Applying Adaptive Instruction to Enhance Learning in Non-adaptive Virtual Training Environments

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Abstract. This paper discusses the use of adaptive instruction to guide learning by stimulating non-adaptive virtual training environments. Adaptive instruction is sometimes referred to as differentiated instruction and is any learning experience tailored to meet the needs and preferences of an individual learner or team. An intelligent tutoring system (ITS) is the technology which delivers adaptive instruction. Adaptive instructional systems (AISs) use human variability and other learner/team attributes along with instructional conditions to develop/select appropriate strategies (domain-independent policies) and tactics (actions). The goal of adaptive instruction is to optimize learning, performance, retention, and the transfer of skills between the training environment and the work or operational environment where the skills learned during training are to be applied.

Keywords: Adaptive instruction · Intelligent tutoring systems (ITSs)
Virtual training environments (VTEs)

1 Introduction

Many training environments today use augmented, mixed or virtual reality technologies to provide each learner or team of learners with the visual and aural cues (and less often olfactory and tactile cues) to facilitate a realistic experience with the goal of enhancing their cognitive, psychomotor, or social skills. These cues are required to stimulate learner decisions and actions during the execution of a task (e.g. identify friend or foe) under a specified set of conditions (e.g., varying distance, lighting conditions, and weather phenomena) to a minimum set of standards (e.g., high accuracy (>95% correct)).

Adaptive instructional systems (AISs) are "computer-based systems that guide learning experiences by tailoring instruction and recommendations based on the goals, needs, and preferences of each learner in the context of domain learning objectives" [1]. AISs are intelligent and situationally aware of both the learner's attributes and the context of the instruction (e.g., conditions at some instance of the instructional path). However, most training environments today are non-adaptive or minimally adaptive where they tailor content based only on the learner's performance and tailor it the same way for every learner. Still other training environments use human-in-the-loop approaches to make decisions and take actions to change the path or outcomes of

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scenario-based training. Many of these systems are very good for training tasks and over time effectively guide learning and develop skills, but there is room for improvement. We propose an approach to reduce the human workload during simulation while simultaneously enhancing the tailoring and thereby the efficiency for both individual learners and teams.

The limitation of current training environments and their associated technologies is primarily tied to their inability to adapt to the needs and preferences of each individual learner. In other words, the learning environment reacts the same way for every user or at best usually only varies with changes in learner performance. AISs model the learner or team to provide tailored experiences based on their domain competence (prior knowledge), their goals, their preferences (e.g., personality factors) and their cognitive, affective, and physical states.

Today, military and civilian organizations have extensive inventories of non-adaptive or minimally adaptive training systems. If there was a methodology to stimulate these systems and their decision processes, their strategies and tactics would be tailored to each individual/team and this would enable the acceleration of learning by reducing previously mastered (redundant) content and by motivating and engaging learners to progress toward their personal goals. The Generalized Intelligent Framework for Tutoring (GIFT) is an augmentation technology which can be applied to many training simulations to guide training in an adaptive fashion.

GIFT is an open-source architecture for authoring, delivering, guiding, and evaluating tailored, computer-based instruction for individuals and teams of learners [2]. As of this writing, GIFT is used by over 1500 adaptive instructional researchers and developers in 76 countries. This paper reviews the modeling, actions, interactions, and specifications needed to drive adaptive instruction in currently non-adaptive systems. The ability of GIFT as an adaptive instructional architecture to interoperate with non-adaptive systems has the potential to significantly reduce the time and cost of instruction across many military and civilian training domains. We start by discussing the return-on-investment (ROI) for augmentation with adaptive instruction.

2 Return-On-Investment (ROI) for Adaptive Instruction

In this section, we attempt to build a case for the ROI for augmenting training systems with adaptive instruction. The typical cost of developing AISs today is significantly higher than non-adaptive systems based on the need to provide additional content for the many new paths created by tailoring instruction to each individual's (or teams) goals, needs, and preferences. Additional cost is due to the time to generate additional content and the expert skill level required for the various phases of the AIS authoring process (e.g., instruction system design, content curation, and content sequencing). The number of hours required to generate one hour of adaptive instruction is 200–300 h of authoring time compared to 40–60 h to generate one hour of non-adaptive instruction. So there is a significant difference in cost between adaptive and non-adaptive systems. Is it worth the investment? Yes.

While there is a higher cost for adaptive instruction, this cost may be recouped by a reduction in both the learner's contact hours and the human workload during instruction. Tailoring instruction reduces the time to reach competency (accelerated learning) by accounting for prior knowledge and identifying opportunities to skip or reduce instruction for previously-learned concepts. Adaptive instruction also reduces the amount of time lost to *off-task behaviors* (e.g., doodling, texting or talking instead of listening) usually encountered when learners are bored [3]. Boredom often occurs when there is a mismatch between the domain competency of the learner (prior knowledge) and the instructional content [4] and tailoring content to each learner is much more engaging.

There is also high potential to reduce the authoring costs of AISs through automation, but we will delay this discussion until Sect. 5 - *Next Steps*. Instead, we will focus next on opportunities to leverage existing non-adaptive systems for adaptive instruction by driving them with adaptive instructional engines like GIFT.

3 A Model of Interaction Design for AISs

Interaction design is "a user-oriented field of study that focuses on meaningful communication of media through cyclical and collaborative processes between people and technology" [5]. In this case we are discussing the interaction of learners immersed within virtual training environments where their learning experience is guided by an AIS (e.g., intelligent tutoring system).

In a typical non-adaptive training system (Fig. 1), learner act on the environment and then observe outcomes resulting from their actions. Based on this observation, learners decide what action to take next. The system is considered non-adaptive because the environment only changes or responds to learner stimuli. The environment is not intelligent enough to change on its own (e.g., goal-based behavior).

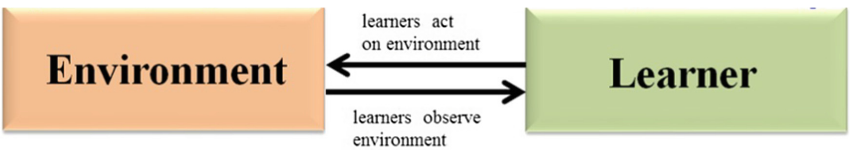

Fig. 1. A model of interaction design for non-adaptive instructional systems

An example of this non-adaptive training process follows: a learner, immersed in a virtual environment, has the goal to navigate from one point in the environment to another. Using a map, the learner estimates the distance and time to move from one point to another and acts on the environment by moving forward toward the south, the direction indicated on the map to get to the next point. When the learner believes he has arrived at the assigned point, he observes the virtual terrain and its nearby features (e.g., hills, roads or rivers) to see if they correspond to his position on the map. If they match up, the learner knows that he has reached the goal. If they don't, the learner attempts to reorient himself on the map and adjust his course. The environment in this case is static.

If we augment this non-adaptive system with an adaptive element (Fig. 2), we expand the capabilities to tailor instruction either by enabling the adaptive tutor to alter the challenge level (e.g., increase the difficulty of the scenario when the learner's performance is very high) or to scaffold the learner (e.g., support or encourage the learner through hints, prompts, or reflective dialogue).

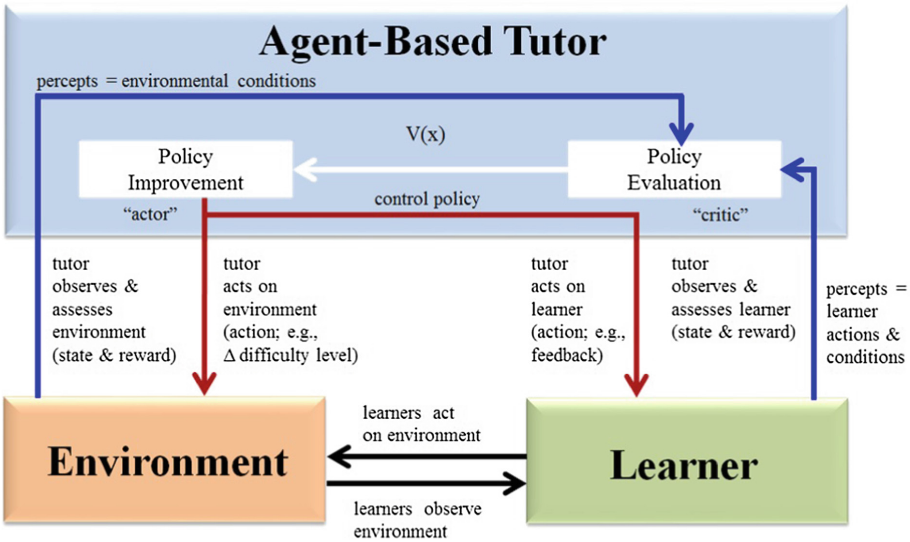

Fig. 2. A model of interaction design for adaptive instructional systems

4 Augmenting Non-adaptive Training Systems with GIFT

In this section we discuss options for augmenting non-adaptive instructional systems with GIFT to create AISs. As we noted earlier, GIFT is a learning augmentation technology that was created to reduce the time and effort required to author, delivery, manage, and evaluate AISs. *Learning augmentation technologies* enhance human productivity or capability [6] with respect to learning outcomes (e.g., knowledge and skill acquisition, performance, retention, and transfer of training). Examples of AISs in the role of learning augmentation technologies include intelligent tutoring systems, personal assistants, and intelligent media used to guide or support learners during training and educational experiences.

Using the model of interaction design in Fig. 2 as a basis, our next step is to focus on additional detail to illustrate how GIFT (or other tutoring architectures) might be used to augment instruction in currently non-adaptive training systems. Figure 3 takes the elements of the agent-based tutor illustrated in Fig. 2 and begins to define its various models and functions.

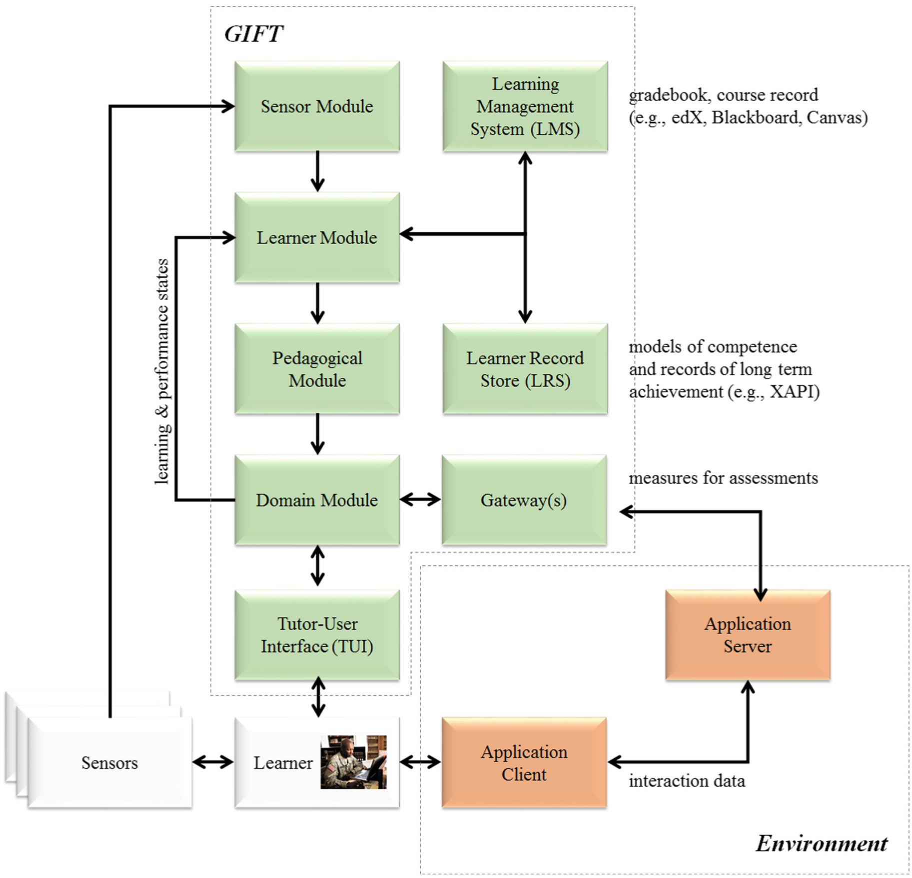

Fig. 3. Interaction between learner, GIFT, and application (environment)

4.1 Elements of GIFT

The elements of GIFT are shown as green boxes in Fig. 3. Starting at the top, the sensor module collects raw and processed state data from individual sensors (e.g., Microsoft Kinect or Zephyr Bioharness) and either processes the raw data or passes on the behavioral or physiological states to the learner module. The learner module tracks the real-time states of the learner (e.g., performance, learning, behavioral or physiological) during adaptive instruction. Learner state information is sent to the pedagogical module, the learning management system (LMS), and the learner record store (LRS. The pedagogical module uses learner states to select optimal domain-independent instructional strategies based on best practices found in the literature. The LMS logs achievements related to objectives (called concepts in GIFT) for all learners in a course of instruction and the LRS logs individual achievements across instructional experiences (e.g., courses, lessons, reading assignments) and constitutes the long term model of the learner based on their experiences and achievements. During instruction, the learner module may also accept information from the LMS and LRS to initialize the learner's states at the beginning of a course or lesson.

The domain module accepts recommended strategies from the pedagogical module and it either stores domain content or points to it. Its primary task is to select optimal tactics or actions based on the pedagogical module's recommendations, the current state of the instruction, and the options available. Tactics involving interaction with the learner (e.g., encouragement, feedback, direction) are presented to the learner through the tutor-user interface (TUI) which is a multi-modal interface and includes textual, verbal, and non-verbal communication modes.

4.2 Interactions Between GIFT and the Training Environment

The orange boxes in Fig. 3 represent the elements of the training environment. In addition to interacting with the tutor in GIFT, the learner also interacts with the training environment through an application client. Interactions between the learner and the training environment result in a set of measures which are defined for GIFT through a condition class. The application server sends information on measures from the training environment via the GIFT gateway. This allows GIFT to conduct assessments of the learner's progress toward learning objectives. The gateway uses a set of measures (variables) that are passed between GIFT and the training environment. These measures are defined by the author of the adaptive instruction and are used by GIFT to make decisions to optimize learning and performance.

Several condition classes have been built in Java to assess the start or completion of conditions as they occur in external training environments. GIFT has also been integrated with several non-adaptive instructional platforms over the last few years to support more interactive and adaptive instruction:

- Engagement Skills Trainer (EST) – virtual trainer for instructing the psychomotor task of marksmanship
- Virtual BattleSpace (VBS) – game-based, desktop training environment for instructing tactical tasks
- Virtual Medic (VMedic) – game-based, desktop training environment for instruction combat casualty care tasks
- Augmented Reality Sandtable (ARES) – projection of tactical maps on 3-D bed of sand
- Dynamic Environment Testbed (DE Testbed) – a virtual environment used to instruct the control and application of heavy construction equipment (e.g., excavator)
- Learning Tools Interoperability (LTI) – facilitates the integration of GIFT with learning management systems and their associated courses
- Unity Environment – provides an exemplar for integrating GIFT with Unity WebGL applications for training
- Distributed Interactive Simulation (DIS) – provides an exemplar for integrating GIFT with DIS-compliant simulations.

Concepts have been developed to ease the integration of previously non-adaptive training modes with GIFT, but have yet to be validated through experimentation:

- Land Navigation – use of adaptive instruction to drive planning and execution of land navigation in both virtual and live training contexts [7]
- Adaptive Triage – a mix of immersive displays and pressure sensors to facilitate live training of hemorrhage control using tourniquets and pressure bandages [8].

5 Next Steps

Based on the interaction design, GIFT in combination with a training environment is an augmentation to both the learner (guides and tailors learning) and the previously non-adaptive training system (expands instructional capabilities). We are currently examining commonalities in the measures of various tasks in order to identify measures that might cut across a variety of domains. The interaction within each task being instructed will influence which measures are needed to assess progress toward learning objectives. For example, location is likely a measure that can be used for a variety of tasks. Interaction and perception modes will also play a key role in the selection of measures. Tasks requiring visual, aural, and haptic perception will determine success criteria for psychomotor tasks.

Next steps are to demonstrate GIFT with a variety of instructional environment to support training and education in cognitive [9], affective [9], psychomotor [10], and especially team task domains [11–13]. Validation of new adaptive instructional concepts through a testbed functionality is a priority. Another objective is to understand how GIFT can drive embedded adaptive instruction in equipment and vehicles [14–16]. The goal for future integrations is to reduce the time and skill required to enable adaptive instruction in the broadest possible context at the lowest cost.

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