ADAPTIVE GAME-BASED TUTORING: MECHANISMS FOR REAL-TIME FEEDBACK AND ADAPTATION

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ABSTRACT

The advantages associated with game-based training platforms in the military domain are apparent. They enable Soldiers to practice the application of knowledge and skills in a safe simulated environment across multiple domains. However, simulation- and game-based training is limited in their ability to stand as instructional tools in the absence of live monitoring and instruction. Through the integration of computer-based tutoring technologies, game-based training has the potential to facilitate practice of executing tasks while having mechanisms to guide performance and facilitate instruction through embedded pedagogical functions. This poses many challenges that must be addressed. In this paper, the authors highlight desired functions and interactions between game-based platforms and computer-based tutoring architectures for support of real-time guidance and adaptation. Games provide unique environments for applying adaptations to specific scenario elements and for providing feedback on performance in real-time.

Keywords: adaptive tutoring, game-based training, real-time, feedback

1. INTRODUCTION

The role of simulation- and game-based training in the military domain is on the rise. They have proven to be an effective tool for enabling Soldiers to practice job relevant skills that are often too dangerous and too expensive to replicate in real world settings. This, in part, is due to continual advancements in computing technologies that enable the development of engaging and immersive interactive simulations that imitate tasks and conditions Soldiers face in theater. The target is to develop training systems that aid in the development of higher-order thinking skills that enable Soldiers to adapt decision-making tactics under variable missions and conditions (Wisher, Macpherson, Abramson, Thorton, and Dees, 2001). In today's combat environment, tasks are executed under a multitude of complex, stressful, and ambiguous settings where decisions must be quick and actions must be executed in a timely manner (Salas, Priest, Wilson, and Burke, 2006). To account for this, training aims at instilling the tenets linked to task execution and the values associated with decision making so as to facilitate an individual in making reasonable choices under difficult circumstances (Bratt 2009).

Videogame and scenario-based trainers are now being utilized to facilitate this need. Videogames are a practical solution because they provide engaging elements associated with their interaction and can be delivered across platforms commonly used in household and school environments. Furthermore, many games are traditionally developed with multiple players in mind. The use of multiple simultaneous players allows for the creation of team-based learning environments (Sottilare, Holden, Brawner, and Goldberg, 2011). However, traditional game design revolves around entertainment value rather than educational purpose. The core concept is that longer play times, or more frequent play, will result in higher profits. Subsequently, games are developed to keep people immersed and entertained, while consuming just enough content such that they do not abandon interaction. In the context of training, these experiential interactions provide realistic settings and conditions skills are executed within, but lack essential components of guidance and feedback inherent to learning. In this paper, the authors will highlight recent advancements in game-based training practices and identify components needed for the integration of adaptive functions. The pursuit is to develop reactive systems based on performance and state for the purpose of supporting individual differences associated with learning and retention.

1.1. Enhancing Game-Based Training

Relevant psychological theory would indicate that learning commonly occurs through experience, which can be replicated through real-life application or simulation (Kirschner, Sweller, and Clark, 2006; Kolb, Boyatzis, and Mainemelis, 2001). This edification represents experience in an environment where errors in performance can be linked to interactions taken, which stimulates deeper understanding of the effect decisions have on outcomes (i.e., cause and effect) (Mengel, 2012). An effective simulation-based training event replicates functional aspects of the real-world that influence action and drive training. However, simply applying and practicing skills in a simulated environment does not on its own promote expertise (Ericsson and Ward, 2007). Functions must be in place to tie game actions with training intent, thus linking performance with objective.

In recognition of this gap, serious games are designed to integrate pedagogical principles and strategies within videogame technologies to facilitate learning and skill development. The development of serious games, or games for the purpose of learning, is not a new idea (Apt, 1970), but is becoming increasingly more common practice (Raymer and Design, 2011). This genre uses an explicit approach where gameplay serves a purpose outside of entertainment by embedding educational functions into game events. Yet, while serious games are beginning to be used in a widespread context, and have decisions informed from sound instructional design methods, their effectiveness is limited to their developed intent and function.

In an attempt to enhance simulation-based training that can be facilitated outside of training environments, the pursuit of this research is to synthesize components of video games and intelligent tutors to deliver tailored training within game-based virtual environments. Specifically, the focus of this effort is to highlight the role adaptation and real-time feedback can play in making serious games a viable tool for both learning and practicing the application of knowledge and skills on the individual level. In the remainder of this paper we will discuss the mechanisms required for integrating personalized and adaptive capabilities in game-based training systems and the apparent restrictions for accomplishing this. Considerations serious game designers must take into account for supporting adaptive function will also be addressed.

2. APPLICATION OF ADAPTIVE TUTORING IN GAME-BASED TRAINING

In this section, we highlight on a conceptual level the functional requirements necessary for the authoring and integration of adaptive mechanisms in any game-based trainer. The notion is for the creation of a domain- and platform-agnostic framework to support the integration of personalized instructional strategies aimed at enhancing learning and motivation.

For an adaptive tutor to operate on a functional level within a game based environment, there are a number of faculties that must be in place for real-time support. This includes knowing what is being trained (domain model), knowing who is being trained (learner model), and knowing strategies for how to train most effectively based on the aforementioned information (pedagogical model). This knowledge is applied for customizing instructional strategies and tactics based on individual differences found to affect training outcomes. Artificial Intelligence (AI) tools and methods are applied to model these relationships and gauge a learner's current state of knowledge as they progress through a session (Kassim, Kazi, and Ranganath, 2004).

The traditional computer-based tutoring system (CBTS) loop consists of several phases (see Figure 1). The learner can be monitored on two dimensions: (1) affective/cognitive states via a suite of sensors and (2) assessment of learner actions within the instructional environment. These states, if present, are combined with an assessment of student actions as they relate to training objectives. Together, this picture generates the idea of whether an instructional intervention is required. If feedback is deemed appropriate, the system executes an authored strategy based on both the characteristics associated with the error in performance and the skills/abilities of the interacting user. Based on subsequent inputs, the system will adapt accordingly based on prescribed pedagogical principles.

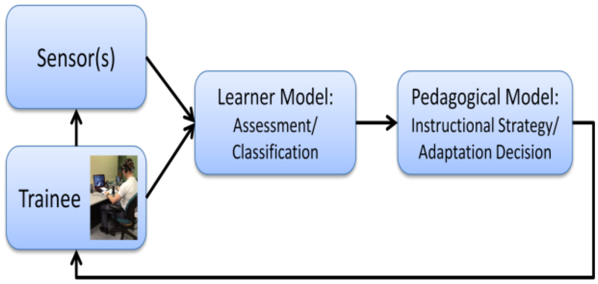

Figure 1: CBTS Loop

The strategies utilized in computer-based tutoring are based on personalized instructional and pedagogical heuristics applied within one-on-one expert tutoring. The benefit of this relationship is a tutor has the ability to guide and adapt instruction based on the strengths and weaknesses associated with a learner. In the context of simulation-based training this requires monitoring user interactions and using AI methods to assess performance and trigger adaptive interventions based on errors and diagnosed states as a result of training stimuli (Goldberg, Holden, Brawner, and Sottilare, 2011). In a Warfighter context, an effective computer-based tutor must have comprehensive knowledge of the operational context a scenario is designed around, have the capability to adapt to trainee fatigue and cognitive load, and to allow Soldiers to 'train as they fight' (Justice 2011). CBTSs must account for these requirements through robust modeling techniques.

2.1. Modeling for a Game-Based Environment

Enabling game-based training environments with adaptive resources is dependent upon the development of models that dictate interaction. This in turn requires assessment and prediction capabilities for both performance and state determinations as they relate to specific users and game engines. Performance metrics monitor progress towards objectives and errors present in execution, while state assessment gauges trainee reaction to training through the tracking of cognitive and affective variables linked to performance outcomes. In the context of game-based training, there are significant challenges associated with both of these functions. Multiple channels of data, derived from the game as well as the individual user, must be monitored and tracked to obtain the comprehensive knowledge needed for understanding learners' interactions within a game-based environment. One key requirement associated with this is the ability to assess both learner performance and state determinations in real-time.

Performance metrics are perhaps the easiest to monitor and include tracking progression towards targeted objectives, errors during execution, results on survey/test assessments during or after training, etc. Within traditional computer-based tutoring systems, performance metrics are used as the primary representation of a learners' current state of knowledge towards a particular domain (Woolf, 2009). This information is contained within a learner model and is used as a basis for adapting instruction as an individual's performance is compared to that of an expert (Kassim, et al., 2004). However, assessing performance requires explicit measures of how actions are related to objectives, which is often fuzzy in game-based environments. For example, what available data from a game designed in Virtual Battle Space 2 (VBS2) to train land navigation signifies a deficiency in calculating an azimuth from a protractor? The only available information is network traffic displaying entity state data, which in turn must be interpreted in relation to defined objectives that must be assessed. Determining a specific cause of performance deficiencies from game actions is an avenue of research that must be addressed.

To meet this need within a platform-agnostic framework, domain independent standards must be developed to author training objective metrics as they relate to system message traffic. However, when expanding adaptive tutoring to game-based training, monitoring the interactions between the game and the learner is more challenging than traditional static environments common to CBTS implementation. System concepts (i.e., inputs, processes, and outputs) vary between game platforms, and there is no unilateral or standardized way of interpreting learner interactions (Shute, Masduki, and Domnez, 2012). Yet, mapping and adapting system concepts to performance and state assessments across multiple games and platforms is achievable. A connection layer is required that translates game state information into user progress through the integration of assessments as they relate to event triggers present in the game world (Sottilare and Gilbert, 2011). This translation layer produces network traffic interpretable to a tutoring framework in terms of real-time game messaging associated with training objective performance. Having a standardized approach to this capacity would assist system developers in authoring message-based assessment models. This granular method makes identifying the root cause of an error achievable, which is essential for providing effective feedback or remediation in time of need.

In addition to real-time performance assessment, monitoring learner states (cognitive/affective) as they fluctuate during training interaction can provide valuable insight during game-based training. This information includes self-report instruments (surveys, interviews, etc.) and sensor technologies that monitor physiological and behavioral markers found to correlate with learning states (boredom, workload, confusion, frustration, etc.) (Carroll, Kokini, Champney, Fuchs, Sottialre, and Goldberg, 2011). Tracking states found to impact learning outcomes can be used to adapt content on the fly with the intention of keeping the user stimulated and motivated to continue interaction. The aim is to instill persistence in achieving objectives in an engaged manner that is conducive to effective knowledge transfer. In this context, research must be conducted to achieve the following functions:

1. Filtering and processing techniques of sensor data using standard computational and classification methods.
2. Functionality to combine sensor and self-report data, learner profile information, and events in the game world.
3. Development of windowed views (i.e., overall, previous, short-term, and long-term predictions) of learner cognition and affect.
4. Functionality to apply windowed learner state data to help interpret performance and apply context to state measures.

Consequently, game-based training platforms must also have mechanisms for acting on state and performance assessment results. This includes the ability to deliver feedback and adapt scenario elements as an individual progresses through task interactions. This is dependent on a platform-agnostic framework to allow the authoring of intervention strategies based on information pertaining to the objectives being monitored and characteristics unique to the individual user of the system. Feedback is provided to correct erroneous actions, promote reflection on concepts and actions taken, and mitigate misconceptions associated with training content (Mory, 2004). In-game adaptations should provide the ability to adjust difficulty levels based on individual performance, adjust the pace and flow of guidance and feedback, and deliver cues in the virtual environment that may act as a form of scenario specific feedback. In essence, these are the visible results produced by monitoring computer-based tutoring technologies. These mechanisms identified make up the desired functions of serious games for delivering tailored experiences, but current platforms lack many of the functions needed to support this approach.

A communication mechanism between the game world and the domain model is required to connect prescribed pedagogical interventions to associated game-specific actions. This mechanism should support both macro-adaptive and micro-adaptive functions, depending on the learner's knowledge, skills, and abilities within a particular domain. Macro-adaptive strategies can be applied to generate custom scenarios intended to balance flow (i.e., pace and challenge) based on learner attributes (Zook, Lee-Urban, Reidl, Holden, Sottilare, and Brawner, 2012). Macro-adaptation adjusts both game and tutor variables prior to interaction in an effort to personalize instruction. This can include varying the level of difficulty associated with a practice scenario and the how much guidance is provided when errors are present. Micro-adaptive strategies are based on real-time system interactions as they relate to defined objectives. Through an integrated CBTS, agents within the game world have knowledge about the learner and can react to requests from the tutor framework. An area receiving attention for this is Markov Decision Processes as they relate to tracking performance states within a training simulation. The notion is to research and develop techniques that can accurately gauge current, as well as predict performance states for the purpose of informing system adaptations. The CBTS can then apply modular, partially programmed agent behaviors that can be triggered by decisions within the pedagogical module. The desired functions highlighted in this section come with a wide array of challenges and questions that must be addressed among the CBTS research community.

3. LIMITATIONS AND FUTURE DIRECTION

The creation of personalized and adaptable serious games for training is of interest to the military and remains to be a challenging task. There are two primary reasons for this: increased developmental cost and associated research requirements. Game development traditionally has a special nature about it, as games and simulations are developed for specific clients under compressed schedules. Game developers frequently do not think to abide by the CBTS/Simulation Interoperability Standard (Stottler, Richards, and Spaulding, 2005), and focus upon the timely delivery of the product. To this effect, frequently each game has a different messaging structure associated with it. Even when a serious game obeys a standardized messaging structure, such as the Distributed Interaction System (DIS) protocol (IEEE, 1998), it is likely to have its own Application Programming Interface (API) for content injection. Depending upon the business structure of the creating company, these components can be closed, unavailable, or difficult to work with.

However, the developmental costs for embedding intelligent tutor capabilities in computer-based trainers are on the decline due to the availability of generalized architectural components that provide standardized practices for authoring tutor functions (Chipman, Olney, and Graesser 2005; Goldberg et al. 2011). This approach supports the development of such systems in significantly less time and with significantly less effort. The generalized approach also supports the authoring and integration of adaptive tutoring functions in already developed games utilized as practice tools following traditional classroom instruction. In a Department of Defense context, there is likely to already be an existing serious game, simulation, or practice environment for the skills taught in a classroom environment. These can be leveraged into existing domain-independent CBTS infrastructures to provide the traditional one sigma of learning gain (Verdu, Regueras, Verdu, Castro, and Perez, 2008) associated with computer-based tutoring, at a relatively low developmental cost. For these reasons, it is attractive to leverage the advantages gained from serious games and game-based environments into the instructional domain of computer-based tutoring.

As mentioned earlier, serious games typically have an Application Programming Interface (API), through which domain content and instructional strategy decision inputs can be captured. This enables interaction between tutoring agents and game-based applications (see Figure 2). Through this communication flow, a CBTS can inform actions to be executed in the game world. The challenge associated with this is applying context to game interaction. For a tutoring agent to effectively act on the game events, the agent must be able to observe the game world and determine the effect behaviors have on game objectives. It is expected that the use of these two technologies will increase, provided that the underlying research on instructional strategies continues.

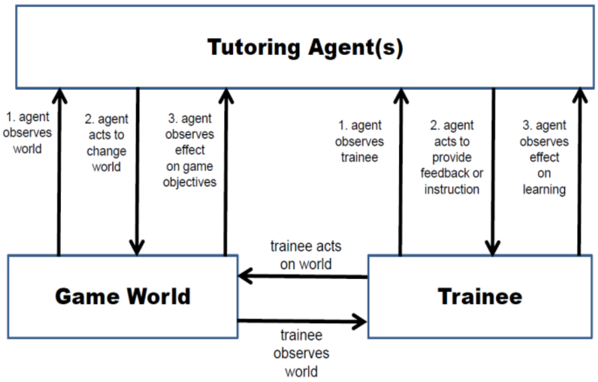

Figure 2: Interaction in Game-Based Tutoring (from Sottilare, 2012)

In addition to developmental limitations, there is also a lack of research on how to effectively adapt instruction and provide feedback within a game environment. This requires two research themes. Identifying techniques for linking scenario specific actions in game environments to defined training objectives and concepts, and identifying adaptation and intervention techniques that do not hamper the benefits associated with game-based training. In order to adapt effectively, empirical research must be conducted to examine feedback and adaptation approaches specifically for virtual game-based environments. Open questions in this area include the comparison of within-game feedback, out-of-game feedback, and within-game character feedback. In addition to reductions in CBTS-game development cost, intelligent tutor architectures also support the design of comparative and ablated studies on adaptation methodologies to test the effectiveness of various instructional strategies.

Overall, the primary hurdle associated with this endeavor is linking game actions and states to specific training objectives the game is designed to instill. From this stance, two efforts currently dominate the minds of the authors in order to address the multi-interface, multi-environment, multi-tutor problem. The first is the development of game interlingua, a common translated language for CBTSs and games. This standardizes communication protocols between game engines and tutoring architectures, eleminating the need for solutions dependent to game messaging structures. The second effort is the development of a simulation connection layer which can translate messages coming out of multiple game enviroments. This is intended to help alleviate the previously mentioned problem. Both of these solutions may require slight modifications to existing game interface layers, but this requires only one instance for the tutoring system in question. This type of solution, coupled with the development of a domain-independent authoring tool for relaying real-time performance assessments (ECS, 2012), may help to transition game and CBTS research to the schoolhouse.

4. CONCLUSION

The authors would urge Serious Game developers to consider the impacts adaptive tutor functions can have upon their products. They have the ability to leverage components and research at a very low cost, provided that they are willing to encode training focused guidance and adaptation in a meaningful way. This aids the designer in two ways: the knowledge requirement for instantiating instructional strategies is significantly decreased, and the ability to claim educational impact significantly increases.

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Robert A. Sottilare, Ph.D. is the Associate Director for Science & Technology within the U.S. Army Research Laboratory - Human Research and Engineering Directorate (ARL-HRED) and directs research within the Learning in Intelligent Tutoring Environments (LITE) Laboratory at ARL's SFC Paul Ray Smith Simulation & Training Technology Center (STTC). He has 28 years of experience as both a U.S. Army and Navy training and simulation researcher, engineer and program manager. He leads the international program at STTC and chairs training technology panels within The Technical Cooperation Program (TTCP) and NATO. Dr. Sottilare holds a patent for a high-resolution, head-mounted projection display and his recent publications have appeared in the Educational Technology Journal, the Journal for Defense Modeling and Simulation and the proceedings of the Intelligent Tutoring Systems Conference 2010. He is a graduate of the Advanced Program Managers Course at the Defense Systems Management College, and his doctorate in modeling & simulation with a focus in intelligent systems is from the University of Central Florida. In January 2012, Dr. Sottilare was honored as the inaugural recipient of the U.S. Army Research Development & Engineering Command's (RDECOM's) Modeling & Simulation Lifetime Achievement Award. The focus of his current research is on the application of artificial intelligence tools and methods to adaptive training environments.