ARCHITECTURAL RESEARCH IN INTELLIGENT TUTORING TECHNOLOGIES

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ABSTRACT

It is well known that personalized and adaptive training, such as from a human tutor, is dramatically more effective than traditional classroom training. Due to reasons such as cost and availability, however, most military training is still provided in the traditional classroom format. The United States Army Research Laboratory has recently published research plans and major thrusts for changing this dynamic. Each of these research plans outlines a different aspect of intelligent tutoring system technology, which are tied together in a unifying architecture for conducting the research. This paper discusses how this path was decided upon, the progress made to date, clarifies the role of the architecture in the research, and discusses some of the advantages of a unified system as part of measuring training effectiveness and overall system improvement.

Keywords: Adaptive and Predictive Computer-based Training, Intelligent Tutoring Systems, Architectural Components, Emerging Standards

1. INTRODUCTION

The United States (US) Army Research Laboratory (ARL) has developed a program of research called adaptive training which includes six interdependent research areas or vectors: individual learner and unit modeling, instructional management principles, domain modeling, authoring tools and methods, evaluation tools and methods, and architectural and ontological support for adaptive training (Brawner et al., 2015). Each of these research vectors has its own objectives, challenges, and research goals. In addition to these vectors and project teams, ARL has been researching and developing a common architecture for the capture of research outputs of various projects, which is known as the Generalized Intelligent Framework for Tutoring (GIFT) (Sottilare, Brawner, Goldberg, and Holden, 2012). GIFT consists of a series of software modules which are able to interface through a messaging standard. The modules are: the learner module, sensor module, pedagogical module, and domain module. The interactions between these modules form a significant portion of the base for the research vectors.

In both the literal and philosophical sense, software architecture has pragmatic purpose and serves a supporting role. As such, the primary function of the “architecture” component of the Adaptive Training group is to support and extend the abilities of the other active areas of research. This is performed through the capture of research performed in other vectors, functionality given to specific vectors, and through the practice of standardization within communication. This paper will discuss the history and origin of the GIFT project, the current direction which it is going, the key components of its implementation, the major architectural research and development challenges, and the opportunity for the international community to contribute.

2. A BRIEF HISTORY OF GIFT

The current progress in GIFT has been slow, but steady. Since its first inception, GIFT has been used in many training domains. These domains range from an unpublished, very simple, addition tutor, to a complex vMedic game-based scenario that monitors performance and offers adaptive feedback. The vision for such a system was documented well before its realization in software as a special report of its functions and intended functions (Sottilare et al., 2012).

Initial versions of GIFT were prototyped in developmental fashion, with a complex setup process that required end-users to set JAVA_HOME variables, install mySQL, and other items which would be typical for developing on a software-intensive project. Based upon feedback, the project has gradually expanded its group of intended users to range from software developers to educational psychologists to military instructors. As a byproduct, the installation process has been greatly simplified into a single “batch” file, which includes no individual variable manipulations, and requiring no administrator privileges. Therefore, the installation procedure is now similar to the experience of clicking “install” that most users are familiar with. Further improvements to the difficulty of configuring GIFT content has resulted in the development of XML-based authoring tools, which have developed into more user-friendly, graphical user interface-based versions, which are currently available. These improvements generally mark the beginning of the transition of the project from a development tool to a user tool.

The project has a three-tiered approach to developing appropriate supporting features for the needed user functionality. At the first tier, GIFT development has been steered by an executive committee, conducted as a series of yearly advisory boards. The output of these advisory boards is a published book that documents the board's generalized architecture recommendations on subjects such as the authoring tools, learner modeling, and instructional strategies (Sottilare, Graesser, Hu, and Brawner, 2015; Sottilare, Graesser, Hu, and Goldberg, 2014; Sottilare, Graesser, Hu, and Holden, 2013). At the second tier, there are a series of approximately 8-13 Government-managed projects which investigate various aspects of using GIFT. These project topics include utilizing sensor data information, generalized instructional engine development, and integrating and testing functions of other tutoring engines, such as AutoTutor. At the third tier are the critical individuals and organizations that develop GIFT modules instantiations, write plug-in code, conduct empirical evaluations, run studies, and are involved in other aspects of development. These three tiers operate together, from a program management perspective, to create functioning software based on well-informed recommendations, research findings, implementation, and testing.

The first version of GIFT (GIFT 1.0) was released in May of 2012, and was followed by various releases at the times shown on Table 1. Each release, so far, has contained a new domain of instruction, which is also backward compatible with previous releases. These domains of instruction include room clearing tasks inside of a VBS2 environment, tactical combat casualty care from a vMedic environment, or simply performance monitoring inside of a PowerPoint environment. Each of the courses associated with these environments have been made freely available to the general public, and are included with GIFT releases. The authors encourage the reader to download the GIFT software and examine them.

Table 1 - GIFT Releases and Versions

Version	Release Date
1.0	05/2012
2.0	11/2012
3.0	05/2013
4.0	11/2013
2014-1X	04/2014
2014-2	09/2014
2014-3X	12/2014
2015-1	06/2015

At the time of writing, GIFT has over 550 users who have registered for accounts on the www.gifttutoring.org portal, and has achieved modest technology transition into the field of use with a joint project with both the US Navy and US Army. This adoption rate has been steady, with numbers increasing each month and year, despite programmatic difficulties involved with decreased spending by acquisition agencies and limited conference travel among the scientific agencies.

GIFT has served as a basis for much of the US Army's research with adaptive tutoring. The expansion of the program to involve additional personnel, and the expansion of each of the research vectors has resulted in the development of a carefully constructed plan to avoid overlap, continue in a unified direction, and provide the functionally separate components that have been intended and designed towards at the outset of the project. Generally speaking, as an active research project, many existing training domains and tasks have been integrated, with new training environments emerging with each additional project need. Table 2 describes training environments to date that have used GIFT, which have been created or tested in support of the US Army's vision for learning in 2015.

Table 2 - GIFT Use in Training Environments

<Company/Organization>	<Type> Training
Learning in Intelligent Tutoring Environments (LITE) Lab	research with memory/retention, marksmanship
Dignitas Technologies	proof of concept in VBS2, medical, COIN
Stanford Research Institute SoarTech	Situational and cultural awareness
Eduworks Corporation	IRB, math, medical
Engineering and Simulation Systems	medical
Florida State University University of Memphis	Physics
Iowa State University	small team training in VBS2
Intelligent Automation Incorporated	COIN operations in UrbanSim
CHI Systems	various among previous (interoperability)
Institute for Creative Technologies	situational pedagogy (for other training)
Problem Solutions Aptima	gunnery training, proof of concept interoperability
Naval Air Warfare Center - Training Systems Division	cryptography equipment
Army Research Laboratory	Civilian Affairs operations
Carnegie Learning and TutorGen	mathematics
Dignitas Technologies, commercial sales division	regulation compliance, driving simulators
United States Military Academy at Westpoint	engineering decision processes
Program Executive Office, Simulation Training and Instrumentation	Marksmanship

3. THE US ARMY LEARNING MODEL

The Army Learning Model/Concept of 2015, originally published in 2011, has served as a motivation for the development of GIFT. Portions of this Model/Concept have now been implemented, but there are still unaddressed requirements. The implementation of the Model/Concept is tasked to the acquisition commands, which leverage the research community to mature the underlying technologies. The authors would like to refresh some of the key concepts in Figure 1, with the knowledge that each of the research vectors is attempting to introduce adaptivity across all objectives:

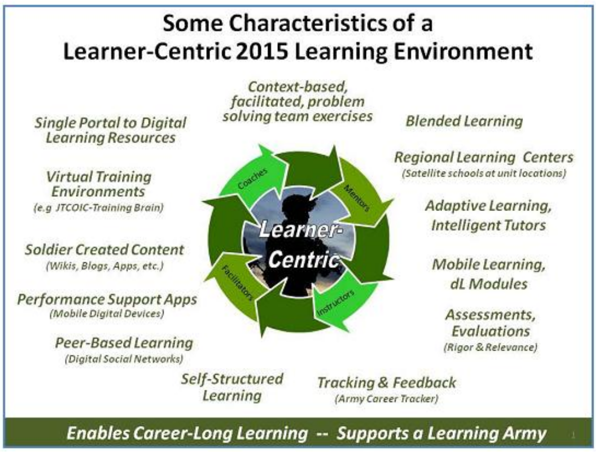

Figure 1: Army Learning Model (Army, 2011)

Some relevant portions of this combined learning picture are: tracking of a total career, digitizing nearly all learning resources, and the prevalence of "continuous learning" environments. A continuous learning environment consists of a training environment which is linked to the tactical equipment (embedded training), a virtual environment/campus, and to refresher training on mobile devices, following the general idea that training will be available anywhere at any time.

Regardless of the environment and delivery system, each of these training experiences should be adaptive and personalized in order to promote learning. Adaptive, in this sense, means responsive to the actions of the user: correcting misconceptions for a cognitive task (e.g., troop placement), or correcting performance errors for a psychomotor tasks (e.g.. marksmanship). Personalized, in this sense, means that the content has been customized for the user who is to receive it. As an example, a user with low motivation may receive material that is highly interactive, as managed by an instructional engine (Goldberg et al., 2012). These decisions are output as data from the modules which make them, and are reliant upon the input data which they receive from other models. The management of this data is shown abstractly as offline and online processes in Figure 2. The Army Learning Model provides a vision of the future, while the following section details the status of the present and paths created to get there.

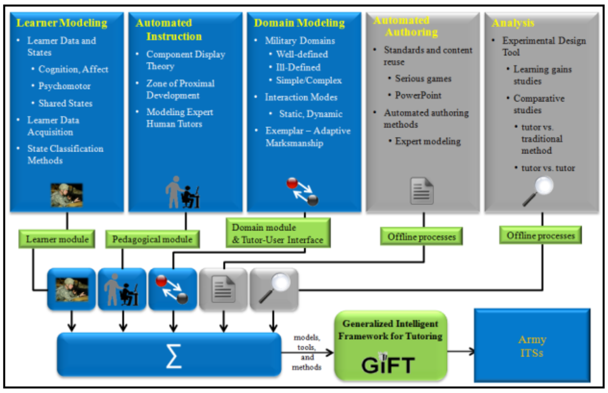

Figure 2: Adaptive tutoring research vectors. (Sottilare, 2013)

4. COMPONENTIZED APPROACH TO RESEARCH AND ARCHITECTURE

One of the authors, in 2010, had the privilege of working with a successful military ITS known as the Tactical Action Officer (TAO) ITS which illustrates the current state of ITS system design (Stottler and Vinkavich, 2006). The system was designed to have computer "virtual role players" take the place of live human instruction, such that a 6-man team could train with only one man present. It was designed with a scenario generator to replicate military scenarios that were of interest, in order to stay relevant in modern military environments. Lastly, it was shown to modestly increase learning in unscientific study, which was not particularly a project goal. The following story of this project provides an illustrative example of the state of the art at the time as well as portions of the guiding design principles behind the GIFT architecture currently.

While this ITS was useful for military training purposes, through elimination and reduction in the number of required instructors, the shortfalls of the field can be seen through the process of its design and support. Firstly, such a system was selected, in open proposal, based on the partnership of an ITS company and a defense contractor; the resultant system required the expertise of instructional designers and subject matter experts in addition to the traditional development staff. Such partnerships, although well structured, should not be required to build a training system; *there should be a platform which encapsulates the current state of the science in an existing system for experimentation and use which can be implemented as a traditional engineering "black box"*.

Next, the schoolhouse which was the recipient of the system wanted to adjust the content. Although an authoring tool was developed for the effort, it created new scenarios for the existing assessment rules to be applied: no change could be made to the assessment logic or provided feedback. Changes in military policy and practice necessitated changes in the system, which then required both instructional knowledge and programming knowledge in the type of partnership described earlier. *The system should be able to readjust its assessment logic without reengineering*.

Further, the Navy schoolhouse found the technology useful, as it made the task of instruction easier through the automation of part of it. The training system program was expanded to include instructional content for the Ship Self Defense System (SSDS). It was found through practice, however, that it was impossible to take the existing instructional models and task assessments from one domain of instruction (TAO) and apply them to a new one (SSDS). This re-crafting of the resultant system was nearly as expensive as the creation of the initial system. *A modern ITS should be able to be repurposed for new tasks on an existing simulation without the reinvention of the system itself*.

Finally, the TAO ITS system required updates to some of its core functions. These updates fell into two general categories: information assurance improvements, and new capability improvements. The information assurance improvements were relatively straightforward, as most modern software systems are designed for ease of maintenance. The modest capability improvements, however, proved difficult, due to the closed and tightly coupled nature of the product requiring member of the initial construction team. *Open architectures are needed to facilitate long-term logistics cost of software*.

The lessons here are relatively clear, and have been learned both in other industries (e.g. car manufacturing) and within the computing industry (e.g. operating systems and drivers): common architecture and reusable components reduce time and cost. Specifically, the architecture for a common learning system should be able to encapsulate the knowledge of the supporting roles such as instructional designers and student models. Components should not be tightly coupled, but loosely integrated, such that individual portions (e.g. assessment logic), can be changed without programming. The architecture should include, as one of these components, a single model of the domain, such that it can be replaced with another domain of instruction for a "new" tutoring system. Finally, the interfaces and data to such a system should be clearly defined in order to create sustainable systems, or to be easily updated.

In response to the needs detailed above, ARL has an ongoing program in adaptive training that is contributing to the state of the art in tailoring training along six research vectors (Figure 2) in support of the US Army Learning Model (Section 3):

1. individual learner and unit modeling
2. instructional management principles
3. domain modeling
4. authoring tools and methods
5. evaluation tools and methods
6. ontological and architectural support for adaptive training

The first vector, individual learner and unit modeling, aligns with and supports both the "individual learner" and "social learning" subsections of "innovation in learning". In this area, we are researching the effect of transient (e.g., near-term learner states including performance), cumulative (e.g., achievements, competencies), and enduring learner characteristics (e.g., personality, gender) on instructional decisions and outcomes (e.g., learning, performance, retention, and transfer). This includes a recently completed literature review of the team performance and tutoring. We are developing team-level state models for team processes (e.g., coordination, communication, and leadership) and emergent team states (e.g., cohesion and conflict) based on their effect on performance and learning in the literature. These models will be validated in team training environments. There is also a developed social media framework as part of GIFT to support the acquisition and evaluation of user-generated content. This research focused on data analytics to support continuous improvement of instructional content, methods, and tools to enable the practical development and use of adaptive training systems.

The instructional management principles for adaptive training are based on the learning effect model and learning theory, shown in Figure 3 (Sottilare, 2012). The engine for managing adaptive pedagogy (EMAP), the default pedagogical module in GIFT, currently supports an instantiation of Merrill's component display theory derived from Gagne's 9 instructional events (Goldberg et al., 2012). The basic driver behind this theory is that there is the presentation of Rules, Example, Recall Practice, where each item builds on the previous items. A summary figure presenting this research is displayed in Figure 3. The work in this area is primarily focused on developing methods for optimal strategy selection based on learner states. The selected strategies drive selection of tactics or actions by the domain module.

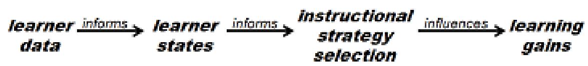

Figure 3: Learning Effect Chain (R Sottilare, 2012)

Domain modeling for Adaptive Training focuses on the representation of knowledge for a particular task or concepts and includes: relationships between goals, learning objectives, concepts, and learner experiences, domain content (a library of scenarios or problem sets); an expert or ideal student model with measures of success; and a library of tactics or actions (e.g., questions, assessments, prompts, and pumps) which can be taken by the tutor to engage or motivate the learner and optimize learning.

Authoring Tools and Methods focuses on research to reduce the time, cost, and skill required to author adaptive training systems. This includes the development of standards to support reuse and interoperability among these systems, interface specifications to support easy integration of existing systems, and automation to reduce or eliminate the authoring burden (e.g., expert model development, and scenario evolution based on a single parent scenario).

Evaluation Tools and Methods focuses on reducing the time and effort required to evaluate the effectiveness of systems, components, tools, and instructional methods. While this area is much broader than adaptive training, it is being specifically applied to adaptive systems as a use case. Items such as automated tools, long-term analysis, behavior change effects, and retention are being addressed from this perspective.

Lastly, the Ontological and Architectural Support for Adaptive Training is focused on standardizing terms, functions, components and their relationships to support modularity, access at the point of need, and the vectors noted above. GIFT is the prototype being developed to capture all we are learning in this area, and has garnered interest from both the US Chief of Staff of the Army's and the US Chief of Naval Operations Strategic Studies Groups.

5. CONTENT AND INTEROPERABILITY

By far, the most difficult design consideration for the GIFT architecture is how to be, and remain to be, domain independent while still contributing something valuable to an individual system. Providing such an architecture requires the removal of much of the context behind performance, and the generalizing of instructional strategies. Information such as when and how to provide feedback is domain general, but information which involves specific mistakes or corrections must be handled by an interchangeable module. To support this end, the Domain Module has a few specific pieces of information made available to it:

- A concept/subconcept hierarchy of the tasks which should be instructed in an individual course
- A link between each of these concepts/subconcepts and a manner in which to assess them, in the form of tasks, conditions, and standards
- Tutoring information available for instructional actions, in the form of hints or adaptations.

The classification of information into this schema allows for a single configuration instance (Domain Knowledge File) to be mostly reused across simulators, for a single simulator to train different tasks according to its tutoring configuration, or to keep all of the other modules of GIFT stable while training a new task in a new domain.

In addition to creating a required method of representing abstract domain structure, domain content is supplemented with information reflecting its content and usage, called metadata and paradata. This information, like the three types of information above, can be abstractly defined for a variety of domains. One of the key features of GIFT is that it allows these features to be built organically; if authored content is available in a compatible manner, it can be seemlessly integrated into the course of instruction, if information (content, assessments, metadata, etc.) is not available, the system defaults to its best guess at appropriate material. The construction of training material in this fashion allows for adaptive capabilities to be built after an initial training system, and to be incrementally constructed.

5.1. Metadata and Paradata

The Engine for Management of Adaptive Pedagogy (EMAP) (Goldberg et al., 2012), the default instructional engine behind GIFT, is able to select among the domain-general content to which it has access. It selects this content based upon domain-general content traits and learner-general traits. As an example, a learner who has been identified as having "Low Motivation" can be served the content with the highest Interactive Multimedia Instruction (IMI) level available. A "High Motivation" learner in the same situation may be given material where the IMI is lower, but the coverage is greater, according to the individual learner's interest and need. The matching of these content traits and learner traits without specific information allows these actions to be performed in a number of disparate instructional contexts. The default instructional engine is based upon a great deal of research, but can be easily reconfigured to support experiments, while tagging individual items with content has additionally been simplified, shown in direct comparison at a glance in Figure 4.

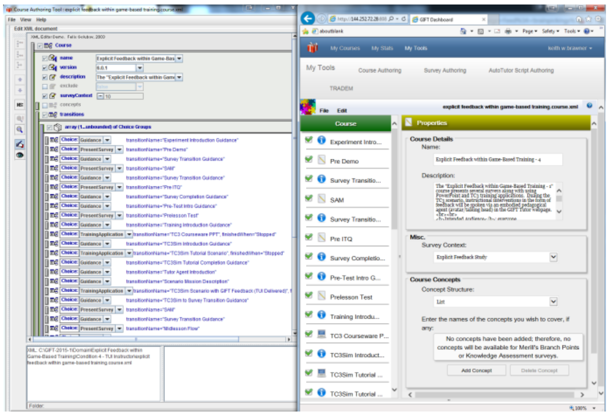

Figure 4: Example of authoring tool simplification

If there are two pieces of content, or instructional events, which have the same metadata descriptions, it raises the question of "which set should be given?". GIFT uses paradata, or usage data, to adjudicate the case for the recommendation of matching or identically described content. Currently this is implemented as a ".paradata" file located next to the content in question, but this serves as the placeholder for larger and more appropriate social media based rating systems, mentioned earlier, to adjudicate appropriateness of individual content selections (Boland et al., 2015).

5.2. Interoperability concerns

As part of the creation of an ontological categorization of domain-specific information, there is difficulty in maintaining the flexibility to the system to adjust to new domains of instruction while supporting both existing research projects and transition into systems of practice. The construction of models which are domain-general and compatible with GIFT is more difficult than the traditional academic approach, but offers different advantages. The research approach of cobbling together a system for the purpose of testing a theory is helpful in that it can quickly prove novel research ideas. The engineering approach of designing a widely applicable and standardized system allows for the use of proven research outside of its original laboratory. Given that ITS research has a long history of being useful, it is the position of the ARL that the time is right to attempt the engineering of a wide-scaled system for practical use. While the incorporation of content in a general-purpose system may be more difficult, it is possible for it to see broader applicability.

A typical training model for current military instruction involves training in multiple environments prior to putting the learned information into practice. As a concrete example, a student may be assigned reading on the operation of a vehicle, given an interactable model of its maintenance, trained in a simulated environment, trained in a practice environment, operate the vehicle in the field, and receive embedded training during downtime. Sharing data across such disparate systems, at a granularity where tasks can be accomplished, is a difficult problem which calls for interoperable standards. Examples of tasks are predictive modeling (will a student with X knowledge succeed at Y course), transferability (student with knowledge X can skip content Y), or effectiveness (student performing well on X performs well in the field). GIFT has chosen xAPI (Regan, 2013) as an emerging standard which can support the need for this type of actionable data and research question investigation. Other emerging standards such as the Human Performance Markup Language (HPML) (Stacy, Ayers, Freeman, and Haimson, 2006) are additionally under consideration for the representation of fine-grained performance data.

6. SUPPLEMENTATION OF CONTENT WITH TUTORING INFORMATION

Initial presentation of content is merely the first part of the tutoring process. A full tutoring process involves content such as hints, prompts, pumps, assessing questions, or topic sequencing. The current manner of generating this type of supplemental content is manual; after the initial training content has been developed, the author is asked to create this type of material. In the creation of an item such as a hint, the domain expert may create an assessing question for each key concept in a supply of training material, a hint for each question, and a series of hints of escalating granularity for concepts which are known to give students issues.

The creation of this supplementary tutoring information generally takes comparable time to the creation of the initial training material. As a byproduct of the time required to create supplementary tutoring information, its creation by training instructors is performed with some trepidation. GIFT allows the creation of training material in the absence of its tutoring information, but these are the types of information are where learning gains over textbook reading are found; without the tutoring information, it is simply a “page turner”.

There are projects involved with automating the tutoring supplemental content. As an example, it is possible, from a variety of texts to establish the order of instruction which is consistent among the domain (Robson, Ray, and Cai, 2013). Assessing questions can be automatically generated through question generation techniques which generate multiple choice questions and distracters (Olney, Graesser, and Person, 2012). Hints can be generated using a historical series of previous student actions, represented as a Markov Chain, to provide a ‘hint factory’ (Stamper, Barnes, Lehmann, and Croy, 2008). Generally, there is some evidence that the types of supplemental material which authors are reluctant to author can be performed automatically.

7. ARCHITECTURAL RESEARCH GOALS

7.1. A Single Point for Training

GIFT does not aim to be a single point for all data to be stored and indexed. However, the goal is to be able to ease integration with a variety of training environments for the purpose of capturing training outcomes and standardizing processes. A good architectural structure should allow for the easy import of existing training content, augmentation of its' resources, sharing of intelligent tutoring system resources, delivery of tutoring instruction, provision of grading information back to instructors, and tracking of long-term learning data. In support of these goals, GIFT has a series of web-based authoring tools, a manner of integration with existing simulators, the ability to share a completed tutoring system. Each of these could have more functionality, but are provided as bare-bones to a diverse set of training systems. The goal is to provide the tools integrate with training systems, and to be able to capture training information where possible. To this end, GIFT may work as an enhanced version of the Gooru Learning platform, which indexes instructional content for use in classroom settings (GooruLearning, 2014).

7.2. A Single Point for Users

To the end that GIFT may function as a single point for training content, it is the intention for it to be a single point for users to access other systems, with tutoring optionally applied as an overlay or integrated into the system directly. User needs are simplistic: to access training content, to store a history of their training, and to provide curation and recommendation for future courses. Previous efforts in this area (Mangold, Beauchat, Long, and Amburn, 2012) are being folded into the GIFT project in an effort to provide this single sign-on and tracking functionality for taking training, gaining access to new training, lodging social media objections, and other items. Future versions of GIFT will be distributed as virtual machines, for set up at individual schoolhouses, with interoperability with existing or external Learner Record Stores (LRS) (Regan, 2013).

7.3. Single Point for Analysis

Using a single system to create and take training allows for research on the creation and use of training. This includes many interesting authoring research questions such as "which types of instructional domains are most difficult to create training for?", "how can semi-automated tools improve to provide additional levels of automation?" and additional learner modeling research questions such as "which courses are the most critical for future leaders to do well in?" or "how long, on average, does it take before someone forgets critical aspects of their medical training?". Standardizing the data flow across disparate systems allows for the creation of analysis tools which can be applied to these systems. The introduction of powerful analysis tools to answer these research questions for disparate systems, at different types, at different granularity, for different users and groups of users is an architectural research goal. Cooperation with different teams in this area (Koedinger et al., 2015) will be a key point for reuse and success.

7.4. Automated background processes

As mentioned in section 6, automation can magnify individual impact. There are a number of opportunities in automation of learning systems. Some of these involve using AI processes to assist a course creator, such as the creation of course content and supplementary tutoring content. Some of these involve enhanced modeling of users for customized recommendations and assistance. Some of these involve the identification of poorly performing, or highly discussed, course content. Some of these involve items such as customized scenario generation to train automatically identified learner weaknesses. Having data in a single point allows for the reuse of these processes across domains of instruction and gives the benefits to the final users of the software.

7.5. Single Point of Integration

Lastly, the lessons learned from the earlier TAO ITS system have not been forgotten. GIFT serves as a platform which encapsulates the current state of the science in an existing system for experimentation and use which can be implemented as a traditional engineering "black box", and provides tools to do so. GIFT is able to readjust its assessment logic without reengineering, through relatively simple changes in configuration files by using existing tools. GIFT is frequently repurposed for new tasks on an existing simulation without the reinvention of the system itself. GIFT has an open architecture to facilitate long-term logistics cost of software, and is released publicly. All of these items allow for the ease of integration with other existing systems.

These integration goals are intended to allow for the proliferation of systems, by making their creation easier. They allow for the change of modules, or introduction of new models within modules, without re-creation of the system. They additionally allow for the ease of data collection and analysis.

8. CONCLUSIONS

Over fifty years of AI research has failed to produce generalized standards for authoring ITSs, automation of their instructional processes, or evaluating their effect. GIFT arose as an open-source, modular architecture to support more standardized processes in ITSs to allow interoperability of components and to reduce the skill/time required to author ITSs. This paper describes the research and development of GIFT capabilities (existing and future needs) and outlines challenge areas in adaptive training research in authoring, automated instruction, domain modeling, and supporting architecture. GIFT serves as community-based project that needs a large group of practitioners to prosper, grow, and drive official standardization. It is essential moving forward that GIFT is architected to support a wide-variety of domains (e.g., cognitive, affective, psychomotor, and social/collaborative) to validate its design principles and to demonstrate its authoring and evaluation tools and methods. To this end, we reach out to the global community to apply GIFT freely and provide feedback on its performance. The development of ITS standards will result in lower development time/cost, and higher levels of reuse across all of the participants.

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