

An Intelligent Tutoring System (ITS) for Battlespace Geometry Tutoring

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ABSTRACT

The use of Combined Arms, a very important set of tactics, techniques, and procedures to the Marine Corps, is complex and requires considerable practice and training of the entire Combined Arms (CA) team. Simulations exist and are being developed that provide a practice and training environment for the Combined Arms team. However, for effective training to occur, use of simulations requires intelligent evaluation and feedback. Furthermore, as practice develops the skills of the team and prepares it to handle more difficult scenarios, additional training scenarios should become more and more complex and realistic. A CA training opportunity was identified and addressed through the development of an Intelligent Tutoring System (ITS). The issue was that no simulation existed which provided intelligent feedback to the Fire Support Team (FiST) as to the correctness of their CA plan. This prevented them from receiving enough practice and training in important aspects of this planning process which impacted the quality of Combined Arms Exercise (CAX) training opportunities. Therefore an ITS which could evaluate and provide feedback on the FiST developed CA plan was developed. This paper first covers the training needs for CA and the FiST then discusses ITSs generally and how their capabilities meet the identified needs. The development methodology used for this project is described. The functional capabilities of the ITS are discussed followed by the underlying architecture that implemented those capabilities. The paper finishes with results, lessons learned, and future work.

ABOUT THE AUTHORS

Richard Stottler co-founded Stottler Henke Associates, Inc., an artificial intelligence consulting firm in San Mateo, California in 1988 and has been the president of the company since then. He has been principal investigator on a large number of tactical decision-making intelligent tutoring system projects conducted by Stottler Henke, including projects for the Navy, Army, and Air Force. Currently, in addition to the CAST UP ITS effort described here, he is working on an intelligent tutoring prototype for the future combat system control vehicle, funded by the US Army STRICOM. He has a master's degree in computer science from Stanford University.

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COMBINED ARMS TEAM AND FiST TRAINING NEEDS

The Marine Corps places strong emphasis on the use of Combined Arms in battle. Combined Arms is the art of combining the effects of mortars, artillery, naval gunfire, close air support, and close-in fire support to inflict the maximum amount of damage on the enemy in a minimum amount of time to support a maneuver element's assault on the enemy [MCAGCC 2000]. However, this is a complex effort that requires the involvement of hundreds of warfighters with dozens of different specialties. An important component of the combined arms team is the Fire Support Team (FiST). The FiST includes the FiST Leader, Forward Air Controller, Artillery Forward Observer, Mortar Forward Observer, and Naval Gun Fire Spotter. Assistants and radio operators complement each of these. The FiST's tasks, like that of many tactical decision-makers divide themselves into two categories - those that relate to planning and those that relate to mission execution. A critically important planning task of the FiST is developing the battle space geometry (BSG). The BSG is a representation of the effects and possible effects (such as minimum safe distances) of the different types of supporting fire. These must be integrated and deconflicted with each other and the maneuver units. Other considerations and principles also apply, such as the importance of using all available assets, redundancy, and other concepts typical of ground unit tactical planning. Once the FiST has developed a plan, approval for it is requested up the chain of command before execution may commence. Once execution begins, planning and deconfliction of fires is continual.

The complexity of Combined Arms (CA) and the large number of members of the extended CA team dictate that considerable practice and training is required. An important component of CA training is the CA Exercise (CAX). CAX instructors have identified a training deficit – FiSTs arriving at CAX are not familiar enough or had enough practice with BSG. This is because there is no existing means like a training simulator that could provides intelligent evaluation and feedback for BSG. The effort described in this paper directly addresses this identified deficit.

This is an especially important training gap to close, given the relationship between BSG and safety.

According to the experts and instructors, the most important parameter in developing effective BSG knowledge and skills is practice.

CAX training consists of both live exercises and simulation training. The Combined Arms Staff Trainer (CAST) has been in use for many years at several sites for the purpose of CA team training. A current development effort, the CAST Upgrade, seeks to implement improvements to CAST to further improve its simulated scenario team training capabilities. The CAST Upgrade is itself a precursor to the Combined Arms Command & Control Tactical Upgrade System (CACCTUS) project. The effort described here is part of the CAST Upgrade which is developing a simulation tool to provide an automatic debriefing of the BSG created by the FiST in a simulated tactical scenario. This tool would be invaluable for every captain going to the Expeditionary Warfare School to receive BSG training through the use of this tool. The goal of the CAST Upgrade is to integrate the ITS with existing tools and training simulation like that of OneSAF to provide practice of the BSG techniques and the ability for mission rehearsal planning. The tool must evaluate the FiST's BSG and make sure the trainees realize the possible ramifications of a mistake. It should gradually increase the complexity of scenarios as the particular FiST demonstrates that they are ready for this increased complexity. This requires that the software infer the state of the team's knowledge and its ability to practically apply that knowledge in an operational context. It should retest the FiST in appropriate scenarios to determine the effectiveness of the debriefing and to ensure the trainees have mastered the required knowledge and skills.

For maximum flexibility, many scenarios should be developed. The Marine Corps therefore needs to have the flexibility to create and customize their own scenarios in a user-friendly interface. By allowing Marine or instructor creation/modification of tactical scenarios, turn-around time will be greatly reduced and precious development dollars saved. Miscommunication and communication overhead

between instructor and developer is eliminated since the instructor becomes the developer of the scenarios.

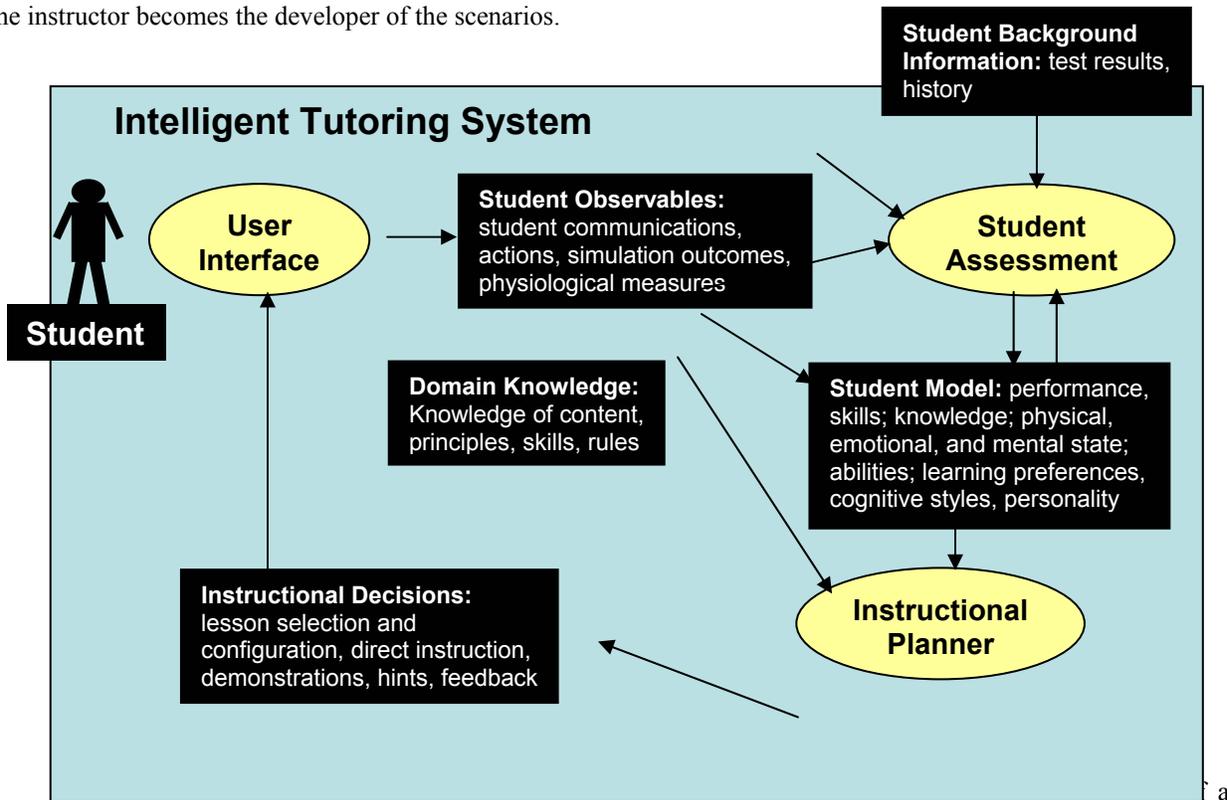


Figure 1. ITS typical ITS - a Student Assessment Module, a Student Model, and an Instructional Planner.

INTELLIGENT TUTORING SYSTEM (ITS) CAPABILITIES MEETING THOSE NEEDS

To increase BSG scenario practice, as recommended above, will require that the evaluation and feedback of BSG be performed by software. Automatic evaluation of decisions in simulated scenarios is an important component of the field of Intelligent Tutoring Systems (ITSs). The ITS should work in concert with a common PC planning tool and training simulation, to facilitate increased access. ITSs automatically monitor and assess trainee performance in simulated tactical scenarios and evaluate the trainee's mastery and progress. This information is used for debriefing after the performance is complete. In the case of BSG, this corresponds to after the CA plan, including the BSG, has been entered. Associated with the debriefing may also be of appropriate multimedia descriptive material. The debriefing is one form of remediation. Others are presentation of related examples (often in the training simulator itself) and further practice in carefully chosen scenarios. Typically the trainee would be re-assessed in simulated scenarios to determine the effectiveness of the remediation. This ability to adapt and customize itself to the trainee requires that the ITS have a well-developed model of the student.

The Student Assessment Module takes as input student observables from a simulation or other application, considers background information, then determines the correctness of the student's decisions and updates the Student Model. An important point is that the ITS can only base its assessment of the trainee on what it can actually observe electronically. This requires that all relevant trainee inputs be digital in nature and that the ITS has access to them which usually entails an interface to the training simulation (considered part of the user interface in this figure). The Battlespace Geometry Tutor (BSGT) concentrates primarily on the assessment module but includes aspects of the other components as well. The Student Model may include estimates of many short and long-term student attributes but should minimally include estimates of the mastery of relevant knowledge and skills. The Instructional Planner makes instructional decisions including the type and timing of feedback as well as what scenarios would be most appropriate for practice or illustration.

BSG ITS DESCRIPTION

Planning Phase Tutoring

As alluded to earlier, the FiST performs during two distinct mission phases - planning and execution. (Although planning and deconfliction continue throughout execution.) Consequently, FiST training consists of two corresponding phases as well. Our tutoring system concentrates on the first phase - initial fires planning, specifically the creation, integration, and deconfliction of BSG. The BSG ITS, called the BSG Tutor (BSGT), first presents a scenario briefing to the FiST, which describes the tactical situation and additional instructions. Normally the situation given to the FiST includes the unit commander's scheme of maneuver and often the timing and location of proposed aircraft delivered munitions. The trainees then view the tactical scenario in C2PC, the Marine Corps Command and Control software for transmitting or receiving the Common Tactical Picture (CTP) or Common Operational Picture (COP) in a Windows environment. Its main display is a 2-D tactical map. Most of the FiST's time with BSGT is actually spent within C2PC. Using a specialized C2PC add-on developed by MTS, the FiST creates a CA quickfire plan. (A quickfire plan is one developed rapidly, usually when contact is first made with an enemy unit). The plan consists of the timing and location of suppressive fires, marking rounds, aircraft delivered ordnance, rotary wing battle positions and routes, and fixed wing attack cones and routes. Associated with each of these are various three dimensional shapes that describe minimum safe distances, exclusion and safety zones, and the time periods when each of these are active. When the team believes it has completed its plan, it requests an evaluation. The BSGT first automatically checks that they have defined the correct shapes with the correct parameters associated with each munition delivery. For example, the FiST should have shown a 400 meter radius circle around a mortar target, corresponding to its minimum safe distance and a rectangle whose centerline is the gun target line (GTL) from the firing mortar unit to the targeted enemy unit and whose width is 800 meters. They should have also drawn routes between the various battle positions. If any of these are omitted or incorrect, the debriefing informs him.

The real heart of the automatic plan evaluation is checking whether the various aspects of the plan have any conflicts. This checking occurs immediately after the correct shape checking described above. Since there are four main categories of the plan (maneuver actions, indirect fires, fixed wing delivered munitions, and rotary wing delivered munitions) there are 6 main categories of possible conflicts corresponding to all of

the possible pairs of the four main plan element categories. These are conflicts between maneuver and indirect fire; between maneuver and fixed wing operations; maneuver and rotary wing operations; indirect fire and fixed wing operations; indirect fire and rotary wing operations; and between fixed wing operations and rotary wing operations. Checking for a conflict between any pair of plan elements entails first checking that they are both active during some overlapping period of time and that the shape associated with each overlaps in three dimensional space. A small number of checks, out of the dozens that BSGT performs, are mentioned below, as examples. BSGT checks if a maneuver element such as a support by fire position or axis of attack is within the minimum safe distance circle of fixed wing, rotary wing, mortar, and artillery munitions when both are active. It checks that the fixed wing attack cone is at least 1000 vertical feet from the trajectory of artillery where the GTL crosses the attack cone. A final example is that it checks that a rotary wing battle position is not inside the threat ring of an unsuppressed enemy air defense unit.

Most of feedback on discovered conflicts may be given immediately. This feedback is usually in the form of text describing the time, location and which aspects of the plan are in conflict. The system can also show the three dimensional shapes that are in conflict in a three dimensional terrain viewer, upon trainee request. In cases where the conflict relates primarily to timing, BSGT can call OTB (the OneSAF Test Bed), skip it ahead to the time of the conflict and show the conflict occurring at that time. For example, if the conflict is the result of a planned maneuver of dismounted infantry toward the objective at a certain time and the team has failed to halt the artillery suppressive fire on the same target early enough, then BSGT would call OTB with the scenario and skip the scenario ahead to the time where the dismounted infantry is entering the minimum safe distance circle for that artillery. It can then show the dismounted infantry unit destroyed by that friendly artillery. In the case of a continually repeated mistake, perhaps because the trainees are relying too heavily on the conflict checking mechanism, feedback on the conflict can be delayed until during the mission execution phase, where having the friendly infantry unit destroyed by friendly artillery is more grievous.

Since the conflict checker of BSGT included capabilities for checking conflicts between shapes, line segments, curves, and points, it was also useful for checking for unplanned conflicts during the real-time simulation. This was also deemed useful for the larger

CAST UP system. Therefore it was modularized and provided as a general network resource that constantly monitored the activities of various plan entities and broadcast any discovered conflicts. This information could be used by an instructor monitoring the exercise or a different, future ITS which evaluated real-time tactical decision-making.

The FiST's knowledge of other principles relating to developing the combined arms plan is also evaluated. Examples of these are making sure marking rounds are planned for fixed wing munitions, that the battlefield will be clean for rotary wing delivered laser guided munitions such as the Hellfire missile, and both mortars and artillery are employed whenever possible. This feedback is generally given immediately.

As an Intelligent Tutoring System, BSGT provides other instruction besides feedback on the correctness of the team's CA plan. One of the more important functions, outside of evaluation is determining when the FiST is ready for more complicated, more challenging scenarios. It makes this decision based on its estimate of the team's mastery of the techniques, procedures, and knowledge required for CA planning. This multi-dimensional collection of estimates is the student model. Each element of the plan and each possible kind of conflict has several principles associated with it. Whenever a component of the team's plan is correct, BSGT increases its estimate of the team's mastery of the associated principles and whenever a component is incorrect, it decreases its estimate. Initially the trainees perform the simplest scenarios. When the large majority of mastery estimates reach the intermediate level, more complex scenarios are selected for the team. Additionally within a single level of complexity, scenarios will be chosen that include components with associated principles that the FiST has not been tested on or has done poorly with (to practice its weakest areas). The team can examine these mastery estimates by looking at BSGT's student model for them. Because trainees using BSGT have already received instruction on BSG, BSGT assumes that they are at least ready to attempt the simplest scenarios available to it without additional instruction so BSGT does not include mechanisms for introducing the concepts to beginners.

Use of BSGT Capabilities During Real-Time Mission Execution

As mentioned above, during mission execution, conflict checking continues to be active. Found conflicts are provided to the instructor immediately. Options that the instructor has include 3-D BSG

conflict shape visualization or immediately destroying the friendly unit involved in the conflict or simply pointing out the problem to the FiST.

An additional capability from BSGT was considered potentially useful for the instructors. Since the C2PC symbology had to be interpreted to be evaluated during the planning stage anyway, it is possible that this capability could be provided during real-time execution to create a user-friendly way of controlling the enemy and friendly units in the scenario. So, for example, if a ground unit movement arrow is shown in the scenario plan for a specific time period, an automated controller could send orders to OTB to move the associated unit along the path described by the arrow at the appropriate time. Similarly if the arrow ends in a SBF position, when the unit reaches it, it could be instructed to occupy a SBF position at that location oriented toward the target. It could then be instructed to fire during the time periods described in the CA plan. For this level of FiST training, enemy units aren't required to behave very realistically. However the capability to define sophisticated behaviors for enemy units could also be incorporated.

Instructor Authoring

As described in the Needs Section, the Marine Corps instructors need to have the ability to author scenario themselves. Since the instructors are already familiar with C2PC, it was logical to use it as a basis for a scenario editor. Using the existing C2PC, instructors can create scenarios for both the planning and execution phases by placing friendly and enemy units and symbols such as arrows and SBF positions that show the commander's scheme of maneuver. Using a specialized C2PC add-on developed by MTS for the instructors, they can also create a briefing that is presented to the FiST at the beginning of the planning session. This briefing typically includes some aircraft delivered munitions and their timing. This add-on also allows the instructors to enter a correct CA plan with associated BSG using a lot of the same functionality provided to the trainees with some important differences. Unlike the trainee version, the instructor version automatically selects the right parameters based on the chosen munitions. Additionally, the instructor can check for conflicts at any time and will always get the complete set of conflicts found. Of course, no modeling of the instructor's expertise occurs during their editing process. Though not used as frequently, the instructors can also modify the evaluation process and instructional methods. The evaluations are represented as Behavior Transition

Networks (BTNs) which are generalizations of finite state machines. These are described more fully in [Stottler & Jensen 2002].

BSGT Architecture

The BSGT context is shown below. The ITS Authoring suite of tools, shown on the right, is used by the subject matter expert (SME) to create a series of files, shown as ovals that together with the domain independent ITS software (not shown) constitute the

BSGT. On the left is the suite of applications that the trainees interact with. As described previously these include using C2PC to initially view the scenario then using it with its add-ons to input a CA plan. This plan is received by the ITS which evaluates it and presents feedback to the trainees as shown. The feedback may include execution of the plan in the simulation, especially to illustrate timing problems. Included in the simulation module of the figure is a 3-D viewer and OTB (later OOS (OneSAF Objective System).

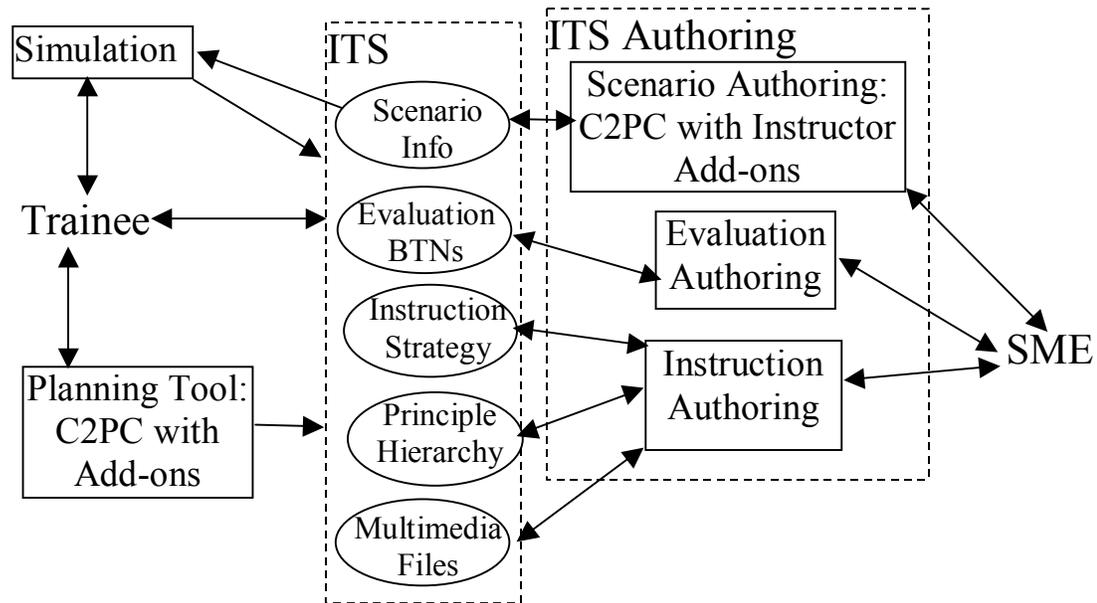


Figure 2. Battlespace Geometry Tutor System Context

The architecture of this Intelligent Tutoring System (ITS) is shown below in figure 3 where the ovals (the ITS files) have been recreated from the previous figure. An additional oval, the student model, is also shown. The ITS Runtime Engine consults the instruction strategy knowledge and the student model and decides on the next instructional event. Usually that is a planning scenario exercise.

Other instructional techniques of the ITS include selecting scenarios to test untested principles or exercise known trainee weaknesses. Scenarios may also be selected and shown to the team as examples for illustrative purposes. The instruction strategy knowledge also specifies when to show principle descriptions. Its decisions are based on the FiST's level of mastery, number of past failures, and

instruction already received. It will generally present easier, less complex, less workload intensive scenarios initially and increase these dimensions as the team shows mastery.

Actions performed during mission planning are both evaluated by comparing them to stored annotated plans and via BTNs. The results of these evaluations go directly to the ITS Runtime Engine and are processed and forwarded to the student modeling component. The student modeling component examines a team's entire history with regard to a specific skill or knowledge item and estimates the FiST's mastery of it. It does this for all skills and knowledge items tested in a scenario. The ITS Runtime Engine forwards the actions and principles that need to be remediated to the User Interface (UI).

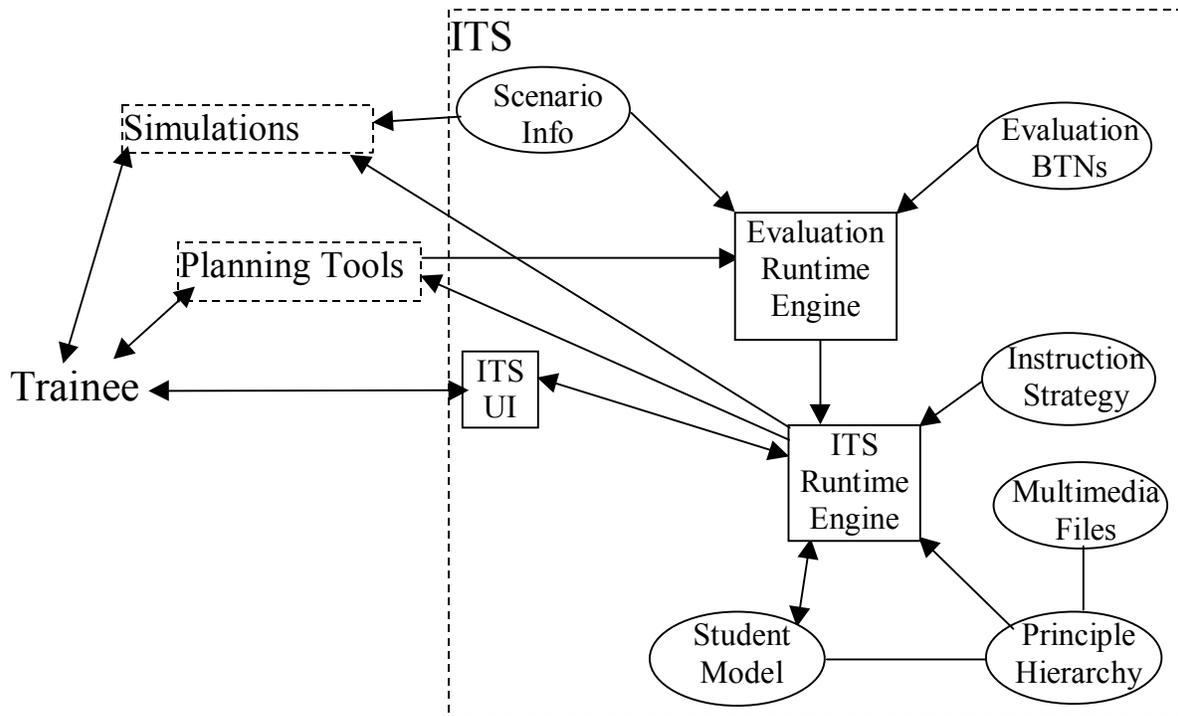


Figure 3. BSGT Architecture

TASK ANALYSES, DESIGN, DEVELOPMENT, AND EVALUATION METHODOLOGY

To develop a beneficial ITS requires following the proper development process, and ITSs, like most training systems do actually follow the standard ISD's steps of Analyze, Design, Develop, Implement, and Evaluate, although the steps sometimes differ in emphasis and are therefore often renamed slightly. The effort to develop the ITS for BSG also followed a fairly standard ISD development methodology. The first step is normally called Knowledge Engineering or Cognitive Task Analysis (CTA). The difference is that there are usually two parallel tracks, one for the domain to be trained (in this case the planning process of creating, integrating and deconflicting the proper BSG) and one for instructional methods, which are tasks performed by the instructor that they have found beneficial in training these types of trainees for these types of tasks. For example, one technique used by instructors teaching BSG is to kill units manually that have violated safety related BSG, even though they would have very probably survived to illustrate the importance of a BSG safety issue. The reason for

this second track of CTA is that the ITS will be designed to support many of these successful instructional techniques and mimic methods of evaluation and feedback. For the BSG domain, CTA first entailed examining the relevant documents. [MCAGCC 2000] turned out to be a very important source of domain knowledge. We then went through hypothetical and training scenarios with experts, noting their decisions and actions, and questioned them in detail regarding each decision. We also observed instructors in action and discussed with them various instructional techniques, actions, and decisions. In particular the instructors were able to describe the required scenarios and how they should increase in complexity. We also questioned the instructors as to the most important aspects to be taught and common trainee errors. In general we also always stay alert for techniques for automatically evaluating the correctness of trainee actions.

After the twin CTA described above, we developed the design. Typically the design is not simply based on the requirements for the best instructional ITS possible, because there are always additional

constraints. A seemingly large constraint was that the ITS would have to be integrated into the CAST Upgrade's evolving architecture and use its existing simulation. However (and unusually), we did not need to make the usual instructional compromises related to utilizing an existing system. This was partly because many of the CAST UP design decisions were delayed until the ITS project was started. But it was probably more related to the fact that the CAST UP architecture had already been designed with close collaboration with instructors to make sure that they could perform their duties well and with all the instructional capabilities they needed. Specifically the data for evaluation was available to them (and to external software). That meant that the data that the ITS would need to evaluate the BSG was already available to it. Additionally, there were a few capabilities required by the ITS that proved to be beneficial to the CAST UP system as a whole so that they were designed as separate modules to be used either by the ITS or by other CAST UP components.

After the design for each module was complete that module was implemented. The implementation for this project was different than most past ITS efforts, but it is becoming more typical. Specifically, the design made use of many existing components which made two subtasks more prominent than usual. These were to assemble the existing components and modify them as required. The existing components directly utilized by the ITS effort included C2PC, OTB, a DIS listener and emitter, SimBionic, and the ITS Authoring Tool. Modifications included add-ons to C2PC to add additional editors for trainees and instructors, changes to OTB affecting how it processed some specific message packets, and the DIS listener/emitter was altered to capture and emit the messages required by the ITS. Components were also developed and interfaced to the existing modules. For example, the software to check for interference of simple shapes was written and integrated into the ITS evaluation module. Additionally, the required domain knowledge had to be entered to customize the generic components to the BSG domain. This included defining the way the evaluation would proceed in SimBionic, defining the principles of the domain (tactics, techniques, and procedures) in the ITS authoring tool and attaching relevant descriptions to these principles, and defining attributes of the scenarios (such as what principles each tested and how complex each was). Of course part of the development process included testing the software both as individual components and in an integrated manner.

Over the Summer and Fall of 2003 the BSGT was evaluated in stages. The first stage was an internal evaluation to confirm that the implemented system met the client's and the CAST UP development group's expectations. The second stage was an external evaluation through demonstration to the instructors. Their comments fed back into the design and development process. In the third stage, the instructors could actually sit down with the software and play the roles of trainees and instructor. We anticipate the fourth stage of evaluation will be a pilot study with a small group of trainees which we expect to occur early in 2004. Metrics that can be used to determine if BSGT is meeting the training needs described earlier include the amount of BSG scenario practice trainees perform before they arrive for a CAX, the amount and level of BSG remediation required from human instructors during the CAX, and the level of training that can be accomplished during the CAX.

RESULTS, LESSONS LEARNED, FUTURE WORK

The overall result is that the development of an Intelligent Tutoring System that can provide an intelligent debrief for a Combined Arms plan is feasible and beneficial. An important lesson for others developing ITSs is that the standard ISD process, with some different emphases does apply, especially if the analysis is cognitive and involves both the tasks to be trained and instructional decisions.

There were several lessons relating to ITS design. It's important to get the ITS developer involved in the project before the decisions relating to them have to be made, if at all possible. Perhaps the most important lesson learned was that an architecture for a training system designed to maximally accommodate the instructors will also accommodate an ITS with little or no instructional compromises. An additional lesson is that software engineers have a tendency to want to include in the design of editors used by trainees helpful features, especially if they are easy to implement. However, these editors must be designed to allow the trainees to make the mistakes that they need to be trained to avoid. Otherwise, the trainees will not have the chance to prove that they would avoid those mistakes on their own, without the helpful features. This is especially important if these helpful features will not exist in

actual operations (where, for example, pencil and paper may be the main tools).

Relating to implementation, it is helpful to have the developers of the training simulation available to make slight modifications to accommodate the ITS's requirements. A current DARPA sponsored effort, DARWARS, among other things, is seeking to develop simulation-ITS interoperability standards which should alleviate this need. During development some of the ITS required software capabilities may be more generally useful and should be modularized and offered for use by the other components.

There are many facets to the planned future work. Most immediately, the BSGT will be further developed, evaluated with trainees, and fielded. Specifically more effort will be placed on increasing the breadth of the evaluation of the FiST developed CA plan and tutoring the individual and team performance of the FiST. The execution phase of CA FiST training will be addressed beyond the existing simple conflict checking capability. CAST UP serves a number of other team members, many of whom are also slated for the development of an ITS. Current plans call for efforts targeting members of the aviation community involved in Combined Arms such as AH-1W, F/A-18, and AV-8B crew, intelligence specialties, etc.

Additionally beyond these ITS for individuals, long-term plans include the development of ITS targeting the team as a whole as well as teaching principles of teamwork within that team. Over time, additional capabilities will be developed. To teach teamwork an ITS will need to understand the verbal

communication that occurs between team members. At least in some circumstances, these communications are highly structured and rooted deeply in the tactical context. Developing capabilities for these kind of communications, while challenging, is still tractable.

Another capability that we have begun to develop for other tactical tutoring applications and that may eventually be added to the CAST UP ITSs is the use of the Socratic method in After Action Reviews (AARs). The Socratic AAR component uses the same information that the simple AAR component presents to the trainees but instead of merely telling the trainees what decisions were right and wrong and why, it asks the trainees a series of questions, with the goal of getting the trainees to determine for themselves what the correct decision was and why. Similarly to hinting, the goal is to use the most general questions first and only proceed to more specific ones if the trainees are having difficulty determining the cause of the mistake.

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