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ABSTRACT

This paper is part of an Air Force planning effort to develop a research, development, and applications program for the use of artificial intelligence (AI) technology in three target areas: training, performance measurement, and job performance aiding. The paper is organized in five sections that (1) introduce the reader to AI and those subfields of AI that are most relevant to this program, (2) report on relevant ongoing research and development sponsored by the Department of Defense, (3) establish the challenges facing the Air Force in three target areas and explain how each presents opportunities for AI applications, (4) draw out important practical concerns that must be faced by an AI research and development program, and finally, (5) propose a set of recommendations for building an Air Force AI applications program in training, performance measurement, and job performance aiding. An eight-page bibliography and a list of current relevant Department of Defense research projects are included in the report. (Author/KC)

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HUMAN RESOURCES

ARTIFICIAL INTELLIGENCE: AN ANALYSIS OF POTENTIAL APPLICATIONS TO TRAINING, PERFORMANCE MEASUREMENT, AND JOB PERFORMANCE AIDING

By

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TRAINING SYSTEMS DIVISION
Lowry Air Force Base, Colorado 80230

September 1983

Interim Report for Period September 1982 – July 1983

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The Public Affairs Office has reviewed this paper, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This paper has been reviewed and is approved for publication.

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This paper is part of a planning effort to develop a research, development, and applications program for the utilization of artificial intelligence (AI) technology in three target areas: training, performance measurement, and job performance aiding. The paper (a) introduces the reader to AI and those subfields of AI that are most relevant to this program, (b) reports on relevant ongoing research and development sponsored by the Department of Defense, (c) establishes the challenges facing the Air Force in the three target areas and explains how each presents opportunities for AI applications, (d) draws out important practical concerns which must be faced by an AI research and development

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ARTIFICIAL INTELLIGENCE: AN ANALYSIS OF POTENTIAL APPLICATIONS TO TRAINING, PERFORMANCE MEASUREMENT, AND JOB PERFORMANCE AIDING

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Chief, Skills Development Branch

This interim report documents a segment of a larger technical program.
It is published in the interest of scientific and technical information exchange.

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CHAPTER I. INTRODUCTION

Artificial intelligence (AI) is one of the emerging technologies of the 1980s. AI is the use of computers to perform tasks typically considered to require intelligence. This form of computing concerns the manipulation of symbols which encode the knowledge and the competence to perform intelligent acts, rather than the familiar form of computing that concerns numerical calculation and record keeping.

Almost all computing done today involves numerical calculation; for example, work in the physical sciences and engineering. However, a vast amount of human productivity involves symbol manipulation: solving legal problems, making medical diagnoses, designing systems, or planning genetic engineering experiments. Edward Feigenbaum has said (Swaine, 1983, p. 12), "Symbolic manipulation will become the dominant type of computer use simply because there are so many more things to be done compared with mere calculation." When will this happen? Feigenbaum predicts, "if not by 1990, perhaps by the turn of the century." Think of the absolutely vast amount of computation that goes on today, and then imagine that amount of computing, or more, being devoted to symbol manipulation. This is the future of AI.

At this level of generality, the requirements of the Air Force and of the other Armed Services are no different from society at large: much work that needs to be done is symbolic in nature. This report focuses on computer applications to the inherently symbolic (as contrast to computational) tasks of designing, developing and delivering instruction; monitoring and assessing personnel performance; and assisting personnel in the performance of their jobs. That is, the operations and maintenance of Air Force systems provide both challenges and opportunities for the application of AI technology.

Background of This Report

This paper is the first step in a 9-month program planning effort, tasked to develop a research, development, and applications program for the utilization of artificial intelligence technology in training, performance assessment and job performance aiding. The objectives of this paper are (a) to introduce the reader to AI and those subfields of AI that are most relevant to this research and development (R&D) program, (b) to report on relevant ongoing R&D sponsored by the Department of Defense (DoD), (c) to establish the challenges facing the Air Force in the three target areas and explain how each presents opportunities for AI applications, (d) to draw out important practical concerns which must be faced by an AI R&D program, and finally, (e) to draw this analysis together by proposing a set of recommendations for building an AI applications program in training, performance assessment and job performance aiding.

Capsule History of AI

The brief history of AI spans about 25 years. Early projections of competent AI applications in language translation and chess were disappointments; AI proved to be much harder than expected. Understandably, a backlash of skepticism was generated by these early failures. But, AI profited from experience. Its research thrust was redirected. It was recognized that computational brute force and generality are not the keys to solving important problems. The beginning of AI's success story was the recognition that knowledge powers the solution to important problems.

By the late 1970s, this redirection brought success to AI research endeavors. AI programs were developed that performed successfully or demonstrated promise in a number of different applications areas; for example, medical diagnosis, speech understanding, spectroscopy, and symbolic mathematics. By 1980, the potential of AI was recognized, and active AI research programs were underway in several large corporations. In 1981, Japan announced a major commitment to AI applications with its fifth generation computer project. The first AI applications business ventures were launched. By 1982, AI could be considered to be entering a period of industrialization and public awareness. Numerous AI business ventures had been launched and the promise of AI had been touted in at least six major broad circulation periodicals.

Thus, AI's time has come. An examination of potential AI applications in the DoD in general, and in training, performance assessment, and job performance aiding in particular, is timely and justifiable.

Artificial Intelligence

Definition

AI is the study and application of what is known about intelligence to the development of computer systems that model intelligent behavior. Intelligent behavior involves tasks for which algorithmic solutions do not exist. Such tasks often involve complexity (designing a bridge), uncertainty (deciding whether to buy or sell on today's stock market) or ambiguity (filling in the details while reading a novel). Usually, a controlled search, rather than a random or exhaustive search, for a solution is necessary. Great amounts of knowledge are typically required for successful performance. AI is concerned with several types of knowledge, principally procedural knowledge (how-to-do-it), declarative knowledge (knowledge of function or structure), and control knowledge (general problem solving strategies).

Research in AI is being conducted in two disciplines with complementary objectives: computer science and cognitive science. As a branch of computer science, the study of AI seeks to develop new tools and new techniques that will support the use of computers to do tasks that require intelligence. As a major branch of the emerging discipline of cognitive science, the study of AI serves to provide controlled environments for experimenting with methods and tools used in studying human intelligent behavior.

> The major source of knowledge (about intelligence) is the experimental study of human behavior to discover mechanisms, followed by construction of simulation systems (e.g., computer programs) to verify whether the discovered mechanisms do indeed have the properties inferred. (Newell, 1973, p. 14.)

As humans, we are our own best exemplars of intelligent behavior. By following our example, we are learning how to teach machines to help us do our work.

AI Elements

Representing knowledge and techniques for processing knowledge are the two basic elements of AI.

Depicting, symbolizing, structuring and communicating knowledge have clearly become a focus in the short history of AI:

> The fundamental problem of understanding intelligence is not the identification of a few powerful techniques, but rather the question of how to represent large amounts of knowledge in a fashion that permits their effective use and interaction. (Goldstein & Papert, 1977, p. 85)

The second element, processes that operate on representations, is predicated on the principle that intelligent behavior is objective-directed or goal-seeking (e.g., in problem solving . . . a solution; in speech understanding. . . meaning; in medical consultation . . . a correct diagnosis and prescription). The attempt to reach a goal requires first creating, then searching an "area" or space within which the goal will lie. Creating the space requires the building of a representation of the problem or situation. In chess this representation could be a tree of all possible al moves and countermoves. After creating a representation, a searc the space is conducted. Controlling search is a major AI issue.

Traditional AI Applications

While all work in AI is ultimately founded on the basic elements of representation and process, the field has a number of traditional applications areas. Robotics is a basic applications area, involving planning and executing physical motions. Vision is another, involving encoding visual scenes into meaningful and useful representations. Another applications area involves language, both understanding and generating written and spoken natural language (that is, English, French, etc.). Understanding spoken language is an extremely difficult problem that has served as an excellent test bed for AI ideas, but the problem is far from solved.

The development of systems that learn from experience, can reason by analogy, and can recognize and manage their own resources and limitations are also important areas of AI research. The development of AI tools is naturally a field of intense interest. Software tools include programming languages, environments, and special purpose, high level systems. Related to software are AI efforts to generate computer programs automatically from English language-like specifications. Hardware is also a tool. In the last few years, special purpose LISP machines have become commercially available on which to do AI development work. Further work on parallel processing hardware systems is an AI research priority.

One AI applications area that just recently gained wide recognition is expert systems. The growth of AI R&D in the next few years will almost certainly be dominated by this applications field. An expert system is an AI program that exhibits or aids professional level human expertise in such areas as medical diagnosis, structural engineering, petroleum exploration, or computer system configuration. The development of expert systems has become a commercial enterprise, and to the extent that these systems do aid humans in the work they must do, expert systems will proliferate.

Expert systems have become successful outside the research laboratory, prior to other AI applications fields, because these systems work in very narrowly constrained environments. For example, the vocabulary and nature of discourse in medical diagnosis are tightly circumscribed in comparison to the vocabulary and discourse that appear in the newspaper every day. The vocabularies associated with professional activities provide a way to begin modeling the expertise involved. But with vision or speech understanding, the knowledge of how these things are done is much less developed.

Developing expert systems, an activity known as "knowledge engineering," is, even so, not an easy task. For most genuine expertise, even though there is a vocabulary to describe what is done, there is no way to state how performance is achieved. People know more than they are aware of knowing. Because the details of expertise are beyond current understanding, knowledge engineering is as much the psychological science of unraveling the mysteries of intelligent human performance as it is the computing science of creating software exhibiting it.

Summary. What AI field is most appropriate to applications in training, performance assessment or job aiding? The answer lies in the nature of the problem. The subject under discussion is technical expertise, and the AI field of expert systems has the most to offer. Expert systems are new, and in many ways fragile. Much work needs to be done on increasing their robustness. But, these systems have demonstrated their worth. This is not yet the case for natural language interfaces or vision systems. Vision and language interfaces will enhance the utility of expert systems, but it is the representation and utilization of technical knowledge that shall always remain at the core of what AI has to offer the operations and maintenance of Air Force systems.

AI Literature

The Handbook of Artificial Intelligence (Barr & Feigenbaum, 1982) is a basic source of information on AI. The handbook "is intended to be an introductory reference book both for researchers within AI and for those outside who need a guide to the unchartered waters of AI research and literature" (Price, 1982, p. 2). It is not a textbook, collection of separately authored papers, or a synthesis of the field. The handbook itself has a section about the AI literature, which is recapitulated here.

The AI literature is generally categorized chronologically: early materials - before 1965, middle materials - from 1965-1975, recent materials - 1975 to present.

Early publications. Books published during the early period include Computers and Thought (Feigenbaum & Feldman, 1963) and Semantic Information Processing (Minsky, 1968). A classic book of this period is Newell and Simon's (1972) Human Problem Solving, which has been heralded as the beginning of the discipline of cognitive science, the synthesis of the fields of artificial intelligence and cognitive psychology.

Middle publications. Books of the middle period (1966-1975) include Understanding Natural Language (Winograd, 1972), Computer Models of Thought and Language (Schank & Colby, 1973), The Psychology of Computer Vision (Winston, 1975), and Representation and Understanding (Bobrow & Collins, 1975). A general introduction to the field of AI during this period includes Sciences of the Artificial (Simon, 1969).

Recent publications. General AI introductions during this period include Godel, Escher, Bach: An Eternal Golden Braid (Hofstadter, 1979) and books by Norman and Rumelhart (1975) and Schank and Abelson (1977), which develop from first principles systems for natural language understanding. Textbooks about AI include Winston's (1977) Artificial Intelligence, and Nilsson's (1980) Principles of Artificial Intelligence. Books dealing with LISP programming include Charniak, Riesbeck, and McDermott's (1980) Artifical Intelligence Programming, and Schank and Riesbeck's (1981) Inside Computer Understanding: Five Programs Plus Miniatures.

Current publications. Books in press include Winograd's Language as a Cognitive Process, and The Psychology of Human-Computer Interaction (Card, Moran & Newell).

Very recently a number of excellent reference sources have been published concerning expert systems. Two books on this subject are Knowledge-Based Systems in Artificial Intelligence (Davis & Lenat, 1983), and Building Expert Systems (Hayes-Roth, 1983). Additionally, there are the following technical reports and journal articles: "The Organization of Expert Systems, A Tutorial" (Stefik et al., 1982), "An Investigation of Tools for Building Expert Systems" (Waterman & Hayes-Roth, 1982), and "An Overview of Expert Systems" (Gevarter, 1982).

Journals, periodicals, and conference proceedings. The most current information about work in AI is found in journals, periodicals, and conference proceedings. These journals and periodicals include Artificial Intelligence; the journal of the Cognitive Science Society, Cognitive Science; the American Journal of Computational Linguistics; the SIGART Newsletter, published by the Association for Computing Machinery; the American Association for Artificial Intelligence (AAAI) AI Magazine; the International Journal of Man-Machine Studies (IJMMS) which also publishes a great number of papers directly relevant to the application of AI to instruction; and several publications of the Institute of Electronic and Electrical Engineers (IEEE).

Associations, conferences, and proceedings include the biennial International Joint Conference on Artificial Intelligence (IJCAI), and the national meetings of the AAAI. The Cognitive Science Society holds annual meetings as well. Carnegie Mellon University annually holds a meeting on cognitive science, and the National Institute of Education and the U.S. Department of Education periodically sponsor seminars addressing issues relevant to the application of AI to instruction.

Bibliographies. The bibliographies of the three volumes of The Handbook of Artificial Intelligence referred to at the beginning of this chapter provide a comprehensive key to the bulk of published literature on AI. Each topical section of the handbook includes a section indicating important references pertinent to that section. Of particular interest to the study of applications of AI to instruction is the handbook section on applications-oriented AI research in education.

CHAPTER II. CURRENT RELEVANT DoD RESEARCH AND DEVELOPMENT

A number of Department of Defense agencies are becoming involved in R&D relevant to the AI applications under consideration in this report. This R&D is summarized in Table 1, which lists the sponsoring agency, project title, and performing organization if different from sponsoring agency and known. In Appendix A the detail of this list is expanded to include the names and telephone numbers of responsible individuals (of both sponsoring agency and performing organization), project durations, levels of funding, and pertinent sources of additional information. Narrative descriptions of relevant projects are integrated into the main body of this report.

The R&D reported in Table 1 is not strictly limited to projects explicitly identified with artificial intelligence. Also reported is R&D in the three areas of interest (training, performance measurement, and job performance aiding) which forms a technology base for applications. The research reported also spans the continuum from basic theoretical work in cognitive psychology to projects that have near-term or midterm applications.

DoD Centers of Activity

As can be seen from Table 1, DoD is sponsoring substantial R&D in the target AI applications fields. The intent of this section is to summarize, at the program level, what each of the involved agencies is doing and is planning to do.

Office of Naval Research (ONR)

A major center of relevant activity is the Office of Naval Research (ONR), Psychological Sciences Division, Personnel and Training Research Program. This program includes areas in theory-based personnel assessment, information processing abilities, instructional theory and advanced training systems, and cognitive processing. R&D in each of these areas is directly relevant to the target AI applications areas. In particular, "work on instructional theories looks to eventual application in generative knowledge-based, automated systems for training. . ." (Office of Naval Research, 1981, p. 1).

Additionally, ONR and the Army Research Institute are jointly funding a program in intelligent computer-based instruction (ICAI). This 3-year program, running from FY 82 to FY 85, has a total program funding level of about $2.5 million.

With respect to the future, program planning at ONR is looking foward to the funding of a center of excellence for ICAI. The goal of this center would be the development of AI tools for the creation and delivery of all types of instructional material, both print and interactive.

Table 1. Current Relevant DoD Research and Development Projects by Sponsoring Agency

Sponsoring Agency	Title	Performing Organization
ONR*	Analysis of Acquiring Strategic Knowledge in Problem Solving	Univeristy of Pittsburgh
ONR	Cognitive and Instructional Factors in the Acquisition and Maintenance of Skills	University of Pittsburgh
ONR	Cognitive Processes in Planning and Control	Rand Corporation
ONR	Comprehension and Analysis of Information in Text and Pictorial Materials	University of Colorado
ONR	Computational Models of Problem Solving Skill Acquisition	Xerox Palo Alto Research Center
ONR	Computer-Based Modeling and Diagnostic Testing of Problem-Solving Skills	Carnegie-Mellon University
ONR	Computer-Based Training of Mission Planning and Control Skills	Perceptronics, Inc.
ONR	Human Understanding of Complex Systems	Bolt Beranek & Newman, Inc.
ONR	Intelligent Automated Tutors for Instruction in Planning and and Computer Programming	Texas Instruments, Inc.
ONR	Intelligent Instructional Methods for Teaching Procedural Skills	Bolt Beranek & Newman, Inc.
ONR	Mental Representation of Circuit Diagrams	Perceptronics, Inc.
ONR	A Model for Procedural Learning	Carnegie-Mellon University
ONR	Modeling Student Acquisition of Problem Solving Skills	Rutgers University

*Office of Naval Research

Table I (cont.)

Sponsoring Agency	Title	Performing Organization
ONR	Procedural-Net Theories of Human Planning and Control	Science Applications, Inc.
ONR	The Role of Prior Knowledge in Operating Devices	University of Arizona
ONR	Simulation Models for Procedural Learning and Expert Memory	Carnegie-Mellon University
ONR	Structural Approaches to Procedural Learning from Technical Text and Graphics	Cornell University
ONR	Studies of Skilled Human Performance	University of California, San Diego
ONR	Topic and Theme Identification in Prose Comprehension	University of Arizona
ONR	Tutoring and Problem-Solving Strategies in Intelligent Computer-Aided Instruction	Stanford University
ONR	Understanding and Executing Instructions	Bolt Beranek & Newman, Inc.
NPRDC*	Advanced Computer-Based Training for Propulsion and Problem Solving: STEAMER	Bolt Beranek & Newman, Inc.
NPRDC	Authoring Instructional Materials (AIM)	NPRDC
NPRDC	Class "A" Electronic Equipment Maintenance Training System	?
NPRDC	Computer-Based Techniques for Training Procedural Skills	?
NPRDC	Theory of Graphic Representation	?

*Navy Personnel Research and Development Center

Table 1 (cont.)

Sponsoring Agency	Title	Performing Organization
NTEC*	Artificial Intelligence Analyses	University of Central Florida
NTEC	Automatic Knowledge Acquisition Techniques for Expert Systems	Perceptronics
NTEC	Computer Aided System for Development of Aircrew Training Enhancement	Rowland and Company
NTEC	Personal Electronic Aid for Maintenance	Texas Instruments, Inc.
NTEC	Voice Technology as the Instructor's Assistant	Honeywell
TAEG**	Computer-Aided Authoring System	University of Central Florida
TAEG	Training Aids Developed from Learning Guidelines	TAEG
AFHRL	Artificial Intelligence in Maintenance Diagnostics and Information Systems	Systems Exploration, Inc.
AFHRL	Automated Performance System C-5 Aircraft	?
AFHRL	Computer-Based Maintenance Aids for Technicians	?
AFHRL	Development of Draft Military Specifications for Maintenance Task Analysis and Logic Tree Troubleshooting Aids	?
AFHRL	Evaluation of Individual Performance in Mechanical Specialties	?
AFHRL	Interactive Computer Graphics Simulation for Intermediate Level Maintenance Trainer	Canyon Research Group, Inc. and Denver Research Institute

*Naval Training Equipment Center
**Training Analysis and Evaluation Group

Table 1 (cont.)

Sponsoring Agency	Title	Performing Organization
AFHRL	Plan for Application of Artificial Intelligence Technology to Technical Training, Performance Measurement, and Job Performance Aiding	Denver Research Institute
AFHRL	Task-Oriented Measurement Technologies	?
AFHRL	Unified Data Base Technology	?
ARI*	Adaptive Computerized Systems (ACTS)	Perceptronics, Inc.
ARI	Advanced Instructional Development: Intelligent Maintenance System	?
ARI	Artificial Intelligence-Based Maintenance Tutor	project in preparation
ARI	Intelligent Tools for CAI	Yale University
AFOSR**	Memory-Based Expert Systems	Yale University
AFOSR	Systems Automation through Artificial Intelligence	
NAVAIRENGCEN†	Technical and Engineering Services to Determine Automatic Test Equipment Technological Use of AI Applications	NAVAIRENGCEN

*Army Research Institute
**Air Force Office of Scientific Research
†Naval Air Engineering Center

Table 1 (concluded)

Sponsoring Agency	Title	Performing Organization
(joint funding)		
ONR/ARI	Computer-Based Program Consultant for Introductory Programming	Yale University
ONR/ARI	Computer-Based Tutoring for Diagnostic Skill Acquisition	Stanford University
ONR/ARI	General Patterns of Scientific Inference	Carnegie-Mellon University
ONR/ARI	Intelligent Computer-Assisted Instruction: An Interactive Reading Tutor	Yale University
ONR/ARI	Intelligent Computer-Based Instruction for Simulation Training of Troubleshooting Skills	Bolt Beranek & Newman, Inc.
ONR/ARI	Principles of Intelligent Computer-Based Instruction for Cognitive Skills	University of Pittsburgh

ONR is planning to start applied work in intelligent maintenance training simulation and intelligent job aids. This program will focus on the principles of human machine intelligence for computer-based training and job aiding. Finally, an effort is contemplated to combine R&D in several funding categories in order to bring together a coordinated effort bearing on the following areas: (1) adult basic skills, (2) technical training with an emphasis on computer-assisted instruction and intelligent maintenance simulations, (3) problem solving aspects of tactical training, and (4) the development of instructional materials, both print and interactive.

Navy Personnel Research and Development Center (NPRDC)

NPRDC has three program areas specifically relevant to this report: personnel and occupational measurement, instructional technology, and training systems. Relevant projects underway at NPRDC are listed in Table 1. A project with the great direct relevance to this report is "Project STEAMER—Advanced Computer-Based Training for Propulsion and Problem Solving."

The objective of this project is to develop an advanced computer-based instruction system for a steam propulsion plant, including a detailed math model of a propulsion system, a graphics interface, and teaching strategies. The complete STEAMER math model with graphics interface has been implemented on development LISP machines. Development of a microcomputer-based STEAMER training system is underway. STEAMER is a long-term, high investment project which has potential for adding considerably to the current state of the art of intelligent computer-assisted instruction.

Another project worth noting is the Authoring Instructional Materials (AIM) project. This has great commonality with the FY 85 ONR thrust area in the development of instructional materials. It is expected that these two efforts will be tightly coordinated.

Navy Training Equipment Center (NTEC)

AI applications in training are being pursued at NTEC. Here, emphasis is being placed on tackling some of the problems associated with team training. Specifically, the concept of AI-based "surrogates" is being developed. For example, consider a surrogate opponent. In one-on-one submarine warfare training simulations, a simulated knowledgeable opponent could enhance the effectiveness of training by freeing the instructors from running the offensive submarine to perform other instructional roles.

The surrogate team member concept is also being explored. When all members of a team are novices, the learning rate for the team as a whole can be slow. Having an individual trainee join a "surrogate team" (which already has competence) can accelerate the trainee's rate of skill acquisition.

In addition to the surrogate concept, AI applications at NTEC are focused on performance assessment. "Assessment" should be interpreted as going beyond the mere collection of data to the analysis and use of performance data in providing instructional direction and feedback to trainees.

AI applications in job performance aiding will most naturally integrate with ongoing advances in JPA technology. Of note is the Personal Electronic Aid for Maintenance (PEAM) and other miniaturized, interactive job aiding devices under investigation at NTEC.

As at ONR and NPRDC, work focusing on the instructional design and development process is also being pursued at NTEC, in particular, the computer-based system, CASDAT (Computer Aided System for Development of Aircrew Training).

Training Analysis and Evaluation Group (TAEG)

Work in the area of computer-aided authoring of instructional materials is also underway at the TAEG, which is located on the same site as NTEC. Work is targeted on automated development strategies for the following kinds of tasks: procedural, paired associate, and visual object classification.

TAEG is also involved with the Naval Technical Information Presentation Program, a 5-year, multimillion dollar program to improve the Navy's efficiency in publishing. This effort is managed by the David W. Taylor Naval Ship Research and Development Center and is now near completion.

Army Research Institute (ARI)

The joint ICAI projects with ONR have already been mentioned. ARI has funded the Adaptive Computerized Training System (ACTS), designed to train electronics troubleshooting procedures. Beyond this, ARI, as of this writing, has no funded projects in AI relevant to the target areas. However, in preparation is a project termed AI-Based Maintenance Tutor (AIMT) which is to function as tutor and job aid.

Air Force Human Resources Laboratory (AFHRL)

The AFHRL R&D program is divided among four thrust areas: (a) staffing and force management, (b) air combat tactics and training, (c) maintenance and combat support, and (d) training design and delivery. AI applications in training, performance measurement, and job aiding are potentially relevant to each of these thrust areas. For example, if the scope of "performance measurement" is expanded to include personnel actions to be taken based on such measurements, much of R&D going on in the manpower and force management area contributes a technology base for potential AI applications. In this R&D area, sample projects include task-oriented measurement technologies; evaluation of individual performance in mechanical specialties; and the development of a prototype, computer-based training decisions system.

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Ongoing research in air combat tactics and training also provides opportunity for potential AI applications, in particular, a desk-top trainer demonstration for utilization in pilot training and microcomputer-based special function trainer. A project focused on automated performance measurement for the C-5 aircraft offers the basis for extension of "measurement systems" to "assessment systems," where data are not only collected, but are analyzed and used to provide instructional feedback. There is apparent potential for collaborative efforts with NTEC in this area. As indicated in the introduction to this paper, AFHRL is planning a program of AI research, development, and application.

The "surrogate" concept is also applicable to team training for operators of command, control, and communications systems. Another project that builds toward potential AI applications concerns the development of draft military specifications for maintenance task analysis and logic tree troubleshooting aids. If this guidance document were implemented as an intelligent, interactive development system, many potential advantages to AI applications would result. A project with similar relevance concerns the development of computer-based maintenance aids for technicians. Much work in the field of maintenance simulation affords opportunity for AI applications because such simulations can help shift the focus of simulation from the equipment to the task, where automated instructional intervention can be provided in response to student performance data. Project data for the efforts mentioned above are presented in both Table 1 and in Appendix A.

As indicated in the introduction to this paper, AFHRL is planning a program of AI research, development and application. This paper addresses AI opportunities in training, performance measurement and job performance aiding. A parallel program planning effort is focusing on applications of AI in the areas of maintenance diagnostics, intelligent maintenance information systems and in built-in test and automatic test equipment. These two parallel efforts are being coordinated because it is realized that engineering design, maintenance, logistics, and training all are closely related and interacting subcomponents of effective and ready weapons systems.

Inter-Agency Coordination

AI is new, and applications efforts even newer. Therefore, formal mechanisms for inter-agency coordination are not yet fully developed and further work on coordination is needed. Two obvious justifications of such coordination are (a) the problems faced by the three armed services in training, performance assessment and job performance aiding are similar and amenable to similar solutions, and (b) the resource pool of trained people to do AI applications work is severely limited.

A good start toward coordinating AI applications in training and maintenance is the Working Group in Simulation, Training and Maintenance of the Panel on Technology Initiatives in Artificial Intelligence, one of seven panels of the Joint Directors of Laboratories (JDL) Panel, a subgroup of the Joint Logistics

Commanders. The charter of the JDL is to put together joint service projects. Each of its seven panels has four working groups: electronic warfare; robotics; command, control, and communications; and simulation and training. Therefore, there is in existence an interservice coordination committee that is directly relevant to the coordination of AI applications in the target areas. The current working group consists of representatives from ARI, NTEC, NPRDC, and AFHRL.

CHAPTER III. CHALLENGES AND APPROACHES

Introduction

The three training issues of concern to this study, training, performance assessment, and job performance aids (JPAs) are actually integrated pieces of the total Air Force training model. In the simplest description of the relationship among the three elements, training provides the basis for baseline job performance expertise, which is in turn augmented and developed through on-the-job training (OJT). The effectiveness of either form of Air Force training is assessed through some form of performance measurement. The JPAs, notably technical orders, support the knowledge and skills of personnel by providing procedural aids for operations and maintenance tasks. Numerous trade-offs are required among (a) which knowledge and skills should be taught formally in residence training, (b) which should be acquired through OJT and experience, and (c) which need not be specifically taught because TOs and other JPAs are available. It is necessary to look at the entire picture both instructionally and institutionally to arrive at a reasonable set of compromises concerning trade-offs.

A common denominator among the three areas of interest is task analysis: it is the basis for training, evaluation, and JPAs. Therefore, task analysis is singled out as a separate issue area in which to consider the potential of AI applications.

Since training, measurement, and job performance are embedded in a larger organizational matrix, a systems analysis is appropriate in analyzing the challenges and opportunities in these areas. Two of the most important considerations from the systems point-of-view are the issues of validation and system maintenance.

Validation is centrally important in training, performance measurement, and JPAs. Often the most effective validation paradigms involve crossing the boundaries among these three fields, as when a training program is evaluated in terms of the on-the-job performance of its trainees.

An issue related to validation is that of maintenance. For example, as field evaluations show training to be deficient in certain areas, the training programs must be maintained to accommodate these deficiencies. If a program of applications of AI technologies were to focus solely on training, individual assessment, and JPAs, then important and consequential opportunities for the application of AI technology would be overlooked; the ultimate payoff of applications in any of the three basic areas might ultimately be discounted by forces operating on the larger systems level.

This section is organized around challenges and opportunities related to task analysis, training, individual assessment, job performance aiding, and the integration of these areas into one system. Within each of these areas, a brief description of relevant challenges is developed, followed by a discussion of potential approaches to the application of AI in meeting these challenges. Related past, current, and planned DoD R&D in each area is integrated into the discussion of approaches.

Methodology

Information regarding the challenges facing the Air Force training, assessment, and job performance support communities has been gathered from various sources. These sources include informal briefings from AFHRL personnel, input from consultants (Dr. Peter G. Polson, Department of Psychology, University of Colorado; Dr. Mark L. Miller, Vice President, Computer*Thought Corporation, Dallas, Texas), the technical literature, and discussions with DoD and civilian professionals working in these areas.

Sources of information regarding approaches to meeting the challenges identified include: the past, current, and planned research activities in the application of AI to these areas. Other sources are advice from consultants regarding the more and less feasible approaches to specific problems and a general synthesis of the potential for application of AI technology to the challenges identified.

Task Analysis

Task analysis is the common denominator of training, individual assessment, and job performance aiding. As embodied in the Tri-Service Instructional Systems Development (ISD) approach, task analysis, in the form of a set of objectives, is the basis for the development of both instructional materials and criterion referenced tests of mastery. Task analysis also plays an important role in performance assessment, as well as in the development of job performance aids.

Naturally, the exact definitions of task analysis, as well as the methodologies and procedures for carrying them out, vary from training, to assessment, to job performance aiding environments. For example, within the training environment, an analysis of the prerequisites to new objectives and desirable sequencing of learning events may be considered a part of task analysis (Gagne, 1977). However, in the fields of performance measurement and JPAs, prerequisites and sequencing are less relevant.

Setting such differences aside, common to training, assessment, and performance support is the need to identify the specific behavioral and information processing actions a human must accomplish in effective and efficient performance of a task or job. Because of this commonality, application of AI technology to the challenges of task analysis will benefit all three areas individually.

Challenges

What are the challenges facing task analysis? Successful solutions to the various training and maintenance problems in the Air Force require a correct description of the kinds of knowledge that are necessary to carry out the various tasks and the development of a training program that in fact imparts this knowledge. Informal analyses of these training requirements, while insightful and often correct, lack the rigor and the detail necessary to develop training programs that are independent of the expertise of a given individual. Informal analyses (even when conducted by very competent individuals) often turn out to be glaringly incomplete because gaps (which must be accomplished by the novice) are filled in implicitly by the set of experts who prepare the training material. They understand the task, they write a description that seems reasonable to them, but since they already know how to accomplish the task, they have no way of evaluating themselves to see if all the steps to accomplishing the task are explicit.

As a remedy for this, an adequate validation can be carried out as a part of the ISD cycle, but this feedback loop is slow because the effects of the training courses must be observed on-the-job and reported back to Air Training Command (ATC) before adjustments to the training can be considered.

Another task analysis problem that impacts both training and assessment is the difficulty of developing a task analysis that is generalizable. For example, a survey of B-52 refueling procedures identified seven different techniques at seven different bases--all technically correct. What is common among these techniques? What motivates the discrimination among them? What should be taught, given that teaching all seven different possibilities is infeasible? What standard should be employed in assessing performance of this task?

Task analysis is critically relevant in the area of performance assessment. A major problem in this area is identifying what is to be measured. Often what is measured is based on an analysis of the job by one isolated content expert. According to some observers, this approach has failed for the Army in its Skill Qualification Test program. A critical question is how to get a representative decomposition of a task. How many experts' performances must be analyzed before a sufficiently broad-base description of performance is in hand? In the author's opinion, the Air Force Occupational Survey Data do not break down tasks into enough detail to be a solution to this problem.

The problem of task analysis is not confined to differences in task approaches within one task area. There is a need to identify subtasks common among sets of tasks, so that training efficiency can be maximized through a proper clustering and sequencing of training objectives. The Air Force needs to have an accurate model of the expertise in its technical corps on which to base manning decisions. The OJT performance records must be more descriptive, recording more than limited, simple numeric scores. A tracking system is needed that can support realistic and effective deployment of technical expertise. Such a system must be based on detailed task analyses.

Approaches

Some tasks are easier to analyze than others. At one end of a continuum are jobs or tasks that are completely routine, fixed-sequence procedures, incorporating known actions and methods in the service of predetermined, specific goals. Normal disassembly of a piece of equipment would fall in this category; so would using a word processor to edit a manuscript. At the other extreme are tasks for which it is difficult or impossible to specify the goal, component actions, and methods. Many management jobs fall at this extreme of the continuum; so do many troubleshooting and problem solving tasks such as fault isolation in digital equipment or writing and debugging computer programs. Let us call those simpler, easier tasks, routine tasks, and the complex, difficult to define tasks, genuine problem solving tasks. Approaches to the challenges of task analysis differ, depending on whether the tasks are routine or are genuine problem solving.

Routine tasks. Kieras and Polson (1982a, 1982b) have developed a theoretical approach to the formal analysis of task complexity in routine cognitive tasks. The tasks of particular interest to their project deal with interactive computing. Their approach is built on and extends previous work in cognitive psychology, cognitive science, and AI. It is a relevant synthesis and application of prior work in these fields to task analysis.

The approach involves the development of a formal description of the user's knowledge of how to use an interactive device and a formal description system for representing the interactive device itself. The user's knowledge of the task and the device are represented using formal representation schemes from AI. Details of both of these representations are presented in Kieras and Polson (1982b). The formal descriptions are computer simulation programs. These two descriptions are validated by running one against the other. In other words, the formal description of the user's knowledge (e.g., the task representation) is validated by seeing if it can interact, in the service of some useful goal (e.g., editing a text), with the formal description of the device. If either description is incomplete or inaccurate, the two simulations will not properly mesh; that is, they will not run, or they will produce erroneous results. This approach is appropriate only for routine cognitive skills--those for which it is possible to completely specify a running simulation of the task. Routine cognitive tasks are certainly required in many career specialties for which this approach, without modification or extension is applicable. Even when jobs do contain genuine problem solving components, the routine tasks can be singled out and treated with the Kieras and Polson formalism.

Given the two models of the Kieras and Polson formalism, a number of metrics of task difficulty can be derived. One way that task difficulty can be interpreted is by the size of the how-to-do-it knowledge representation. Another way is to count the depth of the number of subgoals that need to be invoked to accomplish that task. Once these measures of task difficulty are known, instructional resources can be allocated in proportion to the difficulty of the tasks. Moreover, the task representation for any subtask gives a precise specification of exactly what must be learned in order to perform that task. Such metrics not only help in deciding where to place instructional emphasis, they also help in deciding exactly what it is that must be taught. In fact, it may be fairly straightforward to translate the task representation into instructional text or other media.

The metrics are of similar use in evaluation. Through exploration with simulations, it would be possible to develop a criterion task that exercises an arbitrary proportion of the task hierarchy. Hence, efficient and effective performance measurement tests can be designed. Also, since technicians may often be the least competent on those tasks which require the most learning, such tasks can be placed under special scrutiny, especially if they are critical to the job.

Another outcome from the Kieras and Polson approach is the knowledge that follows from a mapping of the task representation to the device representation. If there is a mismatch between these two, there probably will be difficulty in learning the correct procedures in the areas of the mismatch. This can be corrected by either redefining the way the task is represented (re-doing the instruction), or by redesigning the device itself. In this manner, the man-machine interface can be optimized before a device is developed. In a similar vein, since task complexity is "induced" by the design and structure of the device (as represented by the device representation), prior to prototype development of a device its representation can be manipulated, observing the effect on the induced task complexity. The goal of such an exercise would be to settle on a device design which produced the minimum human operator task complexity.

In addition to the task and device representations, an important representation is of the user's understanding of "how-it-works" knowledge for a device. The knowledge contained in a mental model of a device is a source of meaningful explanations of an individual's procedural knowledge, the task representation. Such mental models help novices' initial attempts to learn how to operate a device. The how-it-works representation is a hierarchy of explanations. Kieras and Polson (1982a) stipulate several criteria for selecting those explanations from the how-it-works hierarchy that should be selected for presentation to a novice.

In sum, the Kieras and Polson formalism provides a method for developing and validating task analyses of routine cognitive tasks that can be used (a) to direct the design of new devices, (b) to identify subtasks that will be difficult to learn, (c) to specify what must be learned, and (d) to specify what how-it-works knowledge would be useful explanation to novices.

<u>Genuine problem solving tasks</u>. For the Air Force the need to support training, measurement, and job performance is more critical for genuine problem solving than for routine tasks. In briefings by staff members at the AFHRL—Training Systems Division, avionics maintenance in particular was mentioned as in need of support. In spite of advances in automated test equipment, this job often requires genuine problem solving competency. Avionics maintenance is representative of a larger class of genuine problem solving tasks, namely, fault isolation, diagnosis, and troubleshooting tasks. There is a large amount of R&D experience with training and performance in these areas that could be pulled

together to form the foundation of AI applications effort in training, assessment, and job performance aiding in these critical task areas.

The task analysis of genuine problem solving tasks can be better understood by considering the work that has been accomplished by researchers in cognitive psychology and AI. Large strides in the theoretical understanding of problem solving behavior have resulted from the synergistic relationship between these two fields. Work in this area has moved away from the domain of games (checkers, the Tower of Hanoi, chess, etc.) and has focused on genuine problems. Much work by psychologists has focused on problem solving in domains such as algebra or physics. Work in areas of "real world" practical significance, combined with an emphasis more on performance than on theoretical development, results in the familiar "expert system."

The methodologies and techniques used by both psychologists and "knowledge engineers" are of use to the Air Force in developing approaches to formal analysis of genuine problem solving tasks. The one pre-eminent consideration is that in the knowledge about a certain field or domain lies most of the power to solve problems in that domain.

Psychologists have developed a modern cognitive theory of problem solving in the tradition of information processing psychology (Chi & Glaser, 1979; Greeno, 1976a, 1976b, 1977; Hinsley, Hayes & Simon, 1976; Larkin, 1979a, 1979b, 1980a; Larkin, McDermott, Simon & Simon, 1979a, 1979b; Mayer, 1974, 1975, 1980; Mayer & Greeno, 1972; Mayer, Greeno & Stiehl, 1975; Newell & Simon, 1972). Problem solving, in this tradition, is characterized as understanding and search (Polson & Jeffries, 1980). Expert "understanding" in physics problem solving, for example, involves the use of a qualitative scientific representation of the phenomena at hand as a guide to the selection of a method of solution (Chi, Feltovich & Glaser, 1980; Greeno, 1980; Larkin, 1980b; Richardson, 1981). "Search," for the expert, has the character of building toward a goal, rather than working backwards from a goal.

A problem solver (expert or novice) when faced with a problem, has a representation in memory to which he or she fits the problem. Depending on the degree of meaningfulness of that fit, the solver then brings to bear a number of search processes that act on the representation, filling out a path to a solution. Depending upon the degree of meaningfulness inherent in the representation to which the solver fits the problem, the search may be straightforward or it may be circuitous; a solution may result forthwith or it may elude the solver entirely. Often a problem representation must be adjusted in the course of developing a solution, for example, from a functional representation to a physical representation, or from a conceptual scientific one to a mathematical one.

It is important to note that the representation (also termed cognitive structure or schema) brougnt to bear on the problem is an organized collection of experience with this and similar problems. Thus, problem solving is knowledge-dependent or knowledge-based. Skill in problem solving is not reducible to a general procedural skill alone. Rather, it is in part determined by a large body of organized knowledge structured for the purposes of solving problems in a particular domain and in part determined by a set of quite specific rules, procedures, or heuristics which act upon that knowledge.

AI research also has much to contribute to understanding genuine problem solving tasks, in particular, expert systems technology. Consider those expert systems in use today based on a technique known as backward chaining. Basically, expertise is captured by a set of rules of the form: if some condition(s), then take this action. In backward chaining, the initial conditions of a goal statement are examined, and rules whose actions will satisfy those conditions are sought. This process is repeated recursively until all of the goal condition is satisfied. An explanation of this process is provided by Waltz (1982). A design goal for such expert systems is to have the set of rules which are comprehensible to human experts. In this way, the human expert can "understand" how the expert system arrived at a particular conclusion or answer by examining the chain of rules which led to that answer.

MYCIN (Shortliffe, 1976) is an example of a backward chaining expert system. The backward chaining control structure is implemented through the interaction of two mechanisms, MONITOR and FINDOUT. MONITOR's function is to verify whether or not a rule is true. To do this, it must establish the truth value of each of its conditions. If one of the conditions is not true, the rule fails and its actions may not be taken. Often it is not possible to determine the truth value of one of the conditions. In such cases the FINDOUT mechanism is called. FINDOUT retrieves the list of rules which have an action which establishes the truth value of the condition in question. At this point, the problem is to see if any of these rules are true. In order to do this, FINDOUT calls MONITOR with the task of examining each of these rules. If a condition in one of these rules is indeterminate, the process is continued working backward (e.g., FINDOUT is called again). Backward chaining is recursive because of the way a mechanism calls itself in the course of processing (e.g., MONITOR calls FINDOUT which calls MONITOR, etc.).

Backward chaining systems typically do not explicitly contain models of causality, functionality, or structure for the domain under consideration. This is a limitation because, for the toughest of problems, it is often necessary to reason from a causal, functional, or structural model of the domain in order to arrive at a solution. These and other issues regarding expert systems are cogently addressed in a paper by Randall Davis (1982).

In seeking help for the challenges facing the Air Force in the development of valid and useful analyses of tasks that require genuine problem solving skills, slight differences in orientation between the psychological and AI oriented approaches must be considered. In psychological models of problem solving, comprehensiveness, rigor, and theoretical value are of more importance than is performance capability. The opposite is true of AI expert systems, because performance is of paramount interest, and at times certain aspects of performance are forced or glossed over in ways that do not parallel or model human performance, for example, in exhaustive search. Both of the approaches to genuine problem solving have value to the Air Force in enhancing the methodologies of task analysis in complex domains. The psychological approach is important because the task analyses will be applied to instruction; ultimately, human performance is the subject of interest. On the other hand, in the area of JPAs, it may be permissible to have an expert system arrive at some conclusion or take some action (such as a curriculum sequencing decision) that is not entirely the way a human would do it.

Training: In-Residence and On-the-Job

Challenges

Training in the Air Force is provided both as formal instruction and on-the-job. By far the greatest formal training emphasis is on in-residence training. For the Military Airlift Command and Strategic Air Command there is a trend toward less formal schooling, and more OJT at the unit level. For ATC the trend is toward more centralized training and more self-paced/CAI training (Rosenblum, 1979). OJT relies almost exclusively on local unit management of training and certification programs, largely on an informal and subjective basis. Challenges in training include:

1. The need for valid, quality, useful task analyses.
2. The need to present instruction that is a proper blend of rote learning of procedures and robust learning of relevant principles.
3. The need for efficient and timely methods of instructional materials development and revision.
4. The need of effective instructional materials.
5. The need for less reliance on actual equipment as the sole source of practical hands-on, job-relevant experience.

Shortage of trained personnel is a good organizing principle for considering training issues. The ultimate source of shortage is personnel attrition. Training programs produce individuals with expertise that is required in the private sector; the Air Force often acts as a training ground for industry. In addition, a shortage of expertise results from the continuing evolution in the complexity of Air Force weapons systems. This generates a demand for personnel who have the skill to understand and work with systems that are increasingly complex and technical.

This issue of expertise shortage is at the heart of a conflict between the training and field missions within the Air Force. The field feels a shortage of trained personnel and would like the graduates of the training programs to be trained to a higher technical caliber. But producing this caliber robs the field of expertise (in the form of instructors) and of useful duty time (in the form of extra time spent in training). The Air Force needs to maximize in-residence training graduates' competence while minimizing the amount of resources spent. A solution to this problem is to increase training effectiveness both in-residence and especially OJT. Of course, this has long been a goal for the Air Force, and progress toward this goal is continuously being made.

The allocation of training objectives differentially to in-residence and OJT programs is currently done on a formal basis. An AFHRL planned Training Decisions System is designed to act as a management aid in making these allocation decisions, decisions which have a large potential impact on overall training effectiveness and efficiency within the Air Force.

AI techniques can provide approaches to increasing training effectiveness. The approaches, suggested below, may be applied to either the in-residence or on-the-job training environments. Because in-residence training emphasizes classroom sized groups of students, applications of instructional technology may be most appropriate in the OJT environment where training is more structured around the individual than in in-residence training. The needs identified previously are found in both in-residence and OJT environments, and approaches suggested in the following paragraphs, in appropriate mixes, will be suitable in both of these environments.

Approaches

Task analysis. AI applications in support of this foundational component of instructional systems design have already been treated in detail. Successful progress in areas of identified need in training depend on front-end work in task analysis. The task analysis does not satisfy, in and of itself, any pressing training need. But, application and use of task analyses are of fundamental importance in instruction. In the remaining subsections, particular training applications of task analyses, the cognitive psychology of problem solving, and work in knowledge engineering and expert systems are presented.

Selection of the appropriate mix of rote learning and general principles learning. This is an old and familiar issue, and some have observed that the current orientation toward this issue swings from pole to pole cyclically. As old and timeworn as this issue is, recent advances in cognitive science provide fresh insights into the problem of rote versus meaningful instruction.

The Kieras and Polson formalism previously discussed provides a straightforward approach to this problem. They have developed a set of criteria for deciding when "how-it-works" knowledge should be useful to novices. Briefly, these criteria are (a) if the user's task representation contains a goal that is unique to the device the user is working with and not previously encountered in different devices, then that goal should be supported with an explanation derived from how-it-works knowledge, (b) if a goal in the task representation is already a part of the user's expected standard repertoire of performance capability, that goal need not be supported with explanation, and (c) if how-it-works knowledge does not correspond with a particular goal in the user's task representation, then that explanation should not be provided. These rules are familiar; the second one addresses the entering behaviors consideration in instructional design, and the third is a tenet of functional context training (Shoemaker, 1960). What the Kieras and Polson formalism contributes is a formal descriptive system on which to base these rules.

Much work has been done on meaningful versus rote learning, beginning with classic studies by Brownell (1935). More recently, the work of Mayer (Mayer, 1974; Mayer & Greeno, 1972; Mayer, Greeno & Stiehl, 1975) sheds light on the importance of this problem. The findings from these experiments on rote versus meaningful instruction for a variety of tasks indicate that qualitative differences in learning outcome are found as a function of instructional treatment. During an instructional treatment, students will selectively attend to particular aspects of the presentation in accordance with the learning "set" activated by the treatment. If students expect instruction to be rote, then they learn by rote. If they expect meaningful instruction, then they attend to meanings. The outcome of a meaningful approach is that students are more capable of solving novel problems, but solve familiar problems less quickly than do students trained with more emphasis on rote learning of fixed procedures.

Overall, work in the psychology of expertise yields the result that, once again, performance is largely a function of command of and access to large amounts of knowledge. It has been estimated that expertise in chess (and perhaps expertise in numerous fields) may be accounted for by some 50,000 "chunks" of knowledge which require upwards of 10 years to acquire. If this is the case, then even though meaningful, principles-oriented instruction promotes a certain robustness in learning and memory, there is no substitute for experience. The training implications of this finding are that in performance areas where expertise is needed (as in genuine problem solving tasks), one should not expect too much from training. If expertise is in critical shortage, JPAs may be a more realistic solution than beefed-up training programs. This is further treated in the section below on JPAs.

One of the most interesting findings of the problem solving literature (cited above) is that novice and expert performance can differ qualitatively in reaching the correct solution to a given problem. The explanation for this lies in the different representations and search methods employed by novices versus experts. Misconceptions in student understanding (McCloskey, 1982; Stevens, Collins & Goldin, 1978) further contribute to the distinction between novice and expert. It has become clear that protocol analyses of novices (e.g., task analyses from the novice's point of view) are critically important in understanding how to approach instruction. It is not sufficient to expect novices to learn the expert approach. First, the misconceptions must be dismantled, and then a transitional, developmental progression from novice to expert must be supported with instruction. This realization is at the root of an approach to the use of an expert system as the basis of a tutorial system (Clancey, 1979; Clancey & Letsinger, 1981). The rules in an expert system are tightly "compiled" pieces of knowledge. They contain, implicitly, structural and procedural knowledge that must be made available, explicitly, to the student. In addition, justifications for the rules must be available to the student. Justifications serve as memory aids for remembering the rules and as a basis for deep understanding that allows students to learn beyond what is captured in the rules. Expertise cannot be transmitted intact; a lot of recompilation of basic principles, under the guidance of experience, is needed before fresh expertise can be developed.

Building blocks and tools for conventional instruction and CAI. NPRDC has launched the Authoring Instructional Materials (AIM) project focused on using computers to automate and assist curriculum development for both computer-delivered and conventional instruction. TAEG has underway the Computer Aided Authoring System project with the objective of developing an authoring system capable of generating job aids, learning aids (procedural and nomenclature), curriculum, instructor guides, and student guides.

There currently exists a number of authoring and/or curriculum development systems, building blocks, tools, or aids, for example, the Writer's Workbench at Bell Labs, the Computer Readability Editing System (CRES) at TAEG, the Computer-Aided System for Developmental Aircrew Training (CASDAT) at NTEC, Computerized Job Aids for ISD at ARI and the Human Resources Research Organization (HumRRO), student flow simulation for course design at the Air Force and Rand, and commercially available authoring systems for computer-based instruction available from such companies as WICAT, Bell & Howell, Control Data Corporation, Hazeltine, etc.

An emphasis or reliance on isolated building blocks and tools for designing and developing instruction may not be the best approach to the problem of developing conventional CAI. A standard way of conceiving of computer-based instruction software systems is to see text and graphics (e.g., display-oriented editors) as a basic building block, which is encapsulated within an instructional interaction editor used to build lessons (e.g., a CAI editor), which is in turn encapsulated within a curriculum management editor controlling the progress of students through sets of lessons constituting courses (e.g., a CMI system). Many systems exist that are structured in this way, c.f.: WICAT, AIS, PLATO, etc. While these systems do provide structures to be filled in at various levels (course hierarchies, objectives, and instructional interactions), there is little or no help and assistance for the instructional designer in making design decisions, such as which objectives to select, how to structure and organize them, how to develop effective feedback, or how to build adaptive branching schemes. It is suggested that this is an area where AI might be applied.

The effectiveness, efficiency, and timeliness of courseware design, development, and delivery can be increased by integrating these three "Ds" into one coordinated system. At AFHRL, the Interactive Graphics Simulation (IGS) project has in place an integrated design, development, and delivery system for task-oriented avionics maintenance simulations. Control Data Corporation is currently placing an emphasis on this approach.

The key to the IGS approach lies in the interactive development, refinement, and modification of a hierarchical task analysis of the job. This is currently accomplished on-line on the AIS through use of specially designed editors. The resultant on-line task hierarchy is then used to develop simulation scenarios, complete with scene-setting text and graphics, video disc control commands, and feedback messages. During delivery, the task hierarchy is used to represent the alternatives available to the problem solver at each step of the way toward a solution. Since correct and incorrect choices are nodes in the task hierarchy, a record of a given student's responses across a number of simulations provides a model of the student's competence in terms of the task hierarchy. This model is then used to control instructional interaction toward the goal of focusing student attention on unmastered portions of the task. For example, when a student's response history indicates that the student has mastered a commonly reoccurring subtask, that subtask is summarized, thus freeing up time and attentional resources for subtasks that do need further practice. Explanations and illustrations of this integrated design, development, and delivery system are presented in Dallman (1982), Richardson (1982) and Pieper (1982).

The key to the success in developing such an integrated system was the pivotal use of an on-line task analysis representation. As emphasized in earlier sections on task analysis, a task analysis approach to integrating systems can be extended beyond adaptive drill and practice (which is what the interactive graphics simulation system is) to include explanatory instruction, performance measurement, and job performance aiding as well. When systems are closely integrated through the use of task analyses, this facilitates courseware maintenance and helps establish courseware validity.

Intelligent CAI. Intelligent CAI (ICAI) offers a way of enhancing the effectiveness of interactive computer-based instruction beyond what is achievable with traditional approaches to tutorial, drill and practice, and simulation courseware. ICAI seeks to emulate the professional competence of good teachers when working one-on-one with a student. Good teachers (a) know what they are doing, i.e., have subject matter competence; (b) are vitally concerned with understanding the state of their students' knowledge, including misconceptions; and (c) have a good "bag of tricks" concerning pedagogical approaches, for example, the good teacher knows that the student needs a proper mix of instruction and practice. AI in general tries to emulate the actions of intelligent agents, and ICAI attempts to emulate intelligent teachers.

The main components of an ICAI system are problem solving expertise, the student model, and tutorial strategies. An exhaustive review of the ICAI literature is beyond the scope of this paper. Integrative reviews of this field have appeared in the literature, and include those by Gable and Page (1980), Barr and Feigenbaum (1982), and Sleeman and Brown (1982).

Table 2 briefly summarizes a number of ICAI systems, indicating literature references and subject matter nature. Not all of the three components of an ICAI system are fully implemented in every system. Each component by itself is a difficult problem, and the successful implementation of a demonstration program often depends on strategic decisions regarding where to try to work at the state of the art, and where to settle for well-known approaches. For example, the more effort that has to be put into explicating domain expertise, the less resources are available for developing student modeling and pedagogical modules. ICAI systems consist of three main components, subprograms, or modules. That is, at the highest level of program organization, an ICAI system

Table 2. Intelligent CAI Systems

SYSTEM	REFERENCES	SUBJECT MATTER CONTENT
SCHOLAR	Carbonell (1970) Collins (1976)	South American geography, text editing systems
WHY	Stevens, Collins & Goldin (1978) Stevens & Collins (1978)	extension of SCHOLAR
SOPHIE	Brown, Burton & de Kleer (1982)	electronics troubleshooting
WEST	Burton & Brown (1979)	elementary arithmetic game
WUMPUS	Carr & Goldstein (1977) Goldstein (1977, 1979) Stansfield, Carr & Goldstein (1976)	fantasy dungeons and dragons game
GUIDON	Clancey (1979) Clancey & Letsinger (1981)	infectious blood disease
BUGGY	Brown & Burton (1978) Brown & VanLehn (1980)	elementary subtraction
EXCHECK	Blaine & Smith (1977) Smith, Graves, Blaine, & Marinov (1975) Smith & Blain (1976) Suppes (1981)	logic, set theory, proof theory
BIP	Barr, Beard & Atkinson (1976)	BASIC programming
ACTS	Hopf-Weichel et al. (1980)	electronics troubleshooting
STEAMER	Stevens et al. (1982)	propulsion engineering
ADA TUTOR	Computer*Thought Corp. (1982)	Ada programming

consists of an expert module, a student model module, and a tutor module. A very brief summary of the three ICAI components follows.

The expert module. The expert module serves to generate and solve problems. The first role for this module is the generation of problems. This function is closely linked with the student model and pedagogical modules because curricular decisions involve what the student knows or does not know and strategic decisions about what to present next and how to present it. The degree to which ICAI systems generate curricula of problems in concert with student modeling and pedagogical considerations is very limited. All systems do have a scheme for sequencing problems, and approaches vary. The second role for the expertise module is in solving problems. This is done in order to evaluate and critique student solutions. ICAI systems with "articulate" problem solvers can explain how they reached a solution or how they would like the student to try and reach a solution. If the problem solver is not articulate, what is termed "opaque," then the system can offer no detailed critique of a student's solution path. The extent to which ICAI systems' problem solvers are articulate or opaque also varies.

The student module. The objective of the student modeling module is to understand what curricular objectives the student has mastered, and to understand or have representations for predictable misconceptions and suboptimal approaches. Input to the student model may be derived from numerous sources including: (a) a differential comparison of the student's behavior and the behavior output of the expert module on a given problem or question, (b) explicit information derived from direct questions asked of the student, and (c) historical assumptions based on the student's experience. The student's knowledge can be represented as an overlay or subset of the expert's knowledge, or it can be represented as deviations from the expert's knowledge (e.g., misconceptions, suboptimal approaches, and "buggy" procedures). This is a very important distinction. As was explained in a previous section on the difference between rote and meaningful instruction, expertise is not something that can be transferred directly to a novice. There is a developmental process that must be gone through as the backward chaining approach typical of "uncompiled" novice competence is refined (through practice, experience, and more knowledge), into the pattern matching, methods application, forward reasoning character of expert performance. To represent and use a genuine expert representation for the expert in an ICAI system may be a mistake, as was discovered by Clancey in his experiments with MYCIN (Clancey & Letsinger, 1981). A deeper representation is needed in order that differences detected between the student's performance and that of the experts are to be minimized. The purposes or plans a student is using must be inferred from the student's actions. Therefore, "plan recognition" and plan representation are of great importance in ICAI systems R&D.

The tutor module. The third module is the tutor module. It is a well-known fact that simply because someone has complete subject matter mastery, his or her ability to transmit that mastery does not necessarily follow. There is a great deal of procedural knowledge involved in effective instruction. This knowledge comprises the basis for the tutoring strategies module of the ICAI system. Pedagogical knowledge of curriculum sequencing is important, for example in selecting an instructive problem, tailor-made to help students see a point for himself. Knowledge concerning how to conduct a Socratic dialog may also form part of the knowledge data base of the tutoring module. The Socratic dialog is a very refined version of discourse. Hence, modern cognitive theories of discourse comprehension and production have much to contribute to the development of tutoring systems. For example:

> Question a prediction made without enough information.
>
> > If: a student makes a prediction as to the value of the dependent variable on the basis of some set of factors, and there is another value consistent with that set of factors,
> >
> > Then: ask the student why not the other value. (Collins, 1978, p.3).

Other ICAI issues. Other issues of concern to intelligent CAI besides the three basic ICAI modules include (a) student-system interface issues, e.g., the use of natural language and all of the problems associated with generating and parsing prose text, (b) self-improving tutors, e.g., ICAI systems that learn how to improve their instructional effectiveness, based on experience, and (c) the use of graphics as a medium of communication. The natural language problem is a major area of AI research in its own right, and it is certainly not solved. Means exist to provide for natural language interaction between student and system, but they are limited and must be treated carefully. Again, there is a resource tradeoff between emphasis on this and other areas of importance in ICAI systems. Very little R&D on self-improving systems has been conducted. The achievement of adequate baseline performance is still a demanding challenge. (See Sleeman & Brown, 1982). The presentation to the student of imagery in instructional systems seems to be simply a matter of broadening the communications channel between system and user and offers no fundamental technical challenges. Having the computer "see" images drawn by the student is, however, not yet possible.

ICAI systems to date have been "hand crafted" and have usually focused on less than the totality of issues, concerns, and components of an ICAI system. This suggests that practical AI applications must not try to press the state of the art on all fronts. Practical efforts should focus on discrete, well defined, and well understood content areas that are priority training areas. Computer programming is a candidate, but its task domain is not yet fully understood. Troubleshooting is a generic area that seems to hold great promise as a candidate applications area, especially because it is a priority training need. Much general work on fault diagnosis and isolation has been done; the area telescopes nicely from general troubleshooting procedures, to electronic troubleshooting, to troubleshooting specific systems. The ACTS system (Hopf-Weichel, Purcell, Freedy, & Lucaccini, 1980) and the SOPHIE system (Brown, Burton, & de Kleer, 1982) are two completed ICAI projects in electronics troubleshooting. Several current DoD research projects are continuing research in troubleshooting. See Chapter II.

For ICAI to be of practical use in the training mission of the Air Force, a fully developed, robust system is needed. Demonstration projects will have little utility in the production and delivery environment. Systems must be designed to be used, not to serve as research vehicles or demonstrate state-of-the-art ICAI techniques. This means that, as a part of the design and development of a practical ICAI system, the field and school must have considerable input from the outset. This approach is being used by the STEAMER project at NPRDC, where interim field tryouts are now underway.

The fact that ICAI systems are currently hand crafted, and that the first few applications environment-oriented systems will also be hand crafted, should not deter a program focused on the development of tools that will be useful in moving toward a mass production capability for ICAI systems. Recall that the design and development process for traditional hard copy and CAI materials is still largely an art. The techniques are well specified, as in the ISD process, but little or no automated design help is yet available.

Task analysis. The techniques reviewed above for automated assistance to the design and development of traditional materials, especially the central role of the task analysis, will probably have a payoff for the design and development of ICAI systems as well. In particular, a large effort focused on developing a "telescoping task hierarchy" for troubleshooting and fault diagnosis tasks might serve as the first step toward design assistance in CAI and ICAI as well. By "telescoping" is meant a representation that is capable of representing: the troubleshooting processes involved in a particular system (e.g., F111 6883 Avionics Test Station); which also serves to outline the troubleshooting process at the next level of generality (e.g., avionics test stations); and so on, to the most general level of detail (e.g., general troubleshooting strategies, approaches, and procedures).

Building blocks and tools. Specialized building blocks and tools for a particular applications area (e.g., troubleshooting or computer programming) may be necessary. Natural language interfaces, pattern matchers, plan recognizers, production system interpreters, augmented transition network compilers, and graphics editors and graphics generators are examples of more general purpose building blocks and tools. A carefully thought-through building block development project should parallel the first few ICAI systems development projects. Given the centrality of task analysis, automatic or semi-automatic means of "knowledge extraction" become important, for a task analysis is an explication of a subject matter expert's expertise. The AFHRL Interactive Graphics Simulator project has demonstrated a technology for semi-automatic knowledge extraction, which is an integrated part of an instructional materials design, development, and delivery system. Finally, instructional design itself is a target area for knowledge extraction, for the procedures inherent in the design of good instruction play an important role in the tutor module of ICAI systems. Certain canonical approaches to instruction may be identified, and their procedural aspects codified in on-line representations.

Use of graphics. Graphical or pictorial imagery (objects, structure, or process) are a major means of communication. Imagery is so important in mental processing that there is great debate in cognitive psychology as to whether encoding in long-term memory is in terms of propositions, images, or perhaps both

(Pylyshyn, 1973). However, when a technician's job involves working with actual objects and pictorial representations of such objects, graphical or pictorial capabilities in instructional systems are necessary.

The recent advent of the video disc and recent improvements and accessibility of computer generated graphics systems make the incorporation of imagery into instructional systems practical. Indeed, it may even be possible to replace large assemblages of equipment, in particular electronics equipment, with graphics simulations. This has important implications for training. More hands-on practice can be provided (albeit simulated) than might other[illegible]e be possible with expensive physical hardware. Also, since these graphics [illegible]ns are designed from scratch, it is possible to design them for the purposes [illegible]ning, such that hour for hour, more learning may go on through interaction with a graphics training device than with the actual equipment. These issues are now being studied in numerous DoD research projects.

Graphics or imagery CBE systems are functionally identical to CBE systems in general. The same distinctions between frame-oriented CAI, drill and practice, and simulation apply. The same opportunities for ICAI exist. Graphics and imagery simply provide an additional modality of communication. This is an incredibly powerful and important modality; therefore, it should be exploited to the maximum. Approaches to the development of quality interactive instruction in general apply to the development of quality video disc or graphics-based instruction in particular. Design and development problems should be attacked at the most general level possible, e.g., at the level of "interactive instruction"; effort need not be duplicated by addressing fundamentally the same issues at the more specific level of detail of "graphics simulations." Therefore, the approaches to design, development, and delivery suggested in preceding sections apply to highly graphics-oriented systems as well.

Performance Measurement

Challenges

Roles of performance measurement in the military include job proficiency assessment, training effectiveness assessment, personnel selection and classification, certification, promotion, and research and development. The focus of job proficiency assessment may be on the individual, team/crew, unit, service, or military-wide readiness. The roles or purposes of performance measurement define different mixes of performance tests and administrators. For example, OJT performance measurement may be based on very informal and subjective judgments on the part of a shop supervisor, who needs to know whether an airman can perform a certain task indicated in an Air Force Job Proficiency Guide. This approach differs greatly, for example, from the performance measurement techniques and data employed by the R&D community, where data requirements are more rigorous, or needed in norm rather than criterion referenced formats.

Career specialty characteristics also influence applicable performance measurement techniques and procedures. For example, career specialties with critical tasks, or tasks associated with high safety risks or high costs, require close specialties monitoring through performance measurement procedures. Each Air Force base now has a quality control group whose duty it is to monitor certain critical career specialties.

Technical career specialties, especially maintenance, require performance monitoring because modern weapons systems are technologically advanced. These systems are complex and maintenance is often far from straightforward, requiring considerable troubleshooting skill. Ineffective maintenance practices can cost the Air Force exhorbitant funds in erroneously replaced units. Moreover, mission preparedness is vitally linked to adequate maintenance capability. The Air Force uses about 28 percent of its workforce and between $5 and $7 billion annually on maintenance (Townsend, 1980).

Excessive maintenance costs can be reduced if job task performance tests or empirically valid symbolic substitutes to them are available to ascertain how efficiently and effectively maintenance personnel perform their tasks (Foley, 1977). Performance measurement is especially feasible in maintenance areas because of the technical nature of these tasks. Performance is the result of a structured application of knowledge, not nuance or intuition. In other words, it is possible to obtain good definitions of the goals and methods of performance in these areas. The task analytic approaches discussed previously can be used to develop, specifiy, and sample specific, concrete, performance measures. The hierarchical nature of task analyses is useful in developing sampling strategies.

The remainder of this section is focused on individual job proficiency assessment in technical career specialties, especially maintenance. Measures of individual job proficiency may be used in turn as inputs to training program assessment.

During and after World War II, the Air Force made extensive use of formal job task performance tests. For reasons of economy, these tests were abandoned in favor of paper-and-pencil theory and job knowledge tests. According to Foley (1977), "none of these substitute measures are sufficiently valid for use as substitutes for job task proficiency tests." This is based on low correlations obtained between job task performance tests, theory tests, job knowledge tests, and school marks.

There are a variety of job proficiency test formats. Some numeric scores for performance (for example, number of problems correct) have no interpretive value. The only useful presentation of job performance data must be some meaningful profile of proficiency. Foley has developed an exemplar of such a profile. Performance is broken down into various functional areas: use of test equipment, repair, remove/install, adjust/align/calibrate, troubleshoot, and checkout. Hierarchical dependencies between these various maintenance functions are identified. Special test equipments use is seen as a component function of adjusting, aligning, and calibrating equipment. The adjust/align/calibrate functions are, in turn, seen as component functions of troubleshooting. In this formalism, troubleshooting is explicitly identified as the highest order function.

Job performance tests require training and on-the-job time. Valid symbolic substitutes to formal hands-on job task performance measurement may reduce assessment costs. Paper-and-pencil symbolic representations of a task have potential for reducing the need for job task performance testing on actual equipment. Much development has occurred in the past several years on simulation systems for maintenance training (Orlansky & String, 1981). Current developments in this field may permit the use of maintenance simulators for performance evaluation and certification of maintenance personnel on an objective basis in operational environments.

In sum, the challenges are to move performance measurement into the operational environments and to integrate it with personnel management and training organizations' programs. The development of symbolic substitutes, based on modern maintenance simulation work (such as interactive graphics simulations utilizing intelligent video discs), also provides a challenge.

Approaches

The development of valid task analyses which form the basis for performance measures can be approached utilizing the methods and techniques outlined in the previous section on task analysis. Since troubleshooting proficiency is a job capability of interest, task representations appropriate to the genuine problem solving type of cognitive skill are appropriate. AI techniques could be applied to assist in the abstraction from a number of sample task protocols of a generic representation for the task. This is similar to the "plan recognition" capability that would be of use in ICAI systems.

From a completed task analysis, performance test problems can be constructed, utilizing the hierarchical nature of the task analysis as a guide in a sampling strategy that may focus on criticality, difficulty, or breadth of coverage. These problems could be administered on actual equipment, or even developed as paper-and-pencil tests. But by far the best medium would be interactive graphics simulation so that the data collection will be automatic, unbiased, consistent, and immediately incorporatable into an integrated performance assessment/training system. By replacing actual equipment with imagery under computer control, an individual's performance protocol can be automatically integrated into a task representation used to characterize that individual's expertise. A problem sequencing component may be used to prescribe a sequence of OJT practice problems, delivered as interactive, instructional simulations, to remediate specific detected inadequacies in the subject's performance. In this way, the next tests that are selected for administration to the subject will be derived from a representation of the career specialist's technical competencies.

As mentioned, traditional job proficiency task performance tests do require on-the-job time and resources. The approach suggested mitigates against this problem in two ways. First, special attention for methods of task sampling across the job tasks can be developed--automatic methods that act on the online job representation. In this way, the amount of performance testing may be reduced. Second, since performance measurement and OJT are administered on a special purpose device, current demands generated by OJT and assessment programs on supervisory time and actual equipment are alleviated.

Job Performance Aiding

Challenges

Material in this section was abstacted from Booher (1978). The Booher report is a survey and conceptual analysis of existing job performance aid techniques, and identifies and categorizes factors important to the selection, design, cost-performance tradeoff, conduct of future R&D, and implementation of performance aiding technology.

Due to increasing personnel costs and declining entry-level skills, there is a great need to enhance the performance of lesser-trained or lesser-skilled personnel. Other R&D projects have found that job performance aiding has major potential for increasing job performance and for reducing associated costs. Analyses reported in Serendipity (1969) and Braid (1975), Rowan (1973), Shriver and Hart (1975), and Shriver (1977) indicate that, through the use of job performance aiding technology, first-enlistment training costs may be reduced from 50 to 80 percent, a significant savings in spares may be achieved due to reductions in erroneous component removal, and a 15 percent decrease in the maintenance labor force may be effected. These savings total $1,675 million annually.

Job performance aiding liteature has a long history, and definitions of JPA go back as far as 1962. Booher (1978, p. 3) proposes the following definition:

> A job performance aid is any device, manual, guide, or tool used on the job to facilitate performance or to avoid costs where learning is incidental.

Although an important aspect of JPAs is the fact that learning is incidental and not a primary product of their use, it is possible to design aids that encourage greater incidental learning. The interrelationship between JPAs and training is treated in the final section of this chapter.

The types of generic JPAs include troubleshooting, nontroubleshooting, and various other types: standard operating procedures, periodic action aids, time critical or hazardous conditions aids, one-trial learning aids, and aids for highly complex integrated systems. In addition to types of JPAs, there are also levels of aiding. Troubleshooting aids vary from fully proceduralized JPAs, to partially proceduralized aids, to simple logic deductive aids, to systems descriptions. These represent a continuum from prescriptive aids (which tell the technician exactly what to do each step along the way depending on the exact circumstances that pertain), to descriptive aids which offer no procedural assistance and which are principally the source of help from which precise actions must be deduced.

JPAs are usually designed with particular personnel qualifications in mind. Fully proceduralized aids are more appropriate for less experienced personnel; more deductive aids, for those more qualified. Hybrid aids are designed to be adaptive to the level of expertise of their users, and support performance in less proceduralized formats and more deductive formats as the user increases in competence. In summary, JPAs are means of extending human capability by providing a means of storing for later retrieval information related to on-the-job performance. JPAs may reduce or even, in some circumstances, eliminate the requirement for technical training.

Booher found that satisfactory aiding techniques exist for all nontroubleshooting operation and maintenance tasks and for most troubleshooting tasks on mechanical, electrical, and electromechanical systems. However, no aiding techniques were satisfactory for complex digital electronic systems. Troubleshooting complex digital electronic equipment, therefore, has been identified as a challenge area for both training and job performance aiding.

Timely and accurate production, distribution, and maintenance of JPA systems have been identified as major weaknesses of JPA systems. The major cost factor of JPA systems is front-end analysis and the amount of graphic enrichment needed to increase intelligibility.

It was found that microform and audiovisual systems are inferior or equal to hard-copy print media. For most job environments, simple hard-copy print media JPAs meet the information aiding needs of operators and technicians. Further research is warranted into devices that can increase the performance capabilities of the user beyond that possible with hard-copy print.

Interactive JPA devices can be considered in a class by themselves. Burkett and Kruse (1977) have postulated that use of such aids may cause a reorganization in the thinking processes of technicians, enhancing the users' capacity to develop and organize thoughts, define necessary steps, and develop the most efficient procedures for problem solutions. Also, these aids, through embedding in their target systems, have the potential for modifying, not simply aiding, task performance. Only interactive JPAs are identified as having high potential is assisting the performance of cognitive problem solving tasks.

JPAs have many of the same logistical and quality assurance problems as does technical training. In particular, without a method for assessing a JPA's value relative to other JPAs and other methods of developing operational performance capability, objective evaluation of the utility of a JPA system is not possible.

Booher has identified several priorities for future JPA R&D. At the systems level, the effects on training, the personnel system, and job design variables should be studied while holding the given JPA system constant. Work on new aiding devices, basic comparison performance data, and hybrid aids is warranted. R&D on readability of technical instructions is recommended, because the standard of counting syllables per word and translating that to a reading grade level is not an adequate method. Finally, R&D into systems that assist in the development and validation of JPAs is needed.

Approaches

Troubleshooting digital electronics is a potential priority area for increased JPA R&D emphasis. Interactive JPAs were identified as the only appropriate approach to this area (Booher, 1978). Therefore, the application of AI technology toward the development of interactive computer-based JPAs for electronics troubleshooting is suggested. Such interactive JPAs have great potential for adapting to user expertise through use of the same base technology that is used in the construction of adaptive CAI. Thus, device-based JPAs in electronics also provide an ideal test bed to further research on hybrid JPAs and adaptive technical orders (TOs).

NTEC is currently investigating the development of a Personal Electronic Aid for Maintenance (PEAM) under a research contract with Texas Instruments, Inc. The primary objective of PEAM is to produce performance specifications, hardware, and software for a PEAM device.

The development of design and development systems is an important applications goal for JPAs and for courseware. Such systems should facilitate timely JPA revision. Any JPA system must be maintainable; an out-of-date JPA is no aid at all.

Readability and intelligibility were identified as areas of need. Currently at ONR, a number of related projects are underway, for example: Comprehension and Analysis of Information in Text and Pictorial Material (Antos, Bourne, Kintsch & Kozminsky, 1981); Structual Approaches to Procedural Learning from Text and Graphics (Hirschfield & Bieger, 1981); Understanding and Executing Instructions (NR 154-461); Topic and Theme Identification in Prose Comprehension (Kieras, 1981), and What People Know About Electronic Devices: A Descriptive Study (Kieras, 1982). Much of this work has cognitive science foundations and the results of this work should be incorporated into the development of device-based JPAs, as well as in the development of design and development aids for hard-copy print media JPAs.

The advent of expert systems has opened a new world of possibility to job performance aiding. Expert systems have been designed which have, within their boundary of expertise, human level competence. At the present time, various manufacturers are attempting to develop intelligent diagnostic support aids.

Traditional distinctions between training, job performance aiding, and automated test equipment are beginning to blur due to the advent of the expert system. This is because the same simulated representations of task and equipment which constitute the core of an expert system are fundamentally useful whether in training, helping a human do a job, or in doing it for him or her.

Integrating Training, Measurement, JPAs, and Job Design

Challenges

Certain information necessary for job performance is better assigned to the "head" via training than to the "book" via JPAs (Chalupsky & Knopf, 1967, Chenzoff, 1973). Training and operational performance are part of a greater whole. As hybrid or adaptive JPA systems become available, there will be less and less reason for separating training and aiding in the initial stages of enhancing job knowledge and skills. Teel and Chaney (1965) found that the combination of training and aiding produced almost double the performance improvement of either method used alone. During the career of a technician, the proper mix of training and aiding varies. Integrating training, assessment, and JPA systems recognizes this.

Tradeoffs between JPAs, training, and job design are often discussed as if each of these technologies were equivalent. They are highly interrelated, yet no one technology is a direct substitute for the other. For example, while a fixed, fully proceduralized JPA yields cost effective performance for entry-level technicians, there is a negative cost associated with not training these people. This shows up later in long-term career development as an inadequacy in having and being able to generalize complex troubleshooting skills.

Job performance aiding technology and technical training technology share much in common, in particular the need for front-end task analysis and the need for formative and summative evaluation. Task analyses designed to cover the requirements of all three issues would result in cost savings through reduced duplication of effort and in increased effectiveness, through explicit recognition of the close relationship between training, job performance aiding, and job design.

A clear challenge is to develop sophisticated design systems that formally take these issues into consideration in the development of residence training, on-the-job training, and JPAs. In addition, when new weapons systems are being designed, the induced effects of device and job design on the training and aiding requirements can be explored and a human-factored design may be approached in a systematic fashion.

Approaches

A kernel, procedural knowledge base can be developed for an existing or in-development weapons system that includes the device representation, a task representation, and a how-it-works representation. This knowledge base can be used to investigate tradeoffs between job performance aiding, residence training and OJT, and device and task design. Such analyses will yield empirically based decisions regarding device configuration, job design, and training and performance aiding requirements. It is then possible to utilize this knowledge base in concert with appropriate design systems, building blocks, and tools in the design, development, and delivery of adaptive instruction and hybrid JPAs. As seen in Clancey's experiments with MYCIN, it is not true that a knowledge base especially suited to performance would be necessarily useful for instruction. But that should not be a problem in this case if the knowledge base is designed to support a basis for experienced technicians to expand their skills, whether in training or on the job. Systems which merely require the input of symptoms and respond with the probable fault are not useful in this regard. The Air Force goal is to build a basis for technicians to improve their performance and to be able to transfer their skills from one job position to another, contributing to a long-term enhancement of the level of human expertise on the job. Therefore, an integrated adaptive training/assessment/JPA design, development, and delivery system addresses the ultimate source of need for training and job aiding in the first place--a shortage of expertise.

If this approach is chosen, it is critical that a means of reducing the labor intensiveness of developing and using the central data base be developed. At the very least, tools and building blocks should be developed to facilitate the construction and use of such knowledge bases. Approaches to semi-automatic knowledge extraction have been mentioned in the section on task analysis. It is critical that the central data base be able to accommodate the variety of views and perspectives and have appropriate interfaces with each user community, so that each can effectively interact with the data base—in defining it, building it, refining it, validating it, and using it. Members of the various user communities must be able to interact with the data base individually, and directly, otherwise its maintainability is compromised. A system that cannot be supported will not be used. And a system that is designed to be used by many people with different yet closely related goals will not be supported unless these people have direct access to it. Direct user involvement contributes to a feeling of "ownership" that goes a long way toward assuring that the system will be accepted.

With a community involvement with a common data base, strong, viable, systemic mechanisms must be in place to ensure that the data base and its products (training, JPAs) are valid and remain valid. In addition to traditional evaluation procedures, the central knowledge base can be used to develop measures of performance, and the various delivery systems can be used to collect performance data, with which to validate the tradeoffs chosen and the utility and effectiveness of the training and JPA system which have been designed.

This integrated system can be extended to incorporate OJT management procedures and the tracking of individual personnel qualifications at a level of detail useful in maintaining an ongoing OJT program for a particular technician. Data on individual qualifications maintained in this integrated system can be interfaced with related management systems, such as the Integrated Training System (ITS) and the Training Decisions System (TDS). These interfaces can be developed utilizing AI concepts and tools which may contribute to the management of complex systems.

CHAPTER IV. PRACTICAL CONSIDERATIONS

Early in its history, AI held forth great promise of near-term applications, for example, in language translation and chess. The failure of this promise to materialize was a great blow to the credibility of AI research. In the interim, as discussed in Chapter I, AI has matured, particularly through emphasis on knowledge-based systems. Now, once again, AI is holding forth promise. Numerous private, for-profit ventures seeking to capitalize on AI applications have recently been formed. Public awareness of AI has been heightened by the Japanese "fifth generation computer" project. DoD has taken a greater interest in near-term applications, an interest which this report serves. It follows that AI procurement commitments must be carefully targeted for success. A second failure for AI on its second rising would be a tremendous blow to AI and to those who sought to apply it.

The remainder of this chapter is organized around the following practical issues: available hardware, software tools, personnel resources, and guidelines for practical efforts.

Hardware

Until the last few years, almost all work on systems of the sort described here has been performed on computers whose typical million dollar price tag has been a barrier to both R&D and practical use. Many sites have tried to use existing data processing facilities, but these systems did not offer suitable languages or interactive capabilities and were ruled out immediately. Fortunately, a selection of much less expensive equipment now exists in price ranges acceptable at least for the development phase, and trends indicate that target machines for delivering this type of system at low cost are just around the corner. For example, for development purposes, high performance personal LISP machines (such as the LM-2 and 3600 systems available from Symbolics) or similar machines could be used. Other comparable systems include the Xerox "Dolphin" and "Dorado," and the LMI CADR. The Xerox machines support INTERLISP and are compatible with the "Dandelion," a possible delivery vehicle. The Three Rivers PERQ has many similarities to the systems just mentioned, but currently has no LISP implementation.

It is very likely that M6800-based systems will begin to be available with production-quality LISP environments, once the 68010 (virtual memory) version of this micro-processor begins to be widely available. The following systems could serve as low cost target systems at that time: Apollo Domain, Sun Workstation, WICAT 150, Fortune, Corvus Concept, and many others. Few have virtual memory at present. (Large virtual memory is the primary architectural requirement for AI.) In some specialized situations, the IBM Personal Computer might be usable as an AI target machine if equipped with Winchester Disk and sufficient memory. These systems at present have no production-quality LISP. (A number of LISP implementations, including one at Utah and one at Yale, are underway at present.)

Software Tools

Creating an AI application means, among other things, creating software. Software languages, environments, and higher order development systems become crucial considerations in the practical development of an AI application. This section considers, in turn, whether LISP is essentially a prerequisite foundation for AI programming and what higher order development systems are available and, ultimately, how useful these can be.

Despite the benefits of widely available (and allegedly more efficient) languages such as FORTRAN or PASCAL, or the structure and portability of Ada, the current technology of AI employs the use of the LISP language. Automatic storage management, the elevation of functions and closures to "first class citizen" status, the concept of property lists, the relationship between variables and symbols, and the central role of an interpreter (rather than a compiler) are features of the language arguing for its use in this type of application. Other AI languages have been developed (Barr & Feigenbaum, 1982), but LISP in its various dialects predominates as the base language.

Attributes that characterize AI-supportive programming languages in general include the following:

1. Focus on symbol manipulation and list processing.
2. Support of representations, which change dynamically.
3. Support of flexible control by pattern matching rather than by procedure calls.
4. Supportive programming environment, including
   a. An interactive (interpreted) language.
   b. A good editor (program construct oriented, not text oriented).
   c. Debugging facilities (traces, breaks).
   d. Standard systems input/output functions.

High Order Development Systems

There are numerous AI "building block" systems available, some from universities without support, and some commercially. An expert systems workshop (funded by the National Science Foundation and the Defense Advanced Research Projects Agency) was recently held, resulting in two important products. One (Waterman & Hayes-Roth, 1982) is a report describing an investigation into the comparative merits of eight very high level programming languages designed for expert systems: EMYCIN, KAS, EXPERT, OPS5, ROSIE, RLL, HEARSAY-III, and AGE.

The other product is a book describing how to build expert systems (Hayes-Roth, 1983). This comparative study describes available systems, their sources, their comparative merits, and lessons learned from a comparative analysis of these systems, in particular, insights regarding choosing a tool appropriate for the problem and designing a tool for expert system building.

Quoting the comparative study (Waterman & Hayes-Roth, 1982, p. 47), maxims suggested for choosing an appropriate tool are:

1. Do not pick a tool with more generality than you need.

2. Test your tool early by building a small prototype system.

3. Choose a tool that is maintained by the developer.

4. Use the problem characteristics to determine the tool features needed.

Various tools exist for knowledge representation, in particular, KRL (Bobrow & Winograd, 1977) and SRL (Wright & Fox, 1982).

For specific applications, one should consider developing tools and building blocks from scratch. An expert, using a LISP machine, could develop an inference/retrieval package in a week or two of intense effort. The resulting package is apt to be more suitable for the specific application than might be the general packages now available. However, in the long-term, the use of such building blocks as components in larger systems will be essential.

Personnel

People with formal training or practical experience with AI are extremely rare. The recent interest in AI by the private sector has created an enormous demand for AI experts, creating, for the experts, a sellers' market. This means self-aware AI experts expect high salaries, interesting work assignments, software and hardware environments they are familiar with and like to use, and evidence of management commitment to their work. Because of this, other practical considerations, such as choice of hardware or software are often forced by personnel choices. This is especially germane to the LISP issue: does one need to do AI in LISP? The question is moot if it is true that most AI experts like to and are accustomed to programming in LISP and may not be interested in working on a project that does not use LISP or one of the higher level tools built upon LISP.

The common advice from people involved in AI projects is to recruit people with proven AI expertise and not simply to declare someone in the data processing department as the AI expert. At the same time, due to the shortage of expertise, an organization should make every possible effort to develop its own expertise internally. Martins (1982) suggests an AI effort be staffed as follows: recruit talent to fill the main initial technology requirements; use the best of existing staff for technology support. With this strategy, the following dynamics will result: technically gifted but probably managerially unsophisticated AI recruits will mature in leadership qualities as the existing staff, already attuned to organizational realities, acquire technical competence in AI.

The personnel "crunch" is widely recognized by managers of DoD applications programs. A solution to the shortage is addressed most directly in a training and education program proposed to the Joint Logistics Commanders. This program would provide funding for increased higher education opportunities in AI and hopefully help to alleviate the undersupply of trained personnel in this field.

As mentioned, AI is becoming a commercial venture; so, to a certain extent, expertise can be directly contracted for with firms active in this area. Reports on those firms have been made in the popular press (cover story in Business Week, March 8, 1982; a major article in Time, May 17, 1982). Of course, in addition to sites of industrial competence, there are the basic university, nonprofit and governmental centers of activity. These too may serve as sources of expertise and potential sources for recruitment.

Guidelines for Practical Efforts

Today's applications promise of AI is real, but past overzealousness has taught a lesson. In any applications effort contemplated today, the following principles of practical and achievable project management must be followed.

The scope of the applications effort must be constrained to highly specialized solutions to narrowly defined problems. From Hayes-Roth (Gevarter, 1982, p. 2): "the problem should be nontrivial but tractable, with promising avenues for incremental expansion." Objective, definable interim milestones should be set. Hayes-Roth (1982, p. 410-411) lists some situations that instigate knowledge engineering initiatives and some kinds of product innovations now possible:

Situations that Instigate Knowledge Engineering Initiatives

1. The organization requires too many skilled people to recruit or retain.

2. Problems arise that require almost innumerable possibilities to be considered.

3. Job excellence requires a scope of knowledge exceeding reasonable demands on human training and continuing education.

4. Problem solving requires several people because no single person has the needed expertise.

5. The company's inability to apply its existing knowledge effectively now causes management to work around basic problems.

Kinds of Product Innovations Now Possible

1. Active instruments that solve problems by producing answers instead of data.

2. Systems that explain how they work and how to use them.

3. Corporate memories.

4. Reasoning aids and thinking prosthetics.

5. Accident-proof machines.

6. Automated sellers.

7. Hypothesis and expectation management systems.

Realistic project cost and personnel effort estimates are crucial inputs to successful applications. These costs depend on the availability of tools. Hayes-Roth (1982, p. 412) cites as the resources required for a typical knowledge engineering project (about 500 knowledge "chunks" in the rule base), utilizing existing tools, to be about $300,000 to $1,500,000 with 2 to 5 personnel years. Included in this estimate is design, development, knowledge engineers, computing and overhead.

Another analysis, based on project costs of exemplary AI projects over the past 15 years led Davis (1982, p. 10) to the following conclusion:

> Even for the best-understood problems, experienced researchers using the best-understood technologies still require at least five man-years to develop a system that begins to be robust.

The stages of development of an expert system include (Davis, 1982) system design, system development (conference paper level), formal evaluation of performance, formal evaluation of acceptance, extended use in prototype environment, development of maintenance plans, and system release. Davis notes that, to date, no current system has completed all these stages.

Case Study: Practical Guidelines for AI Applications Efforts

In order to add substance to the observations regarding development guidelines, this paper includes as a case study the considerations paid those issues by one of the first commercial attempts to capitalize on AI technology, Computer*Thought Corporation's Ada Tutor.

This section describes the current Computer*Thought product development effort as a case study in practical AI-CAI applications projects. The reader should be aware that the project is not yet complete, and so conclusions must be treated as tentative and subject to modification. The material in the remainder of this chapter was provided by Dr. Mark L. Miller of Computer*Thought.

How was the scope of the practical applications effort determined and specified?

The founders of Computer*Thought had been involved, over a number of years, in developing and working with prototype systems for teaching computer programming. It was desired to apply this technology to some need that would be sufficient to warrant the cost of using systems in the Vax or LISP machine class for initial deliveries, on the assumption that personal computers with this performance will be commonplace in the mid to late eighties. With DoD software expenditures in the billions of dollars per year, and many embedded systems contracts involving millions of dollars, the Ada training market provided an ideal opportunity. Computer*Thought is developing a generic AI-CAI technology for teaching computer programming, using Ada as the initial vehicle. As hardware costs continue to decline, programming tutors for new, potentially mass-market languages (e.g., LOGO or SMALLTALK) will be natural follow-ons from this technology). The project scope (in terms of both curriculum and system features) was narrowed until a small team (growing to a dozen technical staff) could complete an initial product implementation within 1 year.

What effect did the following conditions have on the effort?

1. The specificity of the problem.

   Problem specificity is the key ingredient to success in building this type of system at the present time. As the project has progressed, the system designers have continued to revise initial requirements to increase specificity. There are many topics one might include in an Ada curriculum, for example, and many features one might include in such a system. The question, "will this have a first-order effect on overall effectiveness?" has helped to focus system goals.

2. Existence of prior related R&D and prototypes.

   The Ada*Tutor project was specifically chosen because the company founders had experience with several such R&D prototypes. In particular, the BASIC Instructional Program (BIP), the Spade system, ACSES, and TURTLE were previous prototypes which guided the design. Also, existing experimental literature on help systems for learning programming was useful.

3. Project resource expenditures as a function of time or phase.

   Computer*Thought's initial capitalization has been almost entirely devoted to the Ada*Tutor project. Staffing has grown from the 2 founders to 11 at present and is planned to grow to about 20 by summer of 1983. Approximately 80 percent of staff members have primarily technical functions.

4. Personnel qualifications, background, mix.

   Unfortunately, such projects currently require a rare type of talent that is in great demand in industry. Very few universities offer any formal training in this area. A team of 4 to 12 technical people, organized around a single technical leader, seems most effective. A certain amount of administrative assistance, as well as junior staff (e.g., AI graduate students) can multiply the productivity of key personnel considerably. It takes several years of intense study to achieve expertise in AI/LISP programming; hence reassigning conventional computer science personnel to this task, without formally trained outside expertise, is not recommended.

5. Hardware/software tools.

   The level of ambition of the current Ada*Tutor could not have been achieved within the available resources and time were it not for high performance personal LISP machines and the programming environment they provide. Graphics features such as "windows," and interaction features such as menu selection using a "mouse," have made it possible to rapidly prototype, demonstrate, and re-evaluate ideas within a few weeks. AI programming tools, such as the ZMACS LISP-specific screen editor and the ability to rapidly locate callers/users of a symbol within a large system, have been essential factors in project progress.

What are the stages in such a project?

AI product development projects are really too new to reach any sort of generalization at present. It seems clear that traditional software project life-cycle models do not carry over well into the AI and AI-CAI arenas. Current experience seems to be settling on four more or less distinct phases: (a) requirements analysis and initial design, (b) implementation of an initial feasibility demonstration, (c) prototype development and initial testing, and (d) beta testing and final revision. There remains a danger that the level of robustness required for the final product (versus a prototype) will be more difficult to achieve than was originally contemplated.

CHAPTER V. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Training, performance measurement, and job performance aiding are neither separate nor independent Air Force activities. Training (both in-residence and on-the-job) and job performance aiding are related because they are alternative, complementary approaches to the problem of supporting performance capability in career specialties. Performance measurement is related to both training and job performance aiding because it is through performance measurement that training and JPAs are validated, evaluated and improved. The close relationship among these three disciplines is not limited to their interdependence. They are also related because scientific approaches to each of these three disciplines are based on task analysis.

The technology and techniques of AI are based on development of specific knowledge representations and sets of procedures that act on those representations. The performance capability of intelligent systems is based on the representation and utilization of large amounts of knowledge. Job task analysis serves as the means of providing a representation that can, in turn, be processed by training, performance measurement, and JPA systems. Therefore, the fundamental relatedness of this knowledge may be capitalized on in the development of intelligent systems to serve these disciplines.

From a review of the challenges facing each of these disciplines separately, it appears that the development of <u>adequate</u> job task analyses is a basic problem. From a review of AI technology, it appears that AI provides a unique opportunity to develop and validate representations that can serve as task analyses. These representations are machine-readable and can be used with the help of AI techniques to simulate intelligent behavior, for example: to perform the job task of interest, or to develop or provide instruction in the job task of interest. AI (a) provides a mechanism for developing valid task analyses that help solve one of the major problems facing all three of the potential application areas of interest, (b) provides a basis for integrating the three applications areas into a formal integrated system, and (c) does so computationally, providing the foundation for an automated, computer-based system to serve as an aid in increasing productivity and effectiveness in training, performance measurement, and job performance aiding.

The principal recommendation to be derived from these observations is that training, performance measurement, and job performance aiding should be treated as an integrated system, and that an integrated system is the natural way to approach AI applications in each of these areas. Since AI applications are computer-based; a computer-based system is the required medium in which to meet the challenges.

No integrated computer-based system for training, measurement, and job performance aiding exists. There is, therefore, a great opportunity here to design and build a computer-based system, capitalizing on scientific approaches to building a common foundation of task analysis. Whether such a system should be non-AI-based or AI-based may be questioned. However, it is relevant to note that AI itself is founded on formal representations and the procedures acting upon them, and therefore offers a set of tools and techniques that are almost an exact match for the requirements of integrating the three applications areas.

Traditional approaches in each of these areas have weaknesses in the area of knowledge representation. AI offers approaches to meeting the challenges faced by each discipline separately and offers a way of integrating these disciplines in a formal, explicit fashion.

Recommendations

Specific recommendations for the development of an R&D program in applications of AI technology to training, performance assessment, and job performance aiding are presented below. The approach taken is to structure such a program around an integrated technical training, performance measurement, and job performance aiding design, development, delivery, and evaluation system. The details of specific approaches within each of the areas of training, measurement, and job performance aiding are presented in the Approaches sections in the main body of this report.

Recommendation 1

A single, integrated, intelligent, computer-based system should be developed having application to three facets: training, performance measurement, and job performance aiding.

Recommendation 2

The same system should support in an integrated fashion the design, development, delivery, and evaluation of each facet.

Recommendation 3

The integrated computer-based system should support and encourage direct interaction with instructional developers, subject matter experts, course personnel, on-the-job supervisory personnel, evaluators, and the trainee/specialist.

Recommendation 4

A master plan specifying the basic functions of the computer-based system should be developed and used to prioritize its own implementation so that the task analysis representations are developed first and that each project effort can be integrated with the larger system.

Recommendation 5

As early as possible, the system should be configured as a program demonstration.

Recommendation 6

A target career specialty should be selected through careful front-end analysis with the objective of identifying a job area, first, that is of critical importance in the Air Force mission, second, for which there is promise or need of improved productivity and effectiveness or of reduced cost of operations, and third, that is amenable to the detailed analyses required to develop device and task performance models. Avionics maintenance is identified as a general area meeting the above criteria.

Recommendation 7

The central procedural and declarative knowledge bases should include (a) a procedural representation of the device(s) from the perspectives of both operations and maintenance, (b) a procedural representation of the tasks, both routine operations and maintenance, (c) a suitably detailed "how-it-works" hierarchy regarding the device's functionality and structure, (d) an explicit model of the interrelationships between training, measurement, and job performance support and evaluation for the career area chosen, and (e) an explicit body of procedural knowledge relating to curriculum sequencing and pedagogical interaction.

Recommendation 8

The system should be developed in LISP or alternatively, in Ada (assuming that comparability can be established between LISP and Ada). All aspects of the system should share the same computing environment; hence, the delivery modality of the system should also be in LISP.

Recommendation 9

The system should utilize start-of-the-art graphics, including high resolution graphics and graphic overlays on video disc images.

Recommendation 10

The system's terminals or stations should be networked. Local processing should be supported, but it is necessary for data, in particular the procedural and declarative knowledge bases, to be stored centrally. These knowledge bases will be undergoing continual development and refinement throughout the design, development, delivery and evaluation process.

Recommendation 11

System hardware should be state-of-the-art LISP machines or carefully chosen alternatives. The long-term implementation strategy should rely on the fact that delivery versions of these machines will be on the market in 3 to 5 years.

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APPENDIX A

CURRENT RELEVANT DoD RESEARCH PROJECTS--DETAILED LISTING

The information in this section is divided into the following fields:

Project Title

sponsoring agency	performing organization	project duration
project monitor	project contact	level of funding
telephone number of monitor	telephone number of contact	

Reference to material that will provide additional information

For each title, the maximum amount of information available has been included. The information is presented alphabetically by title; Table I may be one useful index for locating project titles in Appendix A, as it is arranged by sponsoring agency.

Abbreviations of the sponsoring agencies are as follows:

AFHRL	Air Force Human Resources Laboratory
AFOSR	Air Force Office of Scientific Research
ARI	Army Research Institute
NAVAIRENGCEN	Naval Air Engineering Center
NPRDC	Navy Personnel Research and Development Center
NTEC	Naval Training Equipment Center
ONR	Office of Naval Research
TAEG	Training Analysis Evaluation Group (Navy)

Adaptive Computerized Training System (ACTS)

ARI B.W. Knerr (202) 274-8872	Perceptronics, Inc. A. Freedy (213) 884-7470	$521,000

Defense Technical Information Center. Work Unit Summaries. Alexandria, VA: DTIC, 1982.

Advanced Computer-Based Training for Propulsion and Problem Solving: STEAMER

NPRDC J.D. Hollan, Jr. (714) 225-7121	Bolt Beranek & Newman, Inc. A. Stevens (617) 492-3656	March 81-March 84 $2,198,543

Defense Technical Information Center. Work Unit Summaries. Alexandria, VA: DTIC, 1982.

Advanced Instructional Development: Intelligent Maintenance System

ARI J. Psotka (202) 274-5540		Sep 83-Jan 86

Analysis of Acquiring Strategic Knowledge in Problem Solving

ONR (667-459)	University of Pittsburgh J.G. Greeno & M. Riley (412) 624-4141

Office of Naval Research. Psychological Sciences Division, 1981 Programs. Arlington, VA: Office of Naval Research, December 1981.

Artifical Intelligence Analyses

NTEC E. Ricard (305) 646-5130	University of Central Florida D. Abbott (305) 275-2216	Jun 81-Sept 82 $201,992

Defense Technical Information Center. Work Unit Summaries. Alexandria, VA: DTIC, 1982.

Artificial Intelligence-Based Maintenance Tutor

ARI (project in preparation)
J. Psotka
(202) 274-5540

Artificial Intelligence in Maintenance Diagnostics and Information Systems

AFHRL Systems Exploration, Inc.

Authoring Instructional Materials (AIM)

NPRDC J.D. Ford (714) 225-7121	NPRDC W.H. Wulfeck (714) 225-7121	Oct 81-Sept 86

Defense Technical Information Center. Work Unit Summaries. Alexandria, VA: DTIC, 1982.

Automated Performance Measurement System C-5 Aircraft

AFHRL (Williams AFB)
R. Hughes
(602) 988-6561

Air Force Human Resources Laboratory. AFHRL Annual Report: FY 81. Brooks AFB, TX: AFHRL, 1982.

Automatic Knowledge Acquisition Techniques for Expert Systems

NTEC R. Ahlers (305) 646-5130	Perceptronics, Inc. (213) 884-7470	$80,000

Defense Technical Information Center. Work Unit Summaries. Alexandria, VA: DTIC, 1982.

CASDAT Enhancement

NTEC R. Bird (305) 646-4701	Rowland and Company N. Marcue (305) 894-7086	Sept 81-Jul 82 $93,831

Class "A" Electronic Equipment Maintenance Training System

NPRDC
V.M. Malec
(714) 225-7121

Navy Personnel Research and Development Center. NPRDC FY-82 Programs. San Diego, CA: NPRDC, n.d.

Cognitive and Instructional Factors in the Acquisition and Maintenance of Skills

ONR (157-430) M.J. Farr (202) 696-4504	University of Pittsburgh R. Glaser, A. Lesgold, J. Greeno, M. Chi, & M. Resnick (412) 624-4895	Jan 79-Sept 82 $1,298,950

Defense Technical Information Center. Work Unit Summaries. Alexandria, VA: DTIC, 1982.

Cognitive Processes in Planning and Control

ONR (667-411)	Rand Corporation B. Hayes-Roth

Office of Naval Research. Psychological Sciences Division, 1981 Programs. Arlington, VA: Office of Naval Research, December 1981.

Comprehension and Analysis of Information in Text and Pictorial Materials

ONR (667-422)	University of Colorado L.E. Bourne, Jr., W. Kintsch, & P. Baggett (303) 492-0111

Office of Naval Research. Psychological Sciences Division, 1981 Programs. Arlington, VA: Office of Naval Research, December 1981.

Computational Models of Problem-Solving Skill Acquisition

ONR (667-477) H. Halff (202) 696-4327	Xerox Palo Alto Research Center J.S. Brown (415) 494-4341	Jan 82-Dec 82 $98,730

Defense Technical Information Center. Work Unit Summaries. Alexandria, VA: DTIC, 1982.

Computer Aided Authoring System

TAEG	University of Central Florida Hosni (305) 275-9101	$39,000

Computer-Based Maintenance Aids for Technicians

AFHRL (Wright-Patterson AFB)
D.L. Thomas
(513) 255-3771

Air Force Human Resources Laboratory. AFHRL Annual Report: FY 81. Brooks AFB, TX: AFHRL, 1982.

Computer-Based Modeling and Diagnostic Testing of Problem-Solving Skills

ONR (154-508) H. Halff (202) 696-4327	Carnegie-Mellon University P. Langley (412) 578-3598	Nov 82-Nov 84 $203,425

Office of Naval Research. Psychological Sciences Division, 1982 Programs. Arlington, VA: Office of Naval Research, December 1982.

Computer-Based Program Consultant for Introductory Programming

ONR/ARI R.A. Wisher (202) 274-5779	Yale University E. Soloway	Jun 83-Sep 84

Personnel Training and Research Group of the Office of Naval Research. News & Notes, 1982, 2(4), 2-5.

Computer-Based Techniques for Training Procedural Skills

NPRDC
E.L. Hutchins
(714) 225-7121

Navy Personnel Research and Development Center. NPRDC FY-82 Programs. San Diego, CA: NPRDC, n.d.

Computer-Based Training of Mission Planning and Control Skills

ONR (154-486) H.M. Halff (202) 696-4327	Perceptronics, Inc. P.W. Thorndyke (213) 884-7470	Feb 82-Feb 85 $225,000

Defense Technical Information Center. Work Unit Summaries. Alexandria, VA: DTIC, 1982.

Computer-Based Tutoring for Diagnostic Skill Acquisition

ONR/ARI J. Psotka (202) 274-5540	Stanford University B. Buchanan & W. Clancey (415) 497-1997	Mar 79-Sep 85 $1,110,?47

Personnel and Training Research Group of the Office of Naval Research. News & Notes, 1982, 2(4), 2-5.

Development of Draft Military Specifications for Maintenance Task Analysis and Logic Tree Troubleshooting Aids

AFHRL (Wright-Patterson AFB)
E.G. McFall
(513) 255-5910

Air Force Human Resources Laboratory. AFRHL Annual Report: FY 81. Brooks AFB, TX: AFHRL, 1982.

Evaluation of Individual Performance in Mechanical Specialties

AFHRL (Brooks AFB)
S. Lipscomb
(512) 536-3551

Air Force Human Resources Laboratory. AFRHL Annual Report: FY 81. Brooks AFB, TX: AFHRL, 1982.

General Patterns of Scientific Inference

ONR/ARI J. Psotka (202) 274-5540	Carnegie-Mellon University J. Larkin & J. Carbonell (412) 578-2000

Personnel and Training Research Group of the Office of Naval Research. News & Notes, 1932, 2(4), 2-'

Human Understanding of Complex Systems

ONR (667-428) M.J. Farr (202) 696-4504	Bolt Beranek & Newman, Inc. A.M. Collins & A. Stevens (617) 497-3377	Mar 79-Feb 82 $292,531

Defense Technical Information Center. Work Unit Summaries. Alexandria, VA: DTIC, 1982.

Intelligent Automated Tutors for Instruction in Planning and Computer Programming

ONR (154-461) H.M. Halff (202) 696-4327	Texas Instruments, Inc. M. Miller (214) 980-6081	(exp date) Sept 81 $99,500

Defense Technical Information Center. Work Unit Summaries. Alexandria, VA: DTIC, 1982.

Intelligent Computer-Assisted Instruction: An Interactive Reading Tutor

ONR/ARI R.A. Wisher (202) 274-5779	Yale University R. Schank & J. Black (203) 436-4771	Jun 83-Sep 84

Personnel and Training Research Group of the Office of Naval Research. News & Notes, 1982, 2(4), 2-5.

Intelligent Computer-Based Instruction for Simulation Training of Troubleshooting Skills

ONR/ARI R.A. Wisher (202) 274-5779	Bolt Beranek & Newman W. Fuerzeig & J. Frederiksen (617) 497-3448	May 83-Sep 84

Personnel and Training Research Goup of the Office of Naval Research. News & Notes, 1982, 2(4), 2-5.

Intelligent Instructional Methods for Teaching Procedural Skills

ONR (154-493)	Bolt Beranek & Newman, Inc. W. Fuerzeig & J. Frederiksen (617) 497-3448	

Office of Naval Research. Psychological Sciences Division, 1982 Programs. Arlington, VA: Office of Naval Research, December 1982.

Intelligent Tools for CAI

ARI	Yale University Soloway	$30,000

Interactive Computer Grahpics Simulation for Intermediate Level Maintenance Trainer

AFHRL (Lowry AFB) J. Deignan (303) 370-3391	Canyon Research Group, Inc. B. Pieper (303) 753-3376	May 81-Sep 84 $700,000

Memory-Based Expert Systems

AFOSR W.R. Price (202) 767-5025	Yale University R. Schank (203) 436-4771	Jan 82-Mar 84 $159,178

Defense Technical Information Center. Work Unit Summaries. Alexandria, VA: DTIC, 1982.

Mental Representation of Circuit Diagrams

ONR (667-491)	Perceptronics, Inc. M.G. Samet & C. Wickens (213) 884-7470	

Office of Naval Research. Psychological Sciences Division, 1981 Programs. Arlington, VA: Office of Naval Research, December 1981.

A Model for Procedural Learning

ONR (154-399) M.J. Farr (202) 696-4504	Carnegie-Mellon University J.R. Anderson (412) 578-2781	Sept 78-Sept 80 $174,987

Defense Technical Information Center. Work Unit Summaries. Alexandria, VA: DTIC, 1982.

Modeling Student Acquisition of Problem-Solving Skills

ONR (154-444) H.M. Halff (202) 696-4327	Rutgers University R.L. Smith (201) 932-3623	Sept 79-Aug 81 $129,992

Defense Technical Information Center. Work Unit Summaries. Alexandria, VA: DTIC, 1982.

Personal Electronic Aid for Maintenance (PEAM)

NTEC B. Rizzo (305) 646-5130	Texas Instruments, Inc.	$100,000

Plan for Application of Artificial Intelligence Technology to Technical Training, Performance Measurement, and Job Performance Aiding

AFHRL G. Walker (303) 370-3391	Denver Research Institute J. Richardson (303) 753-2087	Jan 83-Sep 83 $125,000

Principles of Intelligent Computer-Based Instruction for Cognitive Skills

ONR/ARI J. Psotka (202) 274-5540	University of Pittsburgh J. Greeno & J. Brown (412) 624-4141	Mar 83-Sep 85

Personnel and Training Research Group of the Office of Naval Research. News & Notes, 1982, 2(4), 2-5.

Procedural-Net Theories of Human Planning and Control

ONR (667-414) M.J. Farr (202) 696-4504	Science Applications, Inc. M. Atwood (303) 773-6900	Jan 78-Jun 81 $232,486

Defense Technical Information Center. Work Unit Summaries. Alexandria, VA: DTIC, 1982.

The Role of Prior Knowledge in Operating Devices

ONR (667-473)	University of Arizona D. Kieras (602) 626-2751	

Office of Naval Research. Psychological Sciences Division, 1981 Programs. Arlington, VA: Office of Naval Research, December 1981.

Simulation Models for Procedural Learning and Expert Memory

ONR (157-465)
M.J. Farr
(202) 696-4504

Carnegie-Mellon University
J.R. Anderson
(412) 578-2781

Oct 80-Nov 82
$333,432

Defense Technical Information Center. Work Unit Summaries. Alexandria, VA: DTIC, 1982.

Structural Approaches to Procedural Learning from Technical Text and Graphics

ONR (667-452)

Cornell University
M.D. Glock
(607) 256-1000

Office of Naval Research. Psychological Sciences Division, 1981 Programs. Arlington, VA: Office of Naval Research, December 1981.

Studies of Skilled Human Performance

ONR (667-437)

University of California, San Diego
D.A. Norman & D. Rumelhart
(714) 452-2230

Office of Naval Research. Psychological Sciences Division, 1981 Programs. Arlington, VA: Office of Naval Research, December 1981.

Systems Automation through Artificial Intelligence

AFOSR
D. Fox

Task-Oriented Measurement Technologies

AFHRL (Brooks AFB)
H.W. Ruck
(512) 536-3648

Air Force Human Resources Laboratory. AFHRL Annual Report: FY 81. Brooks AFB, TX: AFHRL, 1982.

Technical and Engineering Services to Determine Automatic Test Equipment Technological Use of AI Applications

NAVAIRENGCEN
J. Kunert
(201) 323-7463

Theory of Graphic Representation

NPRDC
W.E. Montague
(714) 225-7121

Navy Personnel Research and Development Center, NPRDC FY-82 Programs. San Diego, CA: NPRDC, n.d.

Topic and Theme Identification in Prose Comprehension

ONR (667-423)

University of Arizona
D. Kieras
(602) 626-2751

Office of Naval Research. Psychological Sciences Division, 1981 Programs. Arlington, VA: Office of Naval Research, December 1981.

Training Aids Developed from Learning Guidelines

TAEG
R. Braby
(305) 646-5673

Tutoring and Problem-Solving Strategies in Intelligent Computer-Aided Instruction

ONR (154-436)

Stanford University
B. Buchanan & W. Clancey
(415) 497-2300

Office of Naval Research. Psychological Sciences Division, 1981 Programs. Arlington, VA: Office of Naval Research, December 1981.

Understanding and Executing Instructions

ONR (154-461)	Bolt Beranek & Newman, Inc. R.L. Smith, Jr. (617) 492-4841

Office of Naval Research. Psychological Sciences Division, 1981 Programs. Arlington, VA: Office of Naval Research, December 1981.

Unified Data Base Technology

AFHRL (Wright-Patterson AFB)
R.N. Deem
(513) 255-3771

Air Force Human Resources Laboratory. AFHRL Annual Report: FY 81. Brooks AFB, TX: AFHRL, 1982.

Voice Technology as the Instructor's Assistant

NTEC R. Ahlers (305) 646-5130	Honeywell J. Brock (612) 378-4403	Jul 81-Oct 82 $35,000

Defense Technical Information Center. Work Unit Summaries. Alexandria, VA: DTIC, 1982.

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