A Framework for Defining and Experimenting with Adaptation in Technology-Based Training

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ABSTRACT

Training is increasingly becoming technology-based, swapping classroom time and live instructors for distance learning, serious games, and simulation exercises. This presents both challenges and opportunities for tailoring training to accommodate differences in trainees' backgrounds, prior knowledge, and abilities. Our interest is in building comprehensive technology-based instructional environments that adapt to differences and changes in cognitive factors—experience, knowledge, skills, and attitudes.

We describe a space of techniques for adapting instruction in terms of (1) the aspects of a student model that inform individualized instructional decision-making, and (2) the aspects of the instructional experience that can be adapted based on those factors. Student model elements include: (1a) information on experience extracted from background questionnaires, (1b) records of student exposure to instruction and exercises, (1c) assessments of student performance during exercises, and (1d) overall student mastery estimates for system learning objectives. Instructional adaptations include: (2a) choices of didactic instruction, (2b) choices of exercise scenarios, (2c) choices affecting selection and delivery of exercise performance hints and feedback, and (2d) choices controlling pedagogically significant behaviors of simulated agents within scenarios.

We give examples from a problem-based learning environment intended to train U.S. Army Battle Captains on how to supervise current operations in battalion Tactical Operations Centers (TOCs). A prototype implementation provides a unified environment combining instructional presentations, a scenario-driven TOC simulation, and machinery for controlling simulation behavior, student assessment, and instructional interventions. We describe the student modeling and instructional control components, emphasizing the breadth of instructional adaptation supported. We highlight how a control rule language, in the context of the overall system, will enable experimentation with alternate adaptation strategies. Such an environment is an essential tool for establishing an empirical basis for guiding future deployment of adaptive instructional systems.

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WHY SHOULD TRAINING BE ADAPTIVE? A MOTIVATING EXAMPLE

Empirical results support common sense when it comes to instruction: students do better when given individualized attention (Bloom, 1984). Mass instruction—in classrooms and lecture halls—is primarily an economic compromise. Though there are benefits to interaction and collaboration at the level of seminars and small work groups, nobody really thinks that every student needs to hear exactly the same information in the same sequence and format. We know that some students are wasting time by going too slowly, and others need still more time and attention to come up to criterion. Ideally, computer-based training environments should adapt to the needs of each individual student, just as a good instructor might, were the instructor able to devote their full attention to that one student.

The need for adaptive instruction is increased in training applications where the variation in student background and/or ability is large, or where the costs of wasting student time are high. We have been focusing on one such Army application that has the additional property of being only weakly supported by existing Army training. The problem we have been addressing is development of computer-based adaptive training for battalion battle captains (BCs).

In the Army, a battalion-level battle captain is responsible for overseeing the information flow and tracking battles and other operations in the Tactical Operations Center (TOC) (de Oliveria, 1995; Wampler, et al., 1998). Other personnel are primarily responsible for monitoring and logging the various information channels, such as the radio nets, e-mail, chat, and battlespace mapping and unit tracking software, but the battle captain is responsible for noticing whenever events have moved beyond the routine execution of plans and will now require actions and decisions. The battle captain ranks below the S3 (operations officer), the XO (executive officer), and the battalion commander in the chain of command, but the senior officers are frequently away from the TOC, leaving the battle captain in charge of implementing the planned operations and making decisions to support those operations when needed.

The BC position is not defined by doctrine, yet a BC can be found in nearly every battalion or brigade tactical operations center (TOC). Staff jobs in general, and the BC job in particular, are often considered undesirable, relative to commands and billets that take a soldier into the field. Officers and enlisted men with a broad range of backgrounds may find themselves slotted into the BC post at short notice. At the battalion level, a BC might be a captain, lieutenant, or even an NCO; brigade BCs are often majors. The BC job also varies widely with the leadership style of the commander, XO, or S3. In our analysis of the domain, we focused on five terminal learning objectives for battle captains, summarized in Table 1.

Table 1. Battle Captain Learning Objectives

Learning Objective	Description
Help the Commander Manage the Force	Understand the mission and battalion capabilities; issue warnings and orders
Maintain Situation Awareness	Keep track of actors, states, and events along with their implications
Manage Information	Assemble, assess, filter, pull, and push information; use appropriate C3 system
Support Decision Making and Action	Recognize decision points; who needs to decide and by when?
Help Manage the Fight	Anticipate, prioritize, reallocate, and orchestrate resources and actions

Our challenge then is to develop an adaptive battle captain training system that (1) teaches relatively high level situation assessment and decision-making skills, (2) can cope with variation in student background, and (3) can be extended to also address variation in the specifics of target behaviors.

APPROACHES TO ADAPTATION

Most training systems offer students some mixture of didactic instructional presentations, practice problems or exercises, and assessment instruments. In many cases, the practice problems do double duty, serving as interim assessments. Adaptation, in such systems involves taking the individual student's needs into account, in order to adjust the choice, mix, sequencing, and/or composition of instruction, practice, and assessment elements. The system's model of the individual student and their needs is built up from ongoing assessment, possibly primed by some initial demographic data.

Simple Adaptation for Simple Skills

In training applications that emphasize concrete and atomic learning objectives it is often possible to challenge a student with a great number of short, focused problems or quiz items, each of which addresses one (or perhaps a small number of) learning objectives with little ambiguity. Such a system can adapt to individual students simply by choosing fewer or more problems for each objective as a student demonstrates greater or lesser competence on objectives, by giving correct or incorrect answers to challenge problems.

Similarly, the system may have a repertoire of didactic instruction (e.g. texts, illustrations, or multimedia presentations) intended to convey key knowledge that should help students succeed on practice and assessment problems. The presentations are typically used to prepare students for problems, remediate gaps in their knowledge identified by problem failures, or reinforce key points by repetition and/or variation in presentation. The system will have occasion to offer a student fewer or more of these instructional presentations depending on how long it takes them to succeed on enough problems to be considered competent at the covered objectives.

This kind of approach is likely to work best for training isolated sub-skills—often components of larger desired behaviors. As an example, in order to effectively track a battle, a battle captain must be able to interpret map symbology and unit icons. There is a lot to learn here (i.e. much of FM 101-5-1 *Operational Terms and Graphics*), but as an isolated skill, it is relatively easy to tell whether a student can identify or use any particular graphic; a system can easily adapt by choosing targeted instruction and problems or quiz questions.

Complex Skills Training

Map interpretation in support of battle tracking is, however, just one small part of a battle captain's job. The real core of the job is maintaining situation awareness—for what is going on both in the field and in the TOC—ensuring information is flowing to all the right places, recognizing what must be done to keep things on track, and knowing how to respond when they go off the rails. Furthermore, a battle captain cannot just be reactive; he must anticipate what might go right or wrong, and how he can help the unit exploit success or adjust to challenges.

We are interested in training these kinds of higher level cognitive skills. The training challenge is that such skills can only really be exercised in complex contexts: the entire state of the battalion (setting, mission, commander's guidance, current activities, etc.), the availability of resources at various levels (platoons already on patrol, prior commitments of quick response or surveillance resources, availability of brigade or even division assets, etc.), and the larger situation (recent history, current intelligence, host nation and insurgent activities, etc.) can all affect the battle captain's assessments, decisions, and actions. The battle captain does not work alone, but in concert with a host of other actors; coordination is carried out through a wide range of communications channels.

When the dominant aspect of the skill is recognizing and analyzing complex contexts that demand different decisions and actions, it is hard to frame small isolated problems that support valid practice and assessment. For such skills, problems and quiz questions are best replaced with scenarios and simulation-based exercises. Instead of focusing on a single clear learning objective, such exercises tend to address an *interrelated set of objectives*. This reflects (1) a desire to leverage the time spent establishing the context to accomplish as much training as possible, (2) the reality that large-scale contextualized skills typically flow in natural (often somewhat variable) sequences, and (3) the constraint that complex decisions often depend on interaction among multiple goals and activities. For example, if one of a battalion's patrols gets stuck out in the field, there are a number of issues that might be worth considering: Will they be able to get themselves unstuck, or will they need recovery assets to assist them? Will they (or newly tasked recovery assets) be subject to actual or potential threats that require additional surveillance and security assets? How does their immobilization (and the assignment of other assets to assist them) affect the prior battalion plan and allocation of forces throughout the sector?

With respect to the learning objectives summarized in Table 1, this one simple situation can provide a context for exercising skills under each of the major headings:

1. **Help the Commander Manage the Force:** The BC must understand the capabilities of the various units and resources at the battalion's disposal. The BC must issue timely "warning" orders, and appropriate "fragmentary" orders to those resources. *[Is it likely that the stranded unit can self-recover its immobilized vehicle? What kind of recovery asset would be appropriate to recover the kind of vehicle that is immobilized? What are the organic surveillance and security capabilities of the stranded patrol and of a candidate recovery unit? How long should we expect another unit to take in reaching the stranded unit?]*

2. **Maintain Situation Awareness:** The BC must track battalion forces in sector—their locations, missions, and status. The BC's model must include an understanding of who knows what about current events. *[Where is the stranded unit and what were they responsible for doing? What other units are in sector that might be able to assist them? What other units are available to cover for any gaps in combat power?]*

3. **Information Management:** The BC must be able to use all the various communications system effectively, and must pull and push information as needed to ensure that he maintains a good picture of what is happening, and that other key decision-makers and actors remain informed. *[Is there additional information needed to fully understand the situation (the kind of vehicle, the security situation)? Are there others who need to know about the situation (the maintenance company, the quick reaction force, senior leaders)? What are the best mechanisms for pulling or pushing needed information?]*

4. **Decision Making and Action:** The BC must understand when particular kinds of decision must be made. He must know which decisions he is empowered to make, and when he must get others in the loop. *[Is there a significant decision to be made here? If so, who can make it, and when does it have to be decided?]*

5. **Help Manage the Fight:** The BC must notice and/or anticipate changes in situation and deviations from plan, including threats and opportunities. The BC must help manage resources to address such situations, noticing when new or different resources are needed, reallocating resources under battalion control and requesting additional resources as needed. The BC must sequence and prioritize TOC activities, which can include launching and running pre-defined battle drills that orchestrate response to common occurrences. *[Given this situation (not yet especially serious) is there a standard response to set in motion? What else might happen that could make it more serious? What kind of resources might be needed in those cases? What can or should be done to prepare?]*

This quite simple example shows that if we want to train BCs on cognitive skills that constitute the heart of their job, then we naturally end up with exercises that address many learning objectives at once. Once we set up a complex situation with many issues at stake, it is natural—both realistic and efficient—to draw the situation out—to provide time for information gathering and decision-making, which is also time during which the situation may change in ways that raise still more potential training issues.

For instance, if we give the student time to decide what (if anything) to do about an immobilized patrol, then (as often happens in the real world) that patrol may become a target of insurgent attack. Or conversely, if we were trying to set up an exercise about a patrol coming under insurgent attack, it might be useful to have a stream of prior events and message traffic that affect the way that attack should be thought about (e.g. how would the situation differ if we knew the attacked patrol was immobilized, and perhaps that we had already dispatched supporting resources to aid them?).

Adaptation for Complex Skills Training

We have focused on the issue of training for complex cognitive skills—contextually sensitive interpretation and decision making skills. We have suggested that such training benefits from complex exercises—extended simulation-based decision making and rationale exploration interactions that address multiple learning objectives in the context of multiple performance goals. The question then is what can or should adaptation look like in such applications?

The dominant issue is affecting adaptation here is that the grain size of exercises is quite large. Building a training system's practice component around extended simulations versus stand-alone problems raises a set of sub-issues: (1) it takes longer for a student to engage in each exercise, so it is even more essential to adapt exercise content to individual student needs; (2) it takes longer to create or author such large exercises so developing a substantial repertoire of exercises to choose among may become expensive; (3) each exercise may naturally addresses a wide swath of learning objectives so matching exercise to student learning needs may be more difficult.

The natural response to all of these problems is to address the root cause, and to see if we can disaggregate large-scale simulation exercises into smaller components that can be composed to better suit individual student needs. We have identified two main approaches:

1. **Storyline Composition:** Prepare a number of parameterized partial scenarios, each of which represents a coherent extended thread of activity, and which are designed to be woven together in various ways to create a complete scenario. This approach ought to enable variation of learning objectives covered (a composed scenario would typically address the union of the learning objectives covered by the individual storylines). It could also enable variation in difficulty (by manipulating the number and complexity of storylines integrated, and the time-phasing of the demands they place on the student).

2. **Scenario plus Injects:** Design a scenario with a relatively stable backbone of events and issues, and then identify points where additional learning opportunities can be injected by introducing some variant behavior and tracing out its consequences. The same basic concept can be used to identify "rejects"—pieces of a scenario that can optionally be left out to remove challenges what seems appropriate to a particular student. The concept can also be extended to the case where injected behaviors have the effect of simplifying or removing challenges (e.g. if a character takes responsibility for a task the student would otherwise have to do).

In addition to adapting the practice component of training (here extended simulation exercises), it is also worth reviewing options for adapting the instructional component. The simple objective-centric approach to instruction is likely to provide a workable starting point. To the extent that the learning objectives are somewhat independent, the system can at any moment identify some set of objectives that are relevant (e.g. needed to succeed at an upcoming challenge, or requiring remediation based on performance in a recent exercise). A range of instructional presentations are prepared for all the system's learning objectives and they are deployed as needed.

In the kind of training application we are concerned with here, there is room for improvement on this basic approach.

1. **Integrating Multiple Presentations:** Since there are likely to be multiple objectives in play at any given time, there may be several (or many) objective-specific instructional presentations nominated or queued up for the student. Sequencing, bridging, interleaving and/or condensing those presentations to form a coherent, effective, and efficient overall presentation would be a major challenge. For the most part, we do not intend to address this issue since we do not propose to generate novel media on the fly. The exception is that we can optionally control sequencing based on an understanding of dependencies among learning objectives (e.g. prerequisites, subordinates, etc.). However, in practice the sequencing is often left to the student who can choose among a number of relevant presentations identified by the system.

2. **Interaction Presentations:** More interesting than sequencing, smoothing, or merging sets of presentations is the case where the best instruction addresses some *interaction* among objectives. For instance, the BC must understand capabilities, responsibilities, and

availabilities of key assets, and juggle their allocation across actual and potential tasks; a learning objective about anticipating resource needs may interact with an objective about appreciating the capabilities of some resource (e.g. some air assets can provide surveillance support, while others—with more limited availability—can provide both surveillance and security). Introducing instruction that explicitly deals with interactions among objectives expands the space of possible presentations. We continue to assume that system instruction is primarily pre-packaged media presentations. In this case, assuming that a given interaction has been recognized as significant enough to warrant preparation of focused instruction, the remaining issue is to allow indexing of instruction on multiple objectives and to prefer presentations that address multiple objectives currently active for a student.

3. **Dynamic Instruction:** In some cases we may wish to relax the assumption that instruction is delivered as pre-packaged media. For instance, instruction that describes common causal patterns in the domain, or appropriate action sequences, may benefit from discussion of examples. If the student has just played through a scenario that illustrates the causal chain, or that called for a given actions sequence, then it makes sense to discuss the general point in the context of that recent example. This kind of instruction blurs the line with scenario content, and in fact is probably best authored as part of a given scenario, making use of the same behavior encoding techniques (rules and scripts) that are used to generate other character and embedded tutor behaviors.

PROBLEM BASED LEARNING (PBL) AND MULTI-FORMAT SIMULATION

The general training approach outlined in this paper is a form of problem-based learning (PBL, e.g., Savery & Duffy, 1995) adapted for computer-supported individual—versus team or group—instruction. We combine computer simulation with automated assessment and embedded coaching. The simulation allows students to "sense" and "act" in a world that gives them relevant cues and responses. The assessment builds up the individualized student model that ultimately enables adaptation. The coaching helps students learn in context, scaffolds them to succeed at challenges that might otherwise be beyond their current abilities, and helps keep them within the envelope of useful training and effective simulation.

PBL is a constructivist approach to training that contrasts with more common direct instruction approaches. While direct instruction involves "telling" trainees what to do, constructivist approaches emphasize the trainee's role in developing (or "constructing") his/her own knowledge through discovery, inquiry, or exploration (Duffy & Jonassen, 1992). Constructivist approaches such as PBL have become more widespread in the military in recent years, for example through initiatives such as the Adaptive Leaders Methodology (ALM, e.g, Vandergriff, 2006) and the Combat Application Training Course (CATC).

In order to deal with the open-textured reality of a complex interpretation and decision making domain, we advocate relying on a layered mixture of rules and scripting to capture non-player character behaviors, as well as automated tutor assessments and responses. Rules can be efficient ways to encode reusable behaviors, when they apply. However, in the real world, every rule has its exceptions. Sometimes those exceptions can be codified as additional rules that apply in more narrow circumstances. Sometimes all we can do is say that in a particular circumstance—for instance a specific training scenario—that a particular specific behavior is called for. Thus we may have general rules, more specific rules, and scripted responses, depending on the behavior and the situation.

AN EXAMPLE SYSTEM

To illustrate many of the points above, we describe the intelligent tutoring system (ITS) we have been developing for battle captain (BC) adaptive training. Figure 1 shows the main simulation screen of the BC ITS as it appeared during a recent experiment with Soldiers.

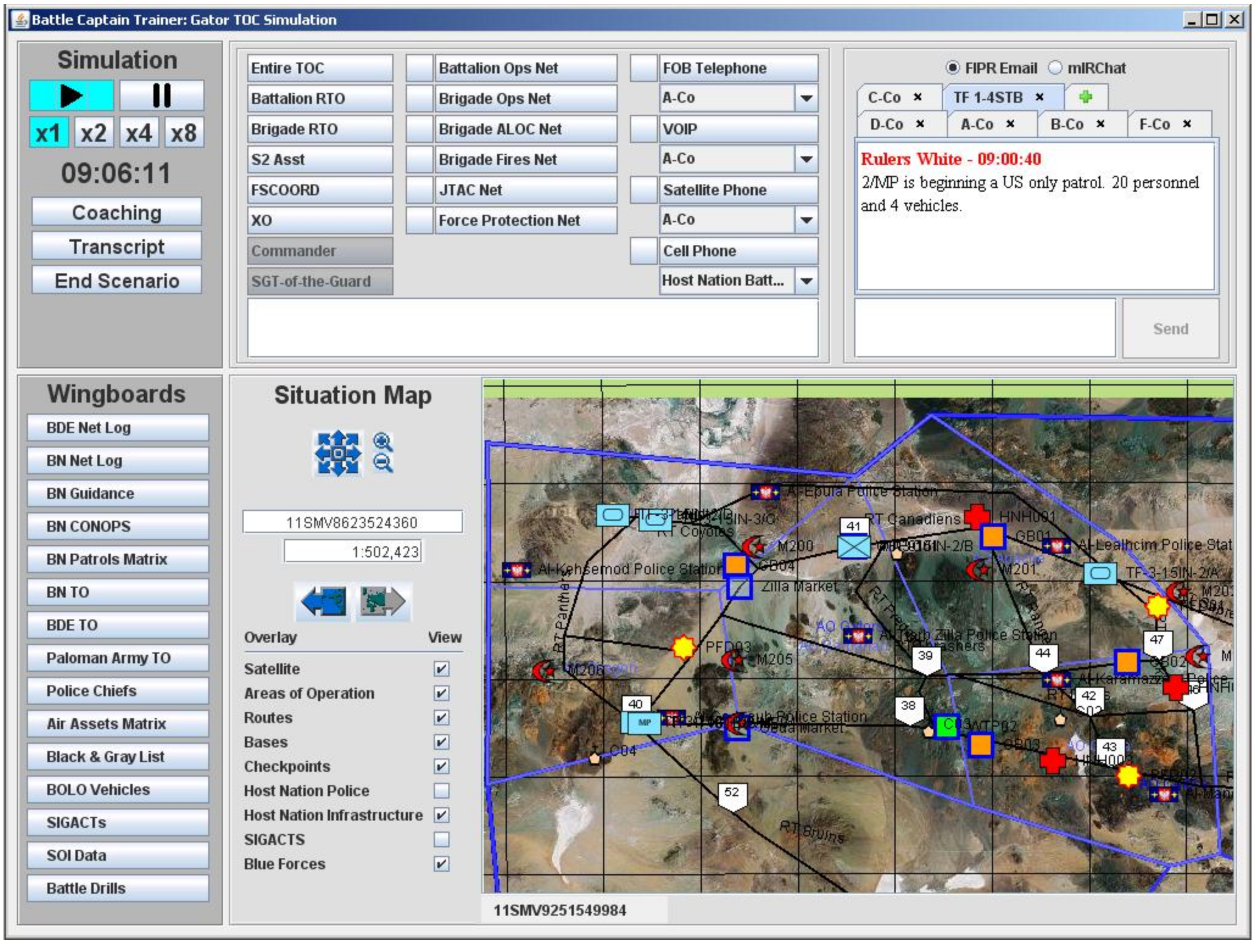

Figure 1. Sample Screen from Battle Captain Training System.

The left margin contains simulation controls (e.g. time manipulation, and access to the embedded tutor), as well as buttons that open "Wingboards" containing reference materials of the kind that would be available in a typical TOC. In the main area, the top section offers controls simulating a variety of communications channels, including (1) face-to-face, (2) radio, (3) telephone, and (4) digital text; the bottom section offers a situation map that offers some of the features of FBCB2, including blue-force tracking. The screen layout reflects the fact that we are emphasizing battle tracking, and that situation assessment and distributed team coordination are major parts of the BC job.

The centrality of communication with simulated agents motivates one of the major research thrusts of this work: development of spoken and written natural language dialog support. The three columns for face-to-face, radio, and telephone communications provide "push-to-talk" buttons tied to a speech input processor; character responses are fed to a speech synthesis system. The digital text pane is likewise tied to a text input processor. Natural language processing is a hard problem, especially in relatively open-ended domains, such as this one, and so the system's language interpretation capabilities are experimental. A menu system provides an alternative input format.

The student is introduced to the simulation mechanics ("buttonology") and the simulated world ("setting") through a series of narrated "micro-scenarios" that ask them to try out various system controls and study the range of wingboards. A planned extension will also introduce them to their simulated unit's SOPs and battle drills to provide further practice and orientation. A complex simulation exercise starts with a narrated briefing on the situation and planned operations. Following the briefing, time may skip forward to a point where significant events start to happen, as reflected in communications and/or map updates.

The student is not left to cope with the complexity of the simulated world on their own. An automated Coach is available to provide hints and prompts to guide action, as well as positive and negative feedback to highlight successes and failures (especially when the natural consequences of student actions would be too long delayed, or too attenuated to serve as effective feedback). Figure 2 shows the coaching window, with a sequence of successively more directive suggestions for the student.

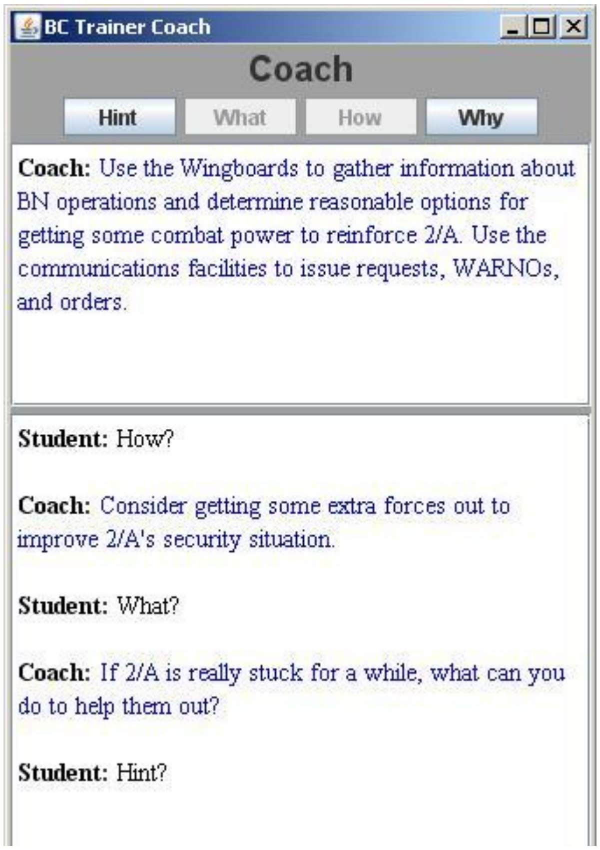

Figure 2. Automated Coaching Window.

The introduction of automated coaching suggests yet another way in which a training system can adapt to individual student needs. If we think of the coach as a non-player character, then the choice to deliver or suppress coaching seems similar to the "Scenario plus Injects" framing of adaptation; however coach actions are simpler since they do not have to make sense with respect to a character's role, and they do not modify the further evolution of the scenario. Alternately, we can frame coaching as "Dynamic Instruction;" but, again the coaching we have so far developed consists of relatively isolated comments rather than extended dialogs exploring causality and rationale.

Student Modeling

The pedagogical decisions made by the BC ITS—including choosing exercise scenarios, selecting instructional presentations, and controlling coaching behavior—are all based on the system's evolving understanding of the particular current student. This understanding takes the form of a *student model*. This model is composed of three kinds of raw data, which in turn is processed to provide more directly useful assessments of student state.

The raw data collected on each student includes: (1) **background** data (e.g. demographic information on the student's prior experience); (2) **exposure** data (e.g. records of which exercises and instruction the student has seen); and (3) **performance** data (e.g. how the system has evaluated the student in the course of exercises and assessments). Background data is gathered using the system's question/answer facility to host a survey questionnaire, asking questions about the student's years in the Army, current rank, specialty, history of deployments, etc. Exposure data is automatically tracked based on system actions such as displaying instructional presentations. Performance data on exercises is logged in association with coach assessments and hints. When conditions are met that could lead to the coach giving positive or negative feedback, the student's performance is assessed as appropriate or inappropriate. When the student gets hints from the coach, a smaller number of performance points are deducted.

The raw data is processed to provide estimates on how the student stands with respect to system learning objectives. Background data can be used to establish initial estimates of mastery for particular objectives. Assessment data can be used to update those estimates based on student performance within the system. The derived metrics in the system include (a) score, (b) mastery, (c) improvement, and (d) progress. A student's score on a particular objective is the system's current estimate on how competent they are expressed as a value between 0 and 1. Each objective has a threshold score above which a student is considered to have mastered the objective.

To maintain pedagogical focus, the system uses a strategy that emphasizes a small set of active objectives at any given time. Objectives move out of the active set when they are mastered (though the system may continue to gather evidence about student competence on the objective, which can lead to downward score revision and reversal of an earlier mastery decision).

Improvement is a measure of how much a student's score has increased (e.g. based on performance in the most recent exercise) on some set of objectives (i.e. all objectives, the active objectives, or some particular objective). Progress is a measure of how many objectives have recently become mastered (e.g. during performance on the most recent exercise).

In addition to the above student-specific metrics associated with learning objectives, we assume that the objectives are also statically ranked and linked in various ways, such as (1) prerequisite relationships, (2) subordinate relationships, (3) other ordering preferences, and (4) a priori difficulty expectations.

Sample Adaptations

The point of defining the above derived student model metrics and learning objective dependencies is to enable statement of a wide range of adaptive pedagogical control strategies. Consider three classes of decisions to be made by the system: (1) which instructional presentations to offer, (2) which exercise scenarios to offer, and (3) which coaching interventions to offer. All of these (and their more specific variants) can be tied to particular learning objectives. Our framework allows for decisions to be based on issues such as:

- Is the learning objective in question part of the current active set of focal learning objectives for this student?
- How long has it been in the active set? How many opportunities has the student had to demonstrate mastery? How much instruction have they had on this point?
- How far from mastery is the student on this learning objective? How far from mastery on related (supporting) learning objectives?
- Has the student been showing improvement on that learning objective in recent exercises? On related learning objectives?
- Has the student been showing progress overall (or on related objectives) during recent exercises?

There are a number of additional system decisions induced by this framework: (1) How many learning objectives should be in the active set at any given time (should this be fixed or adaptive)? (2) When should an objective leave the set (e.g. upon mastery)? (3) Which new objective should be added to the set (e.g. one whose prerequisites are either all mastered, or already in the active set)?

Our sample system has only just begun to exercise this machinery. It implements simple adaptive strategies for two classes of decision. (1) The system chooses initial instructional presentations based on student answers to an intake questionnaire reflecting expectations about what students with particular kinds of experience would be expected to know. (2) The system enables or suppresses certain coaching interventions for individual learning objectives based on the student's mastery estimates for those objectives.

A FRAMEWORK FOR EXPERIMENTAL EVALUATION OF ADAPTATION STRATEGIES

One of the technical goals of our work is to establish a framework in which a wide range of adaptive training strategies can be implemented. A corresponding training research goal is to establish tools that support experimentation with adaptation strategies, enabling us to validate their utility, and characterize the conditions under which they are most applicable. Likewise, we want tools to help us collect the kinds of data on which curricular design and adaptation decisions must ultimately be based.

In addition to putting the above-described technical framework in place, we have made some initial progress on data collection in the context of our work on BC training. In June 2010 we took a version of the BC ITS to Ft. Knox and used its integrated survey capabilities to gather two kinds of data from a group of nineteen junior officers and senior non-commissioned officers intended to represent the range of potential BC trainees. We gathered background information on these subjects, including indicators of seniority, rank, branch affiliation, past deployments, roles, and relevant experiences. We also had them take a quiz on knowledge deemed relevant to the BC role (e.g., Leibrecht, et al., 2009; Wampler, Centric, Salter, 1998). Our intent is to seek correlations between student background and existing levels of mastery for relevant material. This is a necessary starting point for any adaptive training system.

We envision follow-on experiments to investigate the efficacy of particular adaptation strategies expressible within the envelope of student/objective conditions and system pedagogical decisions outlined earlier. A useful technical step towards that end will be to expose the underlying conditions and decision as *tests* and *actions* in a scripting rule language. This will allow experiments to explore a wide range of strategies without requiring extensive programmer involvement.

In support of such experimentation we have already begun development of an observer/controller (O/C) tool that connects to a running simulation over a network. The tool includes a display for visualizing simulation activity as a set of aligned timelines that can partition and abstract complex multi-agent interactions. It also supports injection of some events at the O/C's discretion. In the future, it should support definition and selection of pedagogical strategy rules.

RELATED WORK

Other researchers have developed systems that overlap in various ways with the approach described in this paper. Scenario-based training was developed at Northwestern University's Institute for the Learning Sciences (ILS) in the 1990's (Schank, et al, 1993). The focus of that research was on identifying a family of distinct scenario formats that would enable development of reusable tools embedding the core logic for alternate "scenario architectures." The underlying simulations often had severely restricted envelopes of validity, in part because the systems emphasized getting students to fail early and often as a way of motivating learning; there was less emphasis on confronting them with evolving consequences and more on motivating them to seek immediate lessons. The issue of being able to provide a large number of individually adapted simulation scenarios rarely arose.

More recently and famously within the military community, work on tactical language training (Johnson, 2007) shares many features with the current effort (and earlier ILS work). We are also interested in a military application of scenario-based automated training that makes heavy use of natural language input and output. These systems are responsive to varied student behaviors within a scenario. However they pay little attention to adaptation of scenario learning objectives and hence content within and across scenarios. Natural language input and output for simulation-based training has also been used with a focus on interactive after-action review (Peters et al. 2004).

Finally, we note that the tradition of "tactical decision games" (TDGs, e.g. Schmitt, 1994; Shadrick, Lussier, & Fultz, 2007) offers a related, but somewhat distinct alternative to the kind of simulation we have been advocating. TDGs confront a student with a relatively complex scenario and demand some kind of decision. Since they are often paper-based, they do not provide an evolving simulation, and may, in fact, leave many of the situation details to the student's imagination. Much of the learning comes from discussion (collocated, synchronous, and verbal, or distributed, asynchronous, and written) where the rationale and possible outcomes of alternate student solutions are pursued, ideally with expert commentary.

CONCLUSION

Providing automated adaptive training is highly desirable, yet remains challenging for cognitive skills such as situation assessment and decision making. We describe the difficulties that arise in such applications, focusing on the consequences of the need to simultaneously address interrelated constellations of learning objectives in rich contexts through scenarios and simulation. We characterize several approaches to adapting instruction in such applications, and describe a particular application, including tools for gathering data required to support appropriate adaptation.

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