than do more conventional paper-and-pencil tests. Of course, schools such as SWOS have made a considerable investment in course materials, including test banks, and they cannot be expected to revolutionize every aspect of training overnight.

Previously developed assessment metrics (primarily short-essay questions) are utilized for assessing students. On occasion, however, a student who has demonstrated competence in ASW in the classroom suffers from test anxiety or some other problem that results in the production of marginal answers to a set of questions. To help in assessing such students, they are given a novel Sandbox problem and must describe the reasoning behind the actions that they take. This approach has been used to help students demonstrate their knowledge in an effective way.

**Self-study**

Some students have shown an interest in extending their ASW tactics knowledge by performing additional problems on their own. If a question arises during self-study, the student can go to an instructor later and play back their attempt to solve the problem to the point at which the question arose.

**What-if Exercises: Extending Knowledge**

Later in the course, students are given the opportunity to take the Instructor version of the Sandbox with them. They can use this to author new tactical scenarios, either by editing an existing scenario from a growing library, or by building a new scenario from scratch. Any jpg file can be added as a map, and the Sandbox provides a simple method for assigning a scale to such new maps.

**Problem-based Practice**

This paper has cited a number of research findings that argue in favor of a problem-centered approach to any instructional process that has the goal of teaching people to perform complex tasks. However, the ASW instructors at SWOS developed their approaches to utilizing the Sandbox without being made aware of these findings. Their experience with previous military training contexts had convinced them that a problem-centered course of instruction is the one most likely to be effective. The ASW Sandbox simply made it possible for them to provide more of this type of approach to their students.

## NEXT STEPS

There are both development and research paths that we plan to pursue using the Sandbox.

**Development of a TAO Sandbox**

SWOS instructors have expressed an interest in seeing an expanded version of the ASW Sandbox that can be used for practice in Surface Warfare and Air Defense. With such a tool in hand, it would be possible to extend the problem-based approach to more of the subject matter of the Department Head Course. Additional exposure to the use of the Sandbox might also increase the likelihood of an eventual transition to a simple tactics prototyping tool that can be quickly mastered and widely used by officers responsible for tactical advisement and decision-making.

**Future Research**

The detailed record of performance that is collected in order to replay problem sessions provides data that can be utilized to study complex adult problem solving and learning. We plan to enhance the data recording process by analyzing emergent conditions and events that are important for ASW tactics. These events will also be recorded for analysis.

We also plan to develop models of student knowledge that will update in real time, based on the events detected by the Sandbox as it is used to solve problems. Such models may play roles in assessment and adaptive instruction in future tactics training tools.

## ACKNOWLEDGEMENTS

Work on interactive visualizations, such as the Lines of Sound and Limiting Lines of Approach, was supported by Grant #N00014-06-1-0711 from the Office of Naval Research (ONR). Work on the ASW Sandbox was funded under ONR Grant #N00014-08-1-0126. We thank the staff and leadership of SWOS for their subject matter expertise, advice, encouragement, and constructive criticism, especially LCDR Andrew Ball, CDR Greg Chapman, LCDR (Ret.) Adrian Markey, LT Danielle Litchford, CDR Corey Melton, CAP Carol Hottenrott, CAP Scott Jones, George Ponsolle, and David Monroe. Carley Corporation provided the initial set of maps used in the ASW Sandbox. Our colleagues John Lee, Alan Koenig, Markus Iseli, Joanne Michiuye, and Donna Darling have contributed ideas and assistance.

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