Challenges in Moving Adaptive Training & Education from State-of-Art to State-of-Practice

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Abstract. Adaptive training and education (ATE) systems are the convergence of intelligent tutoring system (ITS) technologies and external training and education capabilities (e.g., serious games, virtual humans and simulations). Like ITSs, ATEs provide instructional experiences that are tailored to the learner and may be more effective than the training or educational systems alone. ATEs also leverage existing environments, content and domain knowledge to reduce the authoring workload. The Generalized Intelligent Framework for Tutoring (GIFT) is an open-source ATE architecture with the primary goal to support easy authoring, automated instructional management during ATE experiences, and a testbed to evaluate the effect of ATE tools and methods. While this paper addresses challenges and goals in bringing ATE solutions from state-of-art to state-of-practice within GIFT, it also highlights generalized challenges in making ITS technologies ubiquitous and practical on a large scale across a broader variety of domains.

Keywords: adaptive training and education (ATE), intelligent tutoring system (ITS), authoring, instructional management, domain modeling

1 Introduction

An adaptive training and education (ATE) system is the convergence of Intelligent Tutoring Systems (ITS) technologies and what might normally be standalone training and educational capabilities (e.g., serious games, virtual humans, and virtual, mixed, and augmented-reality simulations). The resulting integration provides intelligently-tailored, computer-guided learning experiences for both individual learners and teams which leverages and enhances the capabilities of existing training and educational infrastructure.

ATE research is focused on optimizing performance, efficiency (e.g., reduced time to competency) deep learning (e.g. higher retention and reduced need for refresher training), and transfer of skills to the operational environment (on the job). The Generalized Intelligent Framework for Tutoring (GIFT) is an open-source, modular architecture whose goals include reducing the cost and skill for authoring ATE systems, automating instructional management, and tools for the evaluation of ATE technologies [1]. GIFT was created to capture best instructional practices and the results of enabling ATE research objectives including ITS design, data analytics, human-system interaction, automated authoring, and the application of learning theory.

Several ATE integration tools and prototypes have been created and are being evaluated. The Game-based Architecture for Mentor-Enhanced Training Environments (GAMETE), is a middleware tool to integrate serious games (e.g., Virtual Medic) and tutors (e.g., GIFT-based tutors and AutoTutor Lite tutors) [2]. The Student Information Model for Intelligent Learning Environments (SIMILE) is a tool for linking actions in games to ITS learning measures [3]. Newtonian Talk is the integration of Physics Playground, AutoTutor, and GIFT [4] to support interactive discovery learning of key physics principles. Virtual Battle Space 2, a serious military training game, has also been integrated with GIFT [5]. As a result of developing and evaluating these prototype ATE tools and systems, lessons-learned and several challenge areas have been identified.

2 Challenges, Goals, and Objectives

The idea of generalizing the authoring of ITSs for broad application across task domains (cognitive, affective, psychomotor, and social) ranging from simple to complex, and from well-defined to ill-defined is not a new goal [6, 7]. However, there remain several challenges in realizing a generalized tutoring architecture to produce standalone ITSs and integrated ATE systems. We have identified seven challenge areas or barriers to adoption of ATE technologies: affordability and efficiency; adaptability and persistence; accuracy and validity; relevance and generalizability; accessibility; credibility; and effectiveness.

Each of these challenges could also be considered a desired characteristic or end state. While all of the seven challenges may be considered on the critical path to practical ATE systems, the challenges which impact authoring and learner modeling are most critical. The authoring process is critical to affordability and is therefore the most significant barrier to adoption.

Accurate learner modeling is critical to the whole instructional decision process for ATE systems. To fully understand the learner's states and adapt instruction to optimize learning and mitigate barriers to learning, ATE systems (and ITSs) need to meet two challenges: low cost, unobtrusive methods to acquire learner behavioral and physiological data; and highly accurate, near real-time classification methods for learner states based on behavioral and physiological data. The effect of adaptive instruction on learner states and specifically critical learning moderators [8] (e.g., engagement, motivation) is illustrated in Figure 1.

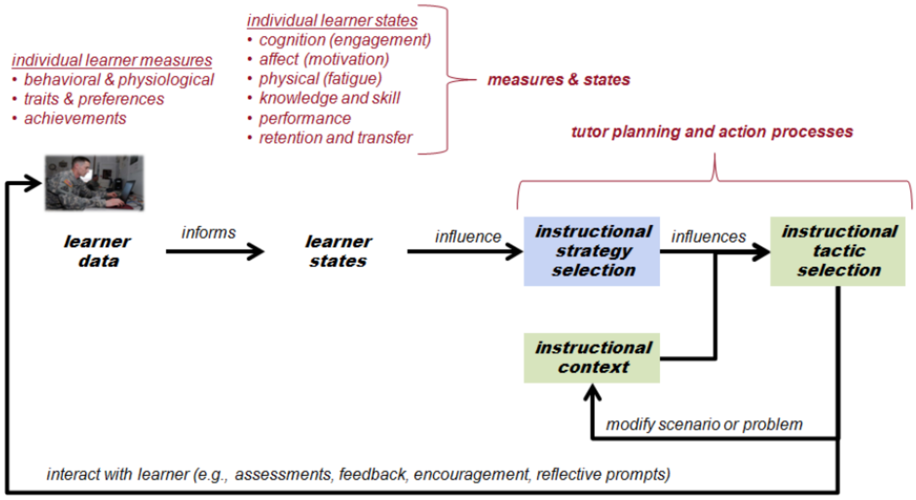

Fig. 1. Updated Learning Effect Model

Inaccurate modeling of learner states can lead to the selection of less than optimal strategies and tactics. Negative outcomes include the selection of instructional strategies which either confuse or frustrate the learner to the point of withdrawal or provide negative training effects because the strategy selected is in opposition to the learner's actual state.

The following is a discussion of the seven challenges and their associated goals and objectives along with a projected impact on adoption in the context of associated ATE/ITS processes: authoring, maintenance, individual learner and team modeling, instructional management, domain modeling, user interface design, and architecture.

2.1 Challenge: Affordable, Efficient, and Effective Adaptive Systems

Due to high authoring costs, the investment in ITS development is only practical for high density courses, those with a high student population. ITS and ATE system developers be able to define what a pound of adaptive training and education is worth in comparison to alternative methods, and they must be able to quantify a return-on-investment and associated breakeven points for these investments [9]. Adaptive systems by their nature require the authoring of additional content and domain knowledge.

To make ATE technologies affordable, we must first examine the authoring and maintenance processes. Aleven, McLaren, Sewall and Koedinger [10] assert that it takes approximately 200-300 hours of development time to author one hour of adaptive instruction. This assertion is based on well-defined, cognitive (e.g., problem solving and decision-making) domains. Research is needed to define the authoring time for more complex, ill-defined domains. A goal for GIFT designers is to reduce authoring time for any domain to just a few hours. This would make it practical for teachers, course managers, and other domain experts to rapidly develop adaptive content and make courses agile and adaptive to learner needs.

However, in the case of ATE systems, we are looking at a broader definition of domain complexity with ill-defined domains and non-cognitive tasks and factors. So given we are developing more complex instruction, our goal is not just to reduce the time and cost to author ATE systems, but also to reduce the skills required to develop and maintain standalone ITSs and integrated ATE systems. To meet this goal, we must improve interoperability and reuse of ITS components and domain knowledge, automate authoring processes wherever possible to take humans out of the loop, improve curation (search, retrieval, management) of domain knowledge, and improve user interfaces to enhance authoring efficiency (ease of use) where human-in-the-loop authoring is required.

What will it take to make ATE authoring available to the masses? A goal is for domain experts to be able to author ATE systems without knowledge of computer programming, instructional design principles, or learning theory. These would be integral to ATE design along with automated authoring tools and artificially intelligent job aids which will guide authors efficiently through the end-to-end development process in the future. As part of the authoring process, we advocate standards to make integration of external training and education systems with ITS easier. Fixing the authoring process is a "must do" to make ATE systems practical (affordable, effi-cient, and effective).

2.2 Challenge: Enhance Adaptability and Persistence

The adaptability of ATE systems is limited when compared to expert human tutors. Our goal is to enhance the ability of ATE systems to provide unique learning experiences for each and every learner. ATE systems by their nature require additional content and associated domain knowledge to support a broad population of learners. This fact drives the cost of ATE systems and limits options for tailoring of ATE experiences for individual learners and teams of learners. By finding tools and methods to reduce the time/cost and skills required to author ATE systems, we can provide more tailoring options in the same or less development time.

Another area for improvement in ATE systems design is in individual learner and team modeling. Our objectives are to enhance short-term and long-term learner modeling to improve the adaptability of ATE systems. Research is needed to understand the relationship between desired outcomes (e.g., learning, performance, retention, and transfer) and the learner's behaviors, transient states (e.g., goals, affect), trends and cumulative states (e.g., domain competency and prior knowledge), and their enduring traits (e.g., personality, gender, and first language) in order to facilitate efficient learner modeling, optimized instructional decisions, and thereby authoring of ATE systems. Adaptive instruction based on long-term modeling of the learner will offer persistence not present in today's ITSs. We can enhance adaptability by making learner and team modeling central to instructional decisions made by ATE systems.

2.3 Challenge: Enhance Accuracy and Validity of Instructional Decisions

In order to make appropriate adaptive instructional decisions, ATE systems need to improve their perception of learner states. Research is needed to develop low cost, unobtrusive methods to acquire learner data to support state classification. In turn, research is also needed to improve the accuracy of real-time classification for both individuals and units [11].

To insure the validity (suitability) of instructional decisions based on sound learning theory, domain-independent instructional strategies (e.g., metacognitive prompts) may be selected based on the accurate classification of the learner's states. For example, imagine a learner whose state is classified as "confusion" by an ATE. If the accuracy of this classification is less than 80 percent, then a metacognitive prompt to have the learner reflect on a recent decision could clarify any ambiguity of the "confusion" classification.

Similarly, domain-specific actions (tactics) based on a selected instructional strategy and context (conditions within the domain). Research is needed to develop methods to optimally select the best possible strategies and tactics given the learners states, the conditions within the training or educational domain, and the availability of options provided by the author of the ATE. Within GIFT, the learning effect model for individual learners [11, 12, 13], as updated in Figure 1, describes the interaction between the learner and the ITS.

2.4 Challenge: Enhance Task Relevance & Implement Generalized Solutions

In order to be practical, ATE systems must be able to represent domain knowledge in relevant task domains. Today, the most popular ITS domains are mathematics, physics, and computer programming. The characteristics of other domains may not be as well defined or as simple. For example, tasks involving psychomotor and perceptual measures (e.g., sports, laparoscopic surgery, and marksmanship) are not well-represented in the ITS community.

Research is needed to expand the dimensions of domain knowledge to support a broader variety of task domains. One objective is to develop standards to represent domain knowledge beyond the cognitive task domain (e.g., affective, psychomotor, perceptual, social, ill-defined, and complex domains). Once the domain can be represented, authoring tools and instructional strategies, tactics, and policies should be tailored to support adaptive interaction with the learner.

As mentioned previously, it will be critical to be able to easily integrate external training and educational environments to reduce the authoring burden, but also to enhance the experiences that are familiar to learners. Representing the domain knowledge of relevant task domains and integrating with other systems will provide the basis for an ATE architecture which we are currently prototyping as GIFT.

2.5 Challenge: Support Tutoring at the Point-of-Need

To be effective, ATE must be accessible at the user's point-of-need. The ATE architecture must develop services to allow access anyplace and anytime (24/7/365). To meet this goal we have formulated two primary objectives. The first is to move GIFT, an adaptive training and education architecture, to the cloud. We are developing a cloud-based architecture that allows real-time access for learners and units to support individual, collaborative (social), and team training and education. Since learners, authors, and other ATE system users may find themselves in areas of degraded communications, we are also developing cloud-based services to download virtual machine versions of GIFT to allow local development and synch with the cloud as needed.

2.6 Challenge: Enhance the Credibility and Supportiveness of the Tutor

To enhance the learner's perception of ATEs as credible training and educational tools (e.g., domain experts, trusted advisors, teachers), we are closely emulating best practices of expert tutors and learning theory. To this end we have implemented component display theory [14] as our default pedagogical module, the engine for managing adaptive pedagogy or eMAP.

To capture and maintain the attention of learners, we are developing methods to evaluate the suitability of user interfaces (e.g., virtual humans) and domain knowledge (e.g., content) to enhance the learner's perception of ATE systems with respect to domain expertise and learner support. To be efficient, we are developing user inter-faces for various roles in the ATE environment (e.g., learners, authors, and power-users). These interfaces will allow users to construct their own mental models and interact in a manner that is conducive to learning.

2.7 Challenge: Continuously Evaluate Effectiveness

As with many systems, we anticipate that ATE systems will be deployed with implementations of *best known practices*. ATE systems must not only provide adaptive instruction, but be adaptive to continuously improve. The challenge is to collect and analyze large datasets on a regular basis to identify trends and issues, and to evaluate the effectiveness of current tools and methods against alternative tools and methods. The ATE architecture must be able to support continuous evaluation of its tools and methods, and be modular in order to support rapid change.

We are developing tools and methods within GIFT to evaluate the effectiveness of the authoring and instructional management processes. Our goal is to support the continuous improvement of ATE technologies. To this end we are developing tools and methods to reduce the time/cost and skill required to evaluate the effectiveness of ITS technologies. We are also developing data analytic methods to evaluate user-generated content (social media) to maintain cognizance of the primary users (learners and authors) and to enable them as change agents.

3 Conclusions

This paper reviewed several challenges to adoption of ATE systems as practical tools for learning. We noted that several ongoing research initiatives and identified several more which are needed to support changes to the authoring and maintenance, instructional management, learner modeling, and domain modeling processes along with underlying services provided by the architecture through the user interface.

We also noted that ATE systems have a long-term focus as well as a short-term learning focus. Big data collected continuously on both the learner populations and the ATE system may be analyzed to provide insight on both effective and ineffective instructional methods and user interfaces for both authoring and instruction. Research is still needed to fully understand the effect of combining ITSs with existing training and education systems in order to quantify a return-on-investment.

We recommend additional research emphasis on the following challenge problems: methods to automate the authoring process to the maximum extent possible; enhanced job aids and user interfaces for the authoring process where automation is not possible yet; methods to automate integration of existing training and education systems with ITSs; methods to increase the accuracy of learner state classification and optimize instructional decisions by the tutor; methods to evaluate the effectiveness of ATE system tools and methods; and methods to evaluate user-generated content (e.g., social media) to enhance learner experiences in ATE systems.

We also note the need to expand ITSs beyond the existing well-defined domains (e.g., mathematics, physics, and computer programming) to include more ill-defined and dynamic domains (e.g. psychomotor domains including sports). Finally, we advocate the development of collective level models (e.g., shared states, team behaviors, and team cohesion) for unit-level tasks and collective learning environments [15].

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