A Blended Approach to Adaptive Learning

Barbara Buck, Ph.D.[1], Matt Genova[1], Robert Sottilare, Ph.D.[2], Benjamin Goldberg, Ph.D.[2]

The Boeing Company[1], U.S. Army Research Laboratory[2]

INTRODUCTION

Adaptive training is often considered the gold standard for addressing the unique training needs of individual users. These unique needs can result from different backgrounds, different experiences, different learning goals, different personal motivations for learning, and different degrees of engagement in the overall learning experience. Adaptivity is the ability of a system to alter (change) itself to better fit or function in a given situation. In order to optimize the learning experience for a unique person, a learning system should adapt to the individual learner or team for the specific situation, much like a human mentor or instructor would adapt to the individual needs of a student.

The goal of an Intelligent Tutoring System (ITS) is to provide automated instruction equivalent to that of a skilled human tutor. ITS development has gained momentum since the 1980's, with numerous automated tutors being developed and applied in both university and Department of Defense settings (Bloom, 1984, Lesgold, Lajoe, Bunzo & Eggan, 1988, Anderson, Corbett, Koedinger & Pelletier, 1995, Hunt & Minstrell, 1994, Graesser & Person, 1994, Cohen, Kulik & Kulik, 1982).

Adaptive training content can be time-consuming and expensive to develop, deliver, and manage. If the adaptive solutions are ever to gain widespread acceptance within the educational and training community, we must find cost-effective ways to develop, deploy and manage content. The U.S. Army Research Laboratory (ARL) has been developing one such solution, the Generalized Intelligent Framework for Tutoring (GIFT). The GIFT program is an ARL effort to develop a framework for personalized, on-demand, computer based instruction to improve the speed and quality of Soldier training (Sottilare, Brawner, Sinatra & Johnston, 2017). In a separate effort, Boeing has been involved in a program of research and development to create an adaptive learning authoring and content delivery system. The Boeing ITS provides a user-friendly authoring environment designed to rapidly create and deliver a rich personalized student-centered learning experience through the modeling of system knowledge, problem-solving rules, and real-time assessment of student performance. The learning experience provides dynamic scenario sequencing, tailored student feedback and student performance summary based on the perceived student strengths and weaknesses (Perrin, Buck, Dargue, Biddle, Stull, & Armstrong, 2007, Perrin, 2009).

In this paper, we will present an aggregate prototype of adaptive learning that leverages these two distinct implementations: ARL's GIFT solution and Boeing's ITS solution. The product of combining these efforts is an integrated adaptive learning prototype. This presentation will describe our efforts to create a seamless adaptive learning experience on the part of the student, as well as plans to conduct an effectiveness study using the adaptive learning methods.

GIFT Framework

GIFT is an open-source, modular architecture developed to ease the burden of authoring, delivering, managing, and evaluating adaptive instruction across a broad array of domains (e.g., cognitive, affective, psychomotor, and social). As an adaptive instructional system (AIS), GIFT guides learning experiences by tailoring instruction and recommendations based on the goals, needs, and preferences of each learner in the context of specific domain learning objectives. GIFT is composed of tools, methods, interfaces, and processes that capture and reinforce best instructional practices, effective learning strategies, and tactical actions for both individual learners and teams. Emerging capabilities include: user dashboards, data analytics, automated content curation, automated after action reviews, and standard messaging for reuse and interoperability.

GIFT has several modules which model and act on data about the learner, instructional decisions, and domain content:

- Domain Module - The primary function of the domain module is to create, maintain and assess domain sessions. This module hosts or points to content used during instruction and contains a domain course file which is an XML file containing information needed to assess the learner's progress toward proficiency for the concepts (learning objectives) identified by the course author.

- Learner Module - The primary function of the Learner module is to determine the learner's state (e.g., real-time performance, real-time emotional, or long term domain competency).

- Sensor Module - The primary function of the sensor module is to read and filter sensor data to determine/predict learner states. There are several sensors integrated with GIFT to provide data about the learner: Microsoft Kinect, Zephyr Bioharness, Affectiva Q Sensor, and others.

- Pedagogical (Instructional) Module - The primary function of the pedagogical module is to use information about the learner's state to generate recommendations (e.g., next course to take) and select instructional strategies (e.g., prompt learner to reflect) to enhance learning. Instructional strategies are passed to the domain module for implementation.

- User Management System (UMS) Module - The primary function of the UMS module is to manage a user session. It is responsible for storing information about the user such as biographical details, in addition to maintaining information about domain sessions. It does not, however, keep scoring records of user's training history. That is handled by the Learning Management System.

- Learning Management System (LMS) Module - The primary function of the LMS module is keep track of a learner's instructional experiences and achievements as part of a history of learning. The GIFT LMS saves the scores of every assessment during every lesson experienced in GIFT.

- Tutor Module - The primary function of the Tutor module is to provide an interface that allows interaction between GIFT and the learner. Often referred to as the tutor-user interface (TUI), this is not a formal module, but is an interface capability.

- Gateway Module - The primary function of the gateway module is to interface with external environments (e.g., game-based simulations). The Gateway Module has interfaces with several applications such as: Distributed Interactive Simulation (DIS) networks, Virtual BattleSpace (VBS) serious game, Augmented REality Sandtable (ARES), Microsoft PowerPoint, Tactical Combat Casualty Care (TC3)/Virtual Medic, and the SCATT Pro Marksman Training Application.

A component of GIFT being utilized specifically for this project is the Engine for Management of Adaptive Pedagogy (EMAP; Goldberg, Hoffman & Tarr, 2015). The EMAP is an underlying pedagogical framework in GIFT based on Merrill's Component Display Theory (CDT; Merrill, 1994). The CDT structures learning across four primary interactions: (1) learning the declarative and procedureal RULES of a domain and its associated concepts; (2) seeing EXAMPLES of those rules applied across various contexts for better understanding of the interacting components; (3) RECALLING those associations on your own based on testing approaches; and (4) PRACTICING the application of those rules within dedicated sceanrios and problem sets. The EMAP then applies personalization strategies within each of those four interactions based on individuals differences stored in GIFT's learner model (e.g., prior knowledge, motivation, self-regularoty ability, grit, etc.). The EMAP also supports automated remediation loops based on performance outcomes in both the recall and practice interactions. The EMAP configurations are housed in GIFT's adaptive courseflow object, which is the integration point for the resulting testbed developed utilizing the Boeing ITS functions.

Description of the Boeing ITS

Boeing's approach to a learner-centered adaptive training implementation has evolved over the course of the past few years. Initial implementations focused on creation of an architecture and authoring solution in support of intelligent tutoring. The product of this effort was Web-based, SCORM®-conformant computer-based training. Details of this approach is provided below.

The Boeing ITS implementation features 3 components (illustrated in Figure 1): a Student Model, an Instructional Model, and an Expert Model. The Student Model implements a profile of dynamically-maintained variables, each corresponding to one learning objective. These variables are evaluated over a number of observations. As a result, changes due to learning are reflected across exercises, as the score increases due to correct performance, or decreases as errors are made. The amount that scores are changed can be weighted according to the degree to which the action reflects mastery of the learning objective. The amount of change is also adjusted according to the degree of support provided to the student by the ITS in selecting this action.

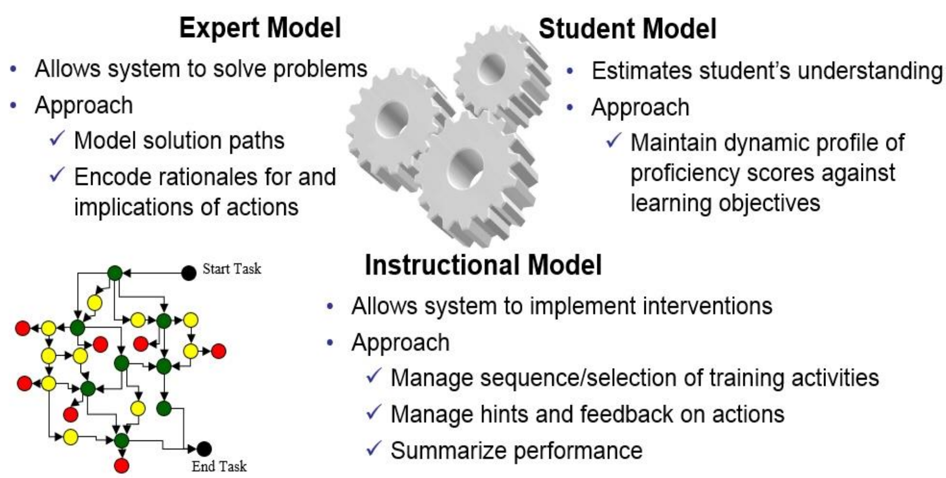

Fig. 1. Overview of ITS modeling approach

The Instructional Model responds to student requests for help or student errors with information on problem-solving strategies. The specificity of the information increases as additional requests are made or additional errors occur. The Instructional Model is also tasked with providing within-scenario feedback to guide the student, as well as performance summaries across all learning objectives at the end of the lesson scenario.

The Expert Model is based on cognitive task analysis technique known as PARI, for Precursor, Action, Results, and Interpretation (Hall, Gott & Pokorny, 1995). PARI provides methods to elicit detailed information from experts on how they represent a given state of a solution (what issues have been resolved and what issues remain), optimal and alternative paths to a solution, and their strategies for selecting actions at each step along those paths. The Expert Model directly encodes these solution paths. For each path, the model also captures the expert's summary of the situation (representation of the problem) and the rationales for the possible next steps. Additional details of the ITS architecture and implementation have been published elsewhere (Perrin, 2009).

Details of the Integrated Prototype

As part of a three-year cooperative research and development agreement, Boeing and ARL have been working to develop an integrated adaptive prototype in which we combine the Army's GIFT adaptive learning framework with the Boeing adaptive learning capabilities. The prototype is based on instructing a student on a basic aircraft maintenance task with aspects of troubleshooting and part replacement. In order to perform the task correctly, the student must understand some basics of electrical safety, as well as multimeter usage. Once they have demonstrated an understanding of those basic concepts, then they are taught the fault diagnosis and repair procedure. Basic lesson flow within GIFT is presented in Figure 2.

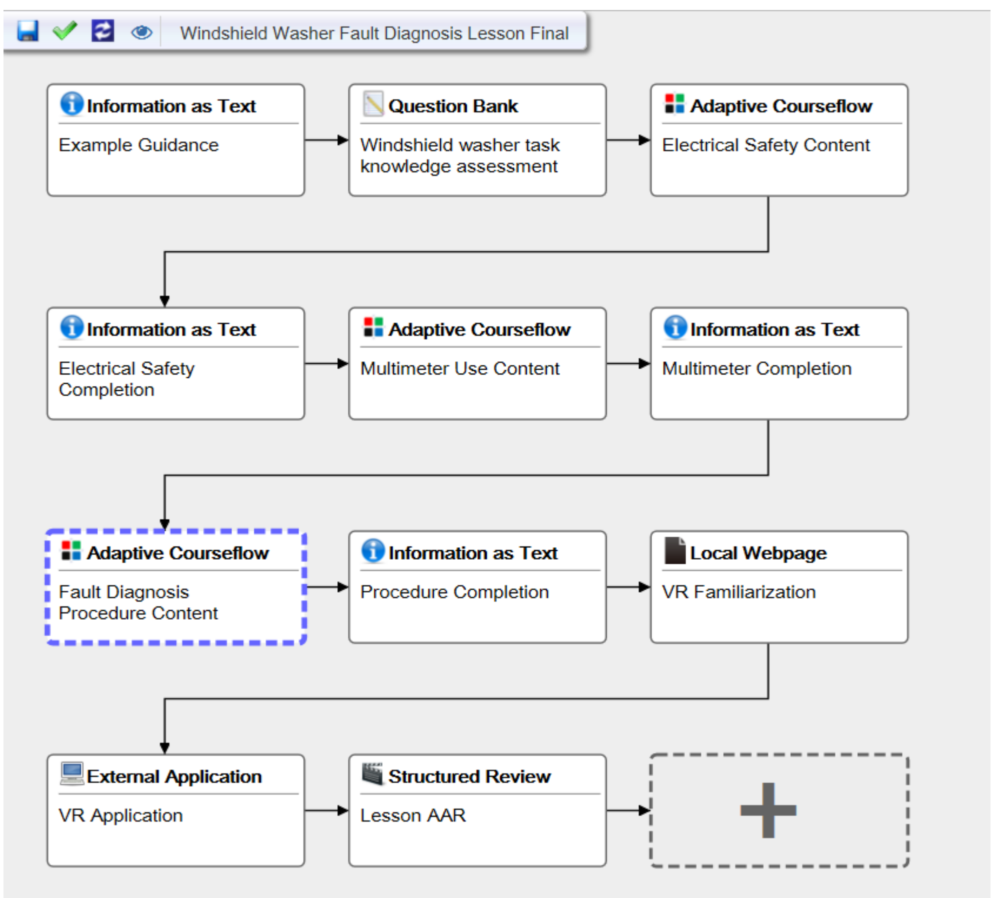

Fig. 2. Lesson flow for the integrated adaptive prototype.

The initial step in the adaptive learning lesson is knowledge assessment based on the course concepts of electrical safety, multimeter use and fault diagnosis procedural knowledge. We employed the Question Bank knowledge assessment functionality within GIFT to assess student understanding on those concepts and to characterize them as a novice, journeyman or expert on each of the three concepts. GIFT then uses those characterizations to sequence course content to the student and to adapt course content based on on-going student parameter characterization as they move through the lesson content. Students are presented with content for the corresponding Adaptive Couseflow Modules (as described above) for each course concept based on their assessed knowledge level. Basic concept rules and examples content was delivered via PowerPoint presentations within the GIFT Adaptive Courseflow Modules. Knowledge checks were presented in GIFT using a subset of the initial Question Bank questions. If the student was deemed proficient, then the Boeing ITS capability provided the practice lesson content for selected learning concepts, launched from within the Adaptive Courseflow Module. While progressing through the practice module for each leaning concept, the ITS adapts within-lesson content to maximize a student's ability to successfully pass the practice portion of the lesson module on the initial attempt. This adaptation included within-lesson remediation on basic concepts if needed. This step is in addition to the normal GIFT content sequencing. GIFT functionality sequences the student through the rules, examples, knowledge check and practice components of each course concept's Adaptive Courseflow Module, and when all are successfully completed, launches the final practice module.

The final evaluated practice module is an external application using Boeing's virtual maintenance training capability (Jacquin, 2016). As part of the final practice assessment, students don a virtual reality (VR) headset, and using two 3D VR hand controllers, they are able to navigate to various places on the aircraft, perform the required troubleshooting tasks while adhering to required safety protocols, diagnose the fault and replace the faulty part (see Figure 3). Automated real-time performance assessment and adaptive learning capabilities within the virtual maintenance training system score the student on targeted learning objectives, provide on-demand student assistance to help locate components, and provide scoring to determine whether the student passes or fails the practical assessment. These final scores on the practical assessment are passed back to GIFT in order to evaluate whether or not the student successfully completed the entire lesson.

Fig. 3. Maintenance trainee performing a task in the virtual maintenance trainer.

At present, the first iteration of the integrated prototype is complete. Current efforts are focused on development of a test plan for the conduct of an adaptive training effectiveness study. Once the design is complete, any required modifications will be made to the adaptive training prototype in support of the effectiveness study.

Initial Test/Study Plan

Plans are in work to evaluate the effectiveness of the Boeing/GIFT prototype using cadets at West Point. The goal is to assess various manipulations of overall curriculum adaptation in an effort to determine which elements are best utilized to optimize student performance. To determine these effeciencie, we are using multiple measures, including: time to competence as measured by performance outcomes, training transfer and knowledge retention.

The plan is to evaluate the combined GIFT/Boeing prototype across a counter-balanced 3x2 experimental design (see Figure 4). The first independent variable is ITS Methods, with three defined conditions: (1) GIFT alone with personalization through the EMAP, (2) Boeing alone, with focused ITS interactions, and (3) GIFT/Boeing prototype that leverages both pedagogical methods. The second independent variable is prior-knowledge, with classification determined by outcomes on pre-test measures. Prior-knowledge will be scored on a concept by concept basis, with GIFT bypassing content on training materials a participant is showing mastery in. One potential option is to randomly assign students to one of those three groups, and then to divide them into high/low competency based on their initial knowledge assessments. Competency is only one of the potential personalization variables that we could use, as GIFT's pedagogical configuration can support strategy determinations across any individual difference deemed worthy to inform personalization. Our initial prototype did not include personalized measures of motivation-based adaptation or personalized feedback based on individual performance. Those are other options we are considering implementing once the study design is finalized.

		Prior-Knowledge	
		High	Low
ITS Methods	GIFT Alone	X	X
	Boeing Alone	X	X
	GIFT/Boeing	X	X

Fig. 4. Preliminary Effectiveness Study Experimental Design.

The outcomes of this study will inform modifications to both the GIFT architecture and Boeing adaptive training approach. These recommended changes will be based on the results of comparative evaluations across performance measures, along with obervations and log-data associated with student interactions and behaviors across all content, assessments and scenarios. New requirements will be defined to better meet the needs of students, with the final year of the CRADA dedicated to instituting those changes.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Throughout the process of blending of two adaptive training solutions into one aggregate prototype, we have learned a number of lessons. There are similarities in the two approaches, as both concepts emphasize development of expertise based on optimizing the learning experience by adapting to the student. While both rely on performance assessment to adapt the lesson, implementations of how each used performance measurement to adapt was different. This led to a number of challenges when merging the two approaches into the combined prototype. On the positive side, we were able to successfully merge these capabilities into a lesson that was seamless from the perspective of the student. We relied on GIFT to perform the initial knowledge assessment, and to determine a starting point within the lesson. For simplicity sake in the initial prototype, we did not attempt to integrate individualized student traits such as motivation or engagement into our pedagogical decisions. We employed the GIFT adaptive modules to sequence through student need-based training, but then employed Boeing's ITS lessons to provide within-module assessments and practice, enabling remediation and practice at a more finite level than that provided by GIFT alone. We also demonstrated the ability to launch an external Unity-based VR practice module from GIFT, and showed that performance within that practice environment could be reported back to GIFT upon completion of the practice exercise.

Along with the positive points, we did identify a number of challenges throughout the course of our development. What follows is a summary of the lessons we have learned along with way.

- With any approach to adaptivity, there are challenges in the implementation of these concepts within a complex task environment. When combining two methods into a single learning solution, there are some additional complexities. For example, the Boeing approach to student assessment and adaptivity was different that the GIFT implementation. In some instances, both adaptation rules could run in parallel, but in other instances, we had to reconcile the different approaches.

- Long-term student record persistence is currently not implemented within GIFT. It would be nice to have the ability to customize lesson content based on a previous lesson learning record, but as of now, all lessons are stand-alone.

- Within a single lesson, we did not have the ability to remediate back to a previous adaptive learning module once it was determined to be mastered by the student. The implementation of our lesson involved completing individual modules and then completing an integrated external simulation exercise which combined aspects of multiple learning concepts. It would be nice to have the ability to remediate the student back to the individual adaptive module if they failed a concept during the final practice. Or, as mentioned previously, to record that failure as a persistent record and then be able to re-launch the lesson and repeat those modules where the student struggled during the final assessment.

- There was no GIFT standard for communicating with external applications. Interfacing external applications with GIFT required the creation of custom gateway modules which involved the implementation of message passing and parsing. Certain naming and scoring conventions between the external application and GIFT domain knowledge files were not intuitive. There was a lot of trial and error to make the process flow as desired. As GIFT becomes more pervasive and others attempt to interface with their existing applications, it would be beneficial to have a more standard approach to communicating with external applications.

- We had a number of usability issues as we initially began to author in GIFT. Some of those were due to bugs in the tool, while others were attributed to complexities in working with external applications. Specifically, we had issues running GIFT behind a proxy. In order to run the authoring tool behind the Boeing firewall, we had to disconnect from the internet and run it in offline mode. We also had difficulties due to size limitations in importing and exporting large lesson files. Users of GIFT could benefit from improved documentation or lessons on how to author.

- Limitations of older technologies within The Boeing-developed applications (e.g. Flash-based lesson playback) made for some complexities in how those lessons were integrated and displayed within GIFT.

We have learned through experience that there are strengths and weaknesses of different approaches to modeling students, providing feedback, and adapting content. As we continue to develop and test the overall effectiveness of adaptive learning in the coming year, we hope to capitalize on the best of each approach in creating a mutually beneficial joint solution.

REFERENCES

Anderson, J.R., Corbett, A.T., Koedinger, K.R., and Pelletier, R. (1995). Cognitive Tutors: Lessons Learned. *The Journal of the Learning Sciences. 4(2)*: 167-207.

Bloom, B. S. (1984). The 2 sigma problem: The search for methods of group instruction as effective as one-to-one tutoring. *Educational Researcher, 13,* pp. 4–16.

Cohen, P.A., Kulik, J.A. and Kulik, C-L. (1982). Educational Outcomes of Tutoring: A Meta-analysis of Findings. *American Educational Research Journal*. 19:237.

Graesser, A. C.; Person, N. K. (1994). Question Asking During Tutoring. *American Educational Research Journal, 31,* 104–137.

Hall, E.M., Gott, S.P., & Pokorny, R.A. (1995). A procedural guide to cognitive task analysis: The PARI methodology. *Technical Report No. AL/HR-TR-1955-0108*. Brooks AFB, TX: AFMC.

Hunt, E. and Minstrell, J. (1994). A collaborative classroom for teaching conceptual physics. In K. McGilly (Ed.), *Classroom lessons: Integrating cognitive theory and classroom practice. Cambridge: MIT Press*

Jacquin, G. (2016). V-22 Maintenance System. St. Louis, MO: *Boeing Technical White Paper*.

Lesgold, A., Lajoie, S., Bunzo, M., & Eggan, G. (1988). SHERLOCK: A coached practice environment for an electronics troubleshooting job. *Technical Report: University of Pittsburgh, Learning Research and Development Center.*

Perrin, B. (2009). Intelligent Tutoring Systems: Facilitating Learning While Holding to Standard Practice. *Paper presented at the International Training and Education Conference,* Brussels, Belgium.

Perrin, B., Buck, B., Dargue, B., Biddle, E., Stull, T., & Armstrong, C. (2007). Automated Scenario-Based Training Management: Exploring the Possibilities. Orlando, FL: *Proceedings of the Interservice/Industry Training, Simulation, and Education Conference.*

Sottilare, R., Brawner, K., Sinatra, A. & Johnston, J. (2017). An Updated Concept for a Generalized Intelligent Framework for Tutoring (GIFT). *Technical Report No. DOI: 10.13140/RG.2.2.12941.54244.* Orlando, FL: US Army Research Laboratory.

ABOUT THE AUTHORS

Dr. Barbara Buck *is a research psychologist in Innovation & Product Management, part of the Boeing Global Services' Training and Professional Services organization. Her recent efforts have focused on adaptive training, including integration adaptive training methods into lower-cost desktop solutions as well as more complex gaming and live simulation exercises. She has been instrumental in developing the Boeing adaptive authoring capability, and has conducted effectiveness research to evaluate the efficacy of adaptive training approaches, virtual reality applications and physiological measures of performance. Barbara holds a Ph.D. and Master's Degree in Cognitive and Engineering Psychology from the University of Illinois.*

Matthew Genova *is a software engineer at Boeing whose current focus is developing virtual reality and augmented reality applications. He has developed adaptive learning software and was instrumental in creating the custom gateways enabling Boeing adaptive learning technology to interface with GIFT. He is part of the Innovation & Product Managmeent team in the Boeing Global Services' Training and Professional Services organization. He holds a Master's Degree in Computer Engineering from Washington University in St. Louis.*

Dr. Robert Sottilare *leads adaptive training research within ARL's Learning in Intelligent Tutoring Environments (LITE) Lab and is a co-creator of the Generalized Intelligent Framework for Tutoring (GIFT). He is ARL's technical lead for the Center for Adaptive Instructional Sciences (CAIS).*

Dr. Benjamin Goldberg *is an adaptive training scientist at the Army Research Laboratory's Human Research and Engineering Directorate. He leads research focused on instructional management within ARL's Learning in Intelligent Tutoring Environments (LITE) Lab and is a co-creator of the Generalized Intelligent Framework for Tutoring (GIFT).*