U. S. ARMY MATERIEL COMMAND'S INTELLIGENT TUTORING SYSTEM TECHNOLOGY BASE PLAN

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ABSTRACT

The Army Technology Base Master Plan identifies the emerging field of artificial intelligence as a technology with high potential to meet the Army's changing needs for fixing, manning, and arming the forces into the next century. In late 1990, the Army Materiel Command's Deputy Chief of Staff for Technology Planning and Management directed a comprehensive master plan for artificial intelligence be developed. This plan serves as a framework from which the Army Materiel Command can manage and execute AI technology development into the 21st Century. The AI Master Plan identifies 13 technology areas considered most relevant to the Army needs. This paper addresses one technology area in the AI Master Plan, Intelligent Tutoring Systems. This is a plan within the master plan and provides a vision and specific direction for closing the gap between today's reality and tommorow's expectation for Army training systems.

INTRODUCTION

In April 1989, the Army published the Army Technology Base Master Plan. The Plan provided guidance to the Army Laboratories and Research Centers to focus the technology base on the most critical war fighting needs. The plan directive is to support force modernization programs while preserving and enhancing our technological superiority over potential adversaries. The Technology Base Master Plan recognized the technology base as an essential corporate investment in the Army future. It also contains the Technology Base Investment Strategy for realizing the leadership's vision of the future Army support for Commander-in-Chief warfighting needs.[1] By identifying a particular area as a key emerging technology, the Army signals its intention to (1) provide sufficient funding for progress on a broad front, (2) stabilize this funding so that laboratory activities can be planned properly, (3) ensure that the technical staff has developed concrete plans, and (4) provide a mechanism by which management can review important areas across organizational boundaries.

Artificial Intelligence (AI) has been identified and designated in the Technology Base Master Plan as one of the 13 key emerging technologies that have been recognized as having a greater impact than other technologies on future warfighting capabilities. The combination of AI being recognized as a critical emerging technology and the specific need for a concrete plan is the motivation for the development of the Army Materiel Command's (AMC's) AI Master Plan.

Given these stated conditions, the objective of this paper is first to inform other government agencies and industry that the Army's AMC is taking decisive steps to organize and focus on AI based technology based activities. A second objective is to review a conceptual framework for conducting research and development on Intelligent Tutoring Systems (ITS). A third and final objective is to provide a brief vision of intent for advancing and applying ITS technology development to meet Army training needs into the 21st Century.

ARMY MATERIEL COMMAND'S AI TECHNOLOGY BASE MASTER PLAN

Objectives

The AMC AI Master Plan addresses the contribution that AI technologies can make to the AMC and Army systems. It emphasizes uniformly the AI technology development, transition, and application phases. It encompasses the research, development, and application activities, as well as, the application of AI to manufacturing, testing, and logistics. The broad objectives of the master plan serves the following purposes:

a. Construct a framework for AI research and development in the organization,

b. Serve as inputs to the AMC Technology Base planning,

c. Catalogue significant current and future AI and AI related projects,

d. Identify AI resources availability and needs,

e. Coordinate all AI projects and activities internally within and externally among various organizations,

f. Demonstrate paths to acquiring skills, services, products, and facilities,

g. Evaluate offers of help from outside agencies,

h. Show ways of applying AI in devices, systems, and services,

i. Demarcate the role of AI by AMC missions, objectives, and goals,

j. Identify funding needs to realize full gain from AI,

k. Identify synergy of AI with other technologies and projects,

l. List benefits and risks of AI systems.

Emerging AI Technologies

In 1956, a group of scientists assembled at Dartmouth College coined the term "Artificial Intelligence" to describe a vaguely defined but emerging technology. The collective initiatives of this group of pioneering scientists resulted in what today is identified as Artificial Intelligence or AI. During the almost four ensuing decades some elements of artificial intelligence have made the transition from the often mysterious topic reserved for laboratory and university research to commercial applications. While most of the early prediction on the achievements of AI fall short of expectations, some areas of the emerging technology have achieved widespread recognition. Key application areas of AI technology include: expert systems, computer vision, natural language processing, speech interfaces, problem solving and planning. Expert systems was the first sub-component of AI technology to achieve a moderate amount of commercial success. The successful development and application of expert systems technology is detailed in The Rise of the Expert Company.[2]

During the last decade DARPA's Pilot Associate and Battle Managements Programs[3] are examples of programs that are focal points of intense development and application of AI technologies. More than 40 Army centers, laboratories, and agencies have indicated either an interest or have AI related activities in ongoing program efforts.

In early 1989, AMC leadership initiated the effort to develop the AI Master Plan. Major subordinate commands were asked to provide inputs to the plan. Technology areas most relevant to the Army needs were defined during ensuing workshops, working sessions, high level straw man plans development, product and specific technical area reviews. The thirteen AI technology areas determined to be most relevant to the Army's needs into the 21st Century are indicated in Table 1. As shown, some technology areas include more than one technology. As expected, the boundaries between the technology areas overlap considerably.

ARTIFICIAL INTELLIGENCE TECHNOLOGIES MOST RELEVANT TO ARMY NEEDS	
1.	EXPERT SYSTEMS KNOWLEDGE LEVEL REASONING, MACHINE LEARNING
2.	NATURAL LANGUAGE AND SPEECH RECOGNITION AND INTELLIGENT INTERFACES
3.	INTELLIGENCE VISION AND IMAGE UNDERSTANDING
4.	INTELLIGENT DATABASE AND COMMUNICATIONS
5.	INTELLIGENT SENSOR AND DATA FUSION
6.	AUTONOMOUS SYSTEMS AND INTELLIGENT CONTROL
7.	INTELLIGENT PLANNING
8.	INTELLIGENCE SIMULATION
9.	AUTOMATIC PROGRAMMING
10.	INTELLIGENT MANUFACTURING AND CONCURRENT ENGINEERING
11.	INTELLIGENT TUTORING SYSTEMS
12.	AI TECHNIQUES, HARDWARE, SOFTWARE, AND NEURAL NETWORKS
13.	LOGISTICS FOR AI APPLICATION

Table 1. Artificial Intelligence Technologies Most Relevant to Army Needs

Along with the plan, a definition was necessary. The AMC AI Master Plan defines Artificial Intelligence as "..computer software that exhibits characteristics which when exhibited by humans, will be recognized as intelligent".

Impact of AI on Army Systems

The AI technologies were considered for impact on Required Technical Capabilities for all systems and operations in the Army's battlefield mission areas (including modernization), system development, logistics, and training. The process involved in the review is depicted in Figure 1. As indicated, training is identified as a function that

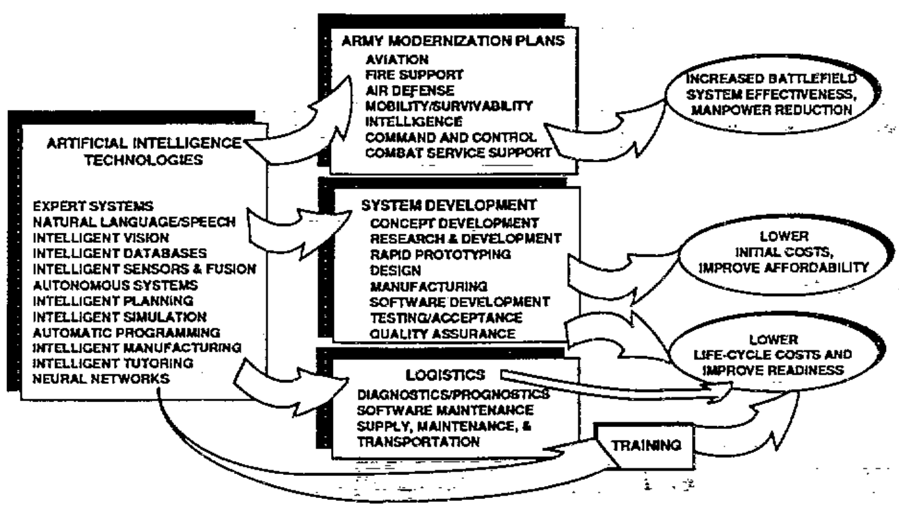

Figure 1. Impact of AI Technologies on Army Missions

impacts all areas of the Army missions including system effectiveness, affordability, and readiness.

A second element in the Master Plan strategy is to distribute the research and development of the AI technologies among the AMC laboratories and research centers. Interested organizations were invited to submit a proposed program of activities, including background on previous AI technology research and development efforts. Teams were formed to pursue technology development in the identified AI technology areas. A technologist from each team was selected to perform as an AMC technology leader. AMC player groups and AMC leaders have been estabished for each of the technologies listed in Table 1. A major objective and responsibility of the AMC technology leader is to plan and prepare for coordinating and leveraging efforts ongoing in other commands, universities, national laboratories, and agencies in the civilian sector.

Technologists from the U.S. Army Missile Command Redstone Arsenal, AL were designated as AMC leaders in the technology areas of Intelligent Tutoring Systems (ITS) and Neural Networks. The focus of the remainder of this report is on the AMC Master Plan for Intelligent Tutoring Systems.

INTELLIGENT TUTORING SYSTEM MASTER PLAN

The vision for the Intelligent Tutoring System Master Plan is to advance and apply the state-of-the-art in ITS to meet the training needs of the Army into the 21st Century. Having stated this, we need to identify, with minimum explanation, a justification for the application of AI to education, tutoring, and training in support of traditional teaching and training methods.

The 2-Sigma Problem

A recent study by B. S. Bloom confirmed the effectiveness of tutoring in small groups with an expert tutor.[4] Using average performances of the control group, results from this research indicates that a teacher presenting material to 20-100 students is one of the least effective methods for educational delivery. Improved results are obtained when the expert teacher not only gives a lecture but involves diagnostic tests to identify where the student might have problems and misconceptions with the subject matter. Student performance in this educational setting is in the 84th percentile compared to the traditional trained student of 50-60th percentile. The most significant results of this study are the results that show the students involved in one-on-one tutoring performs at the 98th percentile or 2-Sigma beyond the conventional teaching. These results from Bloom's study are depicted graphically in Figure 2.

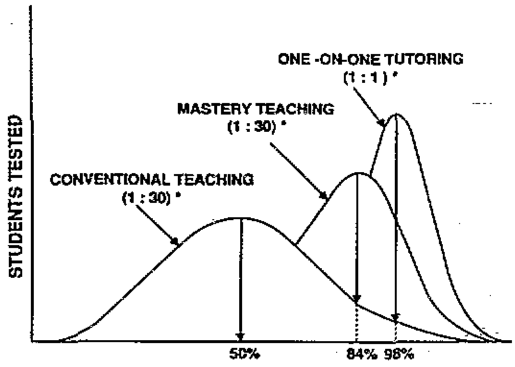

Figure 2. Advantage of One-to-One Tutoring (Bloom 1984)

The results from the Bloom study further confirms the need for a system for education that will facilitate achieving the effectiveness that can be accomplished with a one-to-one human expert tutor/teachers. The resource intensive nature of one-on-one human tutoring precludes this approach from being used except for very special circumstances. What is needed is a device or technology based system that emulates the capabilities and characteristics of a human tutor with wide scale availability and suitability.

Intelligent Tutoring System

During the 1960's the use of the computer in the educational environment was the computer assisted instruction (CAI) system. The goal of the CAI approach to computer use was to produce and present the learning environment with explicit control of the student's learning. While CAI system grew to operate in very complex teaching environments, the challenge of achieving the intended goal was more than could be handled with the basic CAI approach.

Early uses of AI techniques in CAI operation were called generative CAI systems since they stressed the ability to generate problems from large data bases representing the subject they taught. Reactive learning CAI produced an environment in which the student is actively engaged with the instructional system and his interest and misunderstandings drive the tutorial dialogue. With increased emphases on knowledge-based operations and more complex models of the student evolved to drive the system operation, Intelligent CAI (ICAI) became the focus of development efforts.

With the increased use of multiple knowledge bases, cognitive models for reasoning about the student understanding of the domain being taught, ICAI advanced to a threshold identified as intelligent tutoring systems (ITS). Intelligent Tutoring Systems, edited by Sleeman and Brown[5] include papers identifying emerging concepts that provide foundations that drive much of the present day research in ITS. The general trend of ITS theory and development during the past decade is indicated in: Foundations of Intelligent Systems, edited by Polson and Richards[6], Intelligent Tutoring Systems, Lessons Learned, edited by Psotka, etc.[7], and Intelligent Tutoring Systems, Evolutions in Design, edited by Burns, etc.[8].

Intelligent Tutoring System Technology Development

Limited but realizable educational goals have been achieved with ITS in specific areas of training and skill transfer using presently available technologies, see Woolf[9]. The combined technologies of artificial intelligence including: learning models developed in cognitive science; software and symbolic computing architectures developed in Computer Science; the increased cost-benefit ratio of modern microchip based computing are direct contributors in developing currently available intelligent tutoring systems. Additional details on ITS technology base needs will be described in other sections of this paper.

Present activities in the use of AI in the development and application of ITS can be viewed as having two fundamental but different thrusts; one, the focus on the use of ITS with education, including basic principles for grade school and/or college; second, the use of the ITS principles to provide training with skill and knowledge sustaining for a particular domain.

While these two approaches share common principles, the thrust of ITS architectural development places major emphasis on different functional operations. An example, one difference can be viewed as to the degree that emphasis is placed on the transfer of knowledge and the transfer of skills. Skills and knowledge are not independent entities but the degree of emphasis on each entity and the particular performance environment produces different system structures. Intelligent tutoring systems used in applications in an educational environment, which generally has a focus on knowledge transfer, the element of time, in the sense of real-time, are rarely considered. Intelligent Tutoring Systems with a focus on knowledge and skill sustaining, reasoning about problems with real-time applications are critical elements in the learning environment. An example indicating the challenge in teaching real-time tactical thinking is reported by Ritter and Feurzieg.[10]

There are no clearly defined boundaries in the application of ITS for training versus tutoring. While education pays attention to both skills and knowledge, the literature frequently uses the terms training and tutoring interchangeably. As our understanding of what is required in the transference of expertise from expert to novice, and teaching higher order reasoning skills, the boundary between training and tutoring will become less definable. Where it may be deemed appropriate and for definitional purposes here, the application of an ITS for tutoring versus training will be characterized by the degree of modeling as to how the human solves the problem. As will be shown in other sections, this focus on modeling human problem solving increased the reliance on cognitive modeling and requires a flexible architecture for implementing the top level ITS modules.

ANATOMY OF AN INTELLIGENT TUTORING SYSTEM

The anatomy of an ITS can be characterized as consisting of a combination of top level modules. For purposes of focusing on research issues, researchers have identified ITS top level modules to include: human-machine interface; instructional module; diagnostic module; and the domain expert module. Each module is characterized and expanded to include functions that are shaped by special applications and interests of the researcher. The functional structure of the top level modules are depicted in Figure 3.

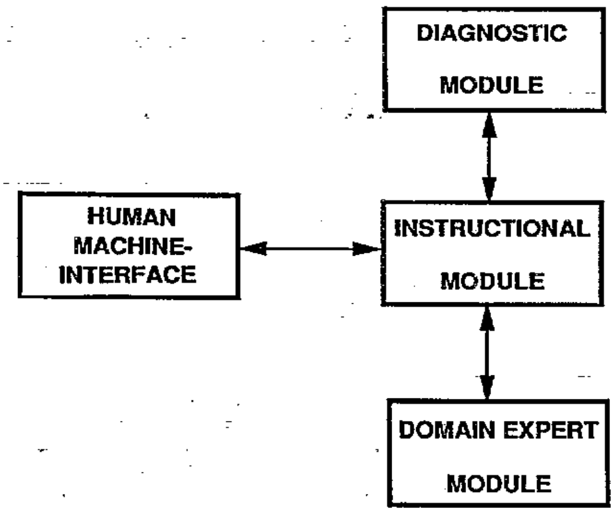

Figure 3. Intelligent Tutoring System Top Level Modules

The transfer of complex knowledge and skills to a student requires an extremely flexible intelligent human-machine interface (IHMI). The IHMI is an integral part of a user conscious system and must maintain knowledge about the user, which includes: what are the preferred methods of interaction; what are the interest, values, and goals of the student; what are the expectation and assumptions of the user? This includes a user dependent knowledge base or user model that would be shared with other ITS knowledge operations. Many factors have been identified for knowledge based systems not being effectively used outside the laboratory and development environment. The human-machine interface has been identified as the most consistent source responsible for rejection of the system by the user.

The instructional module (IM) generates the environment that emphasizes conceptual understanding, levels of abstraction and concept fidelity appropriate to provide the learner with motivation. This module includes the ability to reason about appropriate tutoring strategies for achieving effective and efficient learning for a particular student with individualized learning objectives. An integral part of the IM is the generations of appropriate domain knowledge which could include the use of intelligent simulations. Simulations are used to support task generation and presentation to the student in support of curriculum and instruction operations.

The diagnostic module (DM) has a focus on developing a model of the student or learner's current state of knowledge. Effective tutoring requires the student response to an instruction be compared to the domain expert's response. Differences are analyzed and deficiencies are identified with appropriate knowledge generated for adding to a knowledge structure, or student model, that reflects the user's current state of knowledge about the domain. The student model knowledge is used to identify tutoring strategies, curriculum and instructions to satisfy individual learning objectives of the particular student. It is this feature that gives ITS a unique advantage over other computerized learning systems.

Capturing and encoding the domain knowledge in the expert module (EM) is one of the major tasks in developing ITS. The knowledge in the domain expert module is one of several knowledge bases that can have common usage in an ITS. The expert modules include an expert system with special features that can be necessary for ITS operation. Different types of knowledge, i.e., procedural, declarative, and qualitative, dictate instruction strategies. Options should be available for knowledge representation and reasoning about that knowledge. Constructing an architecture for the expert domains required for ITS operation remains a major challenge in ITS development.

While the ITS can be viewed as modular structured for purposes of research and development, the heart and soul of future ITS will be characterized by the seamless operation of: qualitative reasoning and planning, integrated operation of distributed knowledge bases, and learning and discovery environments for student motivation.

ENABLING TECHNOLOGIES FOR ITS DEVELOPMENT

The ITS can be viewed as a modular structured system with top level modules as identified above. ITS can also be viewed as a tool for educational purposes for teaching basic principles and supplying encyclopedic knowledge bases for the student. Research and development during the past two decades have produced a number of intelligent tutoring systems for specialized domains. Lessons learned from Army sponsored research are providing undeniable indicators that ITS technology trends are moving toward developing training systems with specialized domains of operation (see References 7, 11, and 12). Results from these demonstration models are twofold: first, that effective ITS in limited domains can be constructed; second, progress in developing effective ITS requires advancements and building on past accomplishments in both theory and technology on broad fronts. The enabling technologies include high speed knowledge computing, speech understanding and speech recognition, real-time knowledge based systems, semi-automatic knowledge acquisition and knowledge representation methods, intelligent simulations, intelligent planning, intelligent communication between parallel knowledge systems, and architectures for modular structures operation.

The use of enabling technologies is critically important for present system implementation and future systems development. This implies a close coordination and active support for technologies that are now identified as emerging and technology groups identified and characterized as AI subtechnology areas. This also includes supporting some technology areas not directly identified in the present AI technology base, i.e., cognitive modeling. The complementary nature of enabling technologies that require continuing development for present and future ITS are indicated in Figure 4.

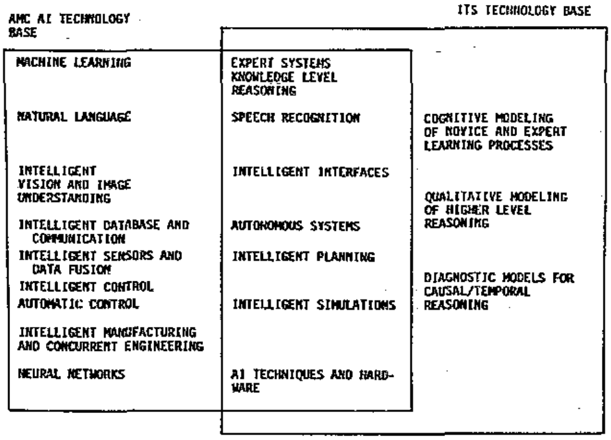

Figure 4. Intelligent Tutoring System Technology Base

VISION FOR AMC AI INTELLIGENCE TUTORING SYSTEMS

The goal of the Master Plan is to promote and advance the development and application of Intelligent Tutoring Systems to meet the Army needs. Three objectives are identified in support of this goal: advance the state-of-the-art in ITS; apply the state-of-the-art in ITS; and identify and implement major thrusts to further facilitate advancing and applying the state-of-the-art in ITS. The functional requirements within the established objectives are identified as: near term, 1 to 2 years; mid-term, 3 to 7 years; long term, and 8 to 17 years. A summary of the near, mid, and long term activities identified in the ITS Master Plan for meeting Army training needs are shown in Table 2.

	ADVANCING STATE-OF-THE-ART IN AREAS OF:	APPLYING STATE-OF-THE-ART AREAS OF:
NEAR TERM	GENERIC ITS ARCHITECTURE FOR INDIVIDUAL AND CREW TRAINING TOOLS FOR REAL-TIME ITS IMPLEMENTATIONS MODELING FOR TEMPORAL REASONING AND REASONING UNDER CERTAINTY COGNITIVE MODELING FOR TEACHING, LEARNING AND CAUSAL REASONING	ANALYZE ARMY TRAINING REQUIREMENTS PROTOTYPE DEVELOPMENT OF ITS WITH GENERIC ARCHITECTURE FOR INDIVIDUAL TRAINING VERIFICATION AND VALIDATION OF ITS OPERATIONS
MID-TERM	SHELL ARCHITECTURE DEVELOPMENT FOR REAL-TIME ITS APPLICATIONS MODULAR GENERIC ARCHITECTURE FOR FORCE LEVEL TRAINING SYSTEMS ADAPTIVE HUMAN-MACHINE INTERFACE USING STUDENT-BASED SENSOR DATA COGNITIVE MODEL DEVELOPMENT FOR KNOWLEDGE AND SKILL TRANSFER	DEVELOP ITS TECHNOLOGY DEMONSTRATION FOR INDIVIDUALIZED OPERATOR TRAINING SYSTEM DEVELOP ARCHITECTURE FOR ITS OPERATING AS AN EMBEDDED TRAINING DEVICE
LONG TERM	MICRO-CHIP TECHNOLOGY FOR ITS DELIVERY PLATFORM THEORY AND ARCHITECTURE DEVELOPMENT FOR REAL-TIME ITS WITH MULTIPLE AND DISTRIBUTED KNOWLEDGE BASES COGNITIVE MODELING FOR DIAGNOSTIC EVALUATION OF STUDENT'S MENTAL MODEL, MISCONCEPTS AND REASONING	DISTRIBUTED ITS FOR TEAM TRAINING WITH CREW MEANDER GEOGRAPHICALLY DISPLACED DEVELOP PORTABLE, PERSONALIZED ITS ADAPTABLE TO SPECIALIZED DOMAINS WITH MODULAR COMPONENTS FOR DOMAIN KNOWLEDGE

Table 2. Research and Development Activities for ITS Development

MAJOR TECHNOLOGY THRUST IN ADVANCING ITS DEVELOPMENT

Confirming cost-benefit ratios and assessing risk factors is a major issue in technology development programs. The major technology thrust program for ITS is a development effort that will demonstrate the confluence of AI technologies in advancing ITS development. The focus of the program is to enhance the development and implementing the functionality of the top level modules described in a previous section. The ITS technology thrust program includes three elements: an ITS architecture development effort for implementing and integrating the top level ITS modules to meet Army training needs; a shell for use in a development environment which includes developing and implementing ITS functions; a micro-chip based ITS for accomplishing symbolic/numeric processing in a delivery environment. A summary of the major elements in the major thrust in advancing ITS development is indicated in Table 3.

ARCHITECTURE
• ANALYZE ARMY TRAINING REQUIREMENTS
• KNOWLEDGE ACQUISITION AND REPRESENTATION IN MULTIPLE DOMAINS
• REAL-TIME OPERATIONS
• COGNITIVE MODELING
SHELL
• ITS PROGRAM DEVELOPMENT ENVIRONMENT
• INTEGRATION OF ITS FUNCTIONS
• INTELLIGENT MAN-MACHINE-INTERFACE
MICRO-CHIPs
• SYMBOLIC/NUMERICAL PROCESSORS
• ARCHITECTURES TO SUPPORT DELIVERY ENVIRONMENT
• MAN-MACHINE-INTERFACE
• REAL-TIME ARCHITECTURE

Table 3. Major Thrust in ITS Development

THE VISION CONTINUES

The development and application of AI technologies to ITS development has been an ongoing effort at MICOM Research, Development, and Engineering Center since 1984. An early cost-benefit analysis was conducted for developing an ITS for a major fielded air defense system. Returns on investment (ROI) were estimated at 7.3. This ROI figure is significant only when based on the degree of realism injected in the evaluator's viewpoints. Returns on investment were based on an economic life of

15 years and manpower reductions associated with training and maintaining critical skills for 100 fielded units. An unspoken assumption in this ROI calculation was that human expert trainees/tutors were available to accomplish the training task and the use of ITS reduced the manpower required to train the student. A more realistic situation is to consider skills that are required but not adequately taught in an institutional or fielded environment due to the lack of the availability of human expert trainers/tutors.[13] An ITS approach would not totally correct this situation, but would significantly improve the conditions. With this viewpoint included in cost benefit calculations, the ROI would increase significantly. This additional factor, however, requires answering the question "What is the cost of not being trained?"

This brief overview of the AMC AI Master Plan also includes a more detailed look at a program for advancing the technology of intelligent tutoring systems. Presently, this is a continuing effort in the planning stage and not readily subject to a conclusion, so the vision continues. The AMC ITS Master Plan is specifically directed toward advancing the state of the ITS technology to satisfy Army training needs. Developing ITS is worth the investment if this technology found application only in this domain.

The need to address the 2-Sigma problem extends beyond the boundary of military needs. The need for an effective teaching system is urgently needed at all levels of our population. If we accept reports about the state of education in our society -- education is in trouble. The slow decline in achievement scores is indicative of the need for a new approach in education. A fully developed ideal intelligent tutoring system will not solve all the problems of education and training. However, in the process of developing such devices, most interesting and exciting challenges lie ahead. These are but a few of the fascinating opportunities provided by these new machines.

ABOUT THE AUTHORS

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