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# Applications of Artificial Intelligence in Military Simulation

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# APPLICATIONS OF ARTIFICIAL INTELLIGENCE IN MILITARY TRAINING SIMULATION

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# ABSTRACT

This report is a survey of Artificial Intelligence (AI) technology contributions to military training. It provides an overview of military training simulation and a review of instructional problems and challenges which can be addressed by AI. The survey includes current as well as potential applications of AI, with particular emphasis on design and system integration issues. Applications include knowledge and skills training in strategic planning and decision making, tactical warfare operations, electronics maintenance and repair, as well as computer-aided design of training systems. The report describes research contributions in the application of AI technology to the training world, and it concludes with an assessment of future research directions in this area.

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# CHAPTER 1

# INTRODUCTION

Military training systems are necessary for instruction in a wide variety of tasks with varying degrees of complexity. The instructional environment may be "paper and pencil," or it may require complex simulators. For all of this diversity, the fundamental goal is to transfer expertise so that a body of knowledge or degree of skill is imparted to the trainee.

Each year the military services spend billions of dollars on training. A large percentage of that amount is spent in the development, acquisition and utilization of training devices. Computer-based training is becoming increasingly prevalent. Current applications include testing, drills, tutorials, games, simulations, and computer-managed instruction. During the past decades there has been a dramatic change in the variety of training tasks to which simulation has been applied. The main change has been an extension of the synthetic training environment to tasks which simulation could previously not support. For example, flight training has developed from the simulations of takeoff and landing to almost all aspects of the tactical use of aircraft. Much of this has been due to the development of software and hardware to create visual displays and sensor simulation of radar, forward looking infrared, and low light level TV, the application of new means of interacting with computer-based trainers, and the proliferation of small computer systems with large amounts of memory.

Recently developed applications have involved interactive graphics, videodisc, voice and microcomputer technologies. One of the most promising applications is based on Artificial Intelligence (AI) technology in combination with cognitive science research, through which "intelligent" tutoring and training systems may evolve. Since teaching and learning involve at least cognitive activities, only machines capable of some degree of thinking skills could serve to augment (or replace) teaching functions or to extend learning capabilities. Intelligent training systems differ from conventional systems in that they "understand what they teach and what the student understands" (Kearsley and Seidel 1985).

Potential applications of AI to military training include intelligent training simulation, instructor aids and support, and automated instructional system development. This report examines and evaluates the applicability of AI technology to the training system domain. In addition to an overview of military training simulation and of AI, the following topics are addressed: training problems that can be alleviated by AI, survey of current AI-based training devices, potential applications of AI to military training, system design and integration issues, researchers' findings and their conclusions, a summary of what was learned through this investigation, and directions for future research.

AI can be expected to have a significant impact on future military training. In view of the shortage of subject matter and instructional experts, intelligent systems may well prove to be cost effective alternatives to meet the military services' severe training requirements.

## CHAPTER 2

## MILITARY TRAINING SIMULATION

### Complexity of Military Systems

In recent decades, military work environments have grown steadily in complexity, as weapon systems, electronics, maintenance equipment, and other hardware used in national defense have proliferated. Today's military workers must pursue goals in technology-laden contexts where interacting with complex machines is the rule. The General Accounting Office, in its report to Congress regarding "How to Improve Effectiveness of U.S. Forces Through Improved Weapon System Design" (1981), focused on the importance of the operator to the overall effective functioning of the weapon system. The report estimated that human errors account for at least 50 percent of the failures of major weapon systems. Their findings attribute this problem to the increasing complexity of modern day systems. One issue evident from this investigation is the need for improved training as a means of reducing operator error.

### Operational Equipment in Training

The use of operational equipment for training is becoming increasingly difficult. Rising costs of weapon system ownership and operation have made it infeasible to use actual equipment as the backbone of instructional systems. Actual equipment is often needed in the field and cannot be spared for school house training. Designers of actual equipment rarely consider training issues, and instructional functions are not embedded in the operational system. In addition, some tasks are dangerous to train on actual equipment or can only be exercised under wartime conditions. The military services have therefore been forced to reevaluate the way individuals are trained.

New instructional techniques using training devices and simulators have afforded the opportunity to train tasks that are difficult or impossible to train using only the actual equipment. Consequences of operator error or inability to appropriately respond to normal and emergency requirements are significantly less in a simulator. Control over training events is vastly superior to that available in the field. Training events can easily be repeated until necessary operator skill levels are achieved, and their utilization rates are significantly greater than actual equipment.

## Simulator Usage

In a simulation, a computer model of a particular process, system or device is created. A training simulator can generally be defined as a simulation of an actual system in order to produce a realistic training situation. Traditionally, simulators have been designed to support practice in as many of the tasks needing to be learned as possible. In general, this has resulted in the development of display, control and computational technologies capable of replicating the interfaces between the student and the actual equipment, its systems and its environment. Applications range from teaching maintenance principles to tactics training for sophisticated aircraft. The most familiar training device is the aircraft flight simulator, featuring a replica of the cockpit controls and displays. Flight simulation has been extensively used in both military and commercial aviation training for the past several decades.

Another commonly used simulator is for maintenance training. Maintenance teams play an important role in military operations. Formal training of maintenance technicians is conducted both in the classroom and on the job. Classroom instruction typically involves the use of simulated equipment maintenance trainers as well as traditional lecture methods. These simulators provide familiarity with component locations and Technical Order (T.O.) procedures while avoiding the use of actual resources. Safe simulation of malfunctions without damage to the real equipment is therefore possible.

Other examples of military training simulations are tank crew training simulators for the U.S. Army, simulated radar for countermeasures training, pierside combat system trainers which enable a surface ship commander to react under battle conditions while still in port, propulsion engine plant simulators, missile launch procedures trainers and Command, Control and Communications team trainers. In the U.S. Air Force, simulators range from simpler procedures trainers to more complex training systems. Part Task Trainers, for example, are operator trainers which allow selected aspects of the overall task to be practiced. An air refueling part task trainer for instance provides training for a task which is a part of a larger team effort. A radar operations trainer provides training for a task which is a part of the operator's overall task. An Operational Flight Trainer is a device that dynamically simulates the actual flight characteristics of a particular aircraft and thereby helps to train flight crews in cockpit, instrument flight, emergency communications, and navigation procedures. A Weapon System Trainer is a device which provides not only a synthetic flight environment, but also a tactics environment, whereby aircrews work individually or as a team in completing simulated missions (Air Force Regulation 50-11 1977).

## The Simulator: An Instructional System

Training simulation involves more than systems simulation. Two attributes make the simulator something other than a working model of a system: first, its ability to represent elements of a mission task which are important for the operator to be trained in, and second, its ability to control additional parameters which support, facilitate, enhance and ensure learning. For many years, the first attribute was emphasized almost at the expense of the second, as training administrators and simulator designers attempted to recreate the operational task environment to the greatest extent possible. Efforts to advance the state of the art had for many years focused primarily on system capabilities and fidelity rather than instructional value, often short-changing the role and the needs of the simulator instructor. The simulator instructor, however, performs key functions in the instructional process which maximize the training utility of simulators. Some of these functions can and have been automated, and moreover, the instructor can be given ready access to the instructional capabilities he or she requires. Training simulators, therefore, typically include instructional support features in addition to a replication of the student's work environment. Later, it will be seen that opportunities for applying AI techniques to simulator-based training can be directed at instructional functions in addition to tactical environment simulation.

# CHAPTER 3

# ARTIFICIAL INTELLIGENCE: AN OVERVIEW

## Scope of AI

The field of AI involves the study of computational mechanisms which allow machines to perform tasks which were previously performed only by humans. These tasks involve functions of understanding and generating written and spoken natural language, encoding visual scenes into meaningful and useful representations, planning and execution of physical motions, complex decision making and learning from experience.

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

The long-term goals of constructing intelligent machines is still more of philosophical than practical interest. However, AI is also a part of advanced computer science, and computational techniques pioneered by the AI community have found widespread practical application.

## Intelligent Problem Solving

Intelligent behavior involves tasks for which algorithmic solutions do not exist. These tasks often involve complexity, uncertainty, or ambiguity, where a controlled heuristic search rather than a random exhaustive search for a solution is necessary. A heuristic is a rule of thumb, trick, strategy, simplification, common sense or other method that aids in the solution of complex problems. The heuristic search reduces the size of the space in which one needs to search for solutions to the problem at hand.

The beginning of AI's current success was the recognition that knowledge powers the solution to important problems. AI can be concerned with several types of knowledge: procedural, declarative, and control. Representing knowledge and techniques for processing knowledge are basic elements in 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 and Papert 1977).

## Expert Systems

One AI application area that has gained wide recognition is expert systems. An expert system is an AI program that exhibits or aids professional level human expertise in areas such as medical diagnosis, legal judgement, structural engineering, computer system configuration and petroleum exploration. These systems make use of information obtained through extensive interaction with experts to imitate the expert's reasoning process when it confronts a problem. Expert systems have become successful outside the laboratory because, unlike other AI application fields, they work in very narrowly constrained environments, with limited vocabularies and narrow domains of knowledge.

Expert systems are said to be knowledge-based, and the technique for constructing them is called knowledge-engineering. The raw material of knowledge engineering is knowledge. Knowledge engineering involves obtaining this knowledge from a human expert, structuring it in a way which allows for its representation, and organizing the process for the utilization of the knowledge.

Expert systems use knowledge and inference procedures to solve problems. The knowledge consists of facts and heuristics, where facts are a body of information that is generally agreed upon by experts in the field, and heuristics are rules of good judgement, plausible reasoning, or good guessing that characterize expert level decision making in a field. The performance level of an expert system is primarily a function of the size and quality of the knowledge base it possesses (Feigenbaum 1982). The knowledge is supplemented by an inference mechanism that enables drawing conclusions from the knowledge.

## AI-Based Tutoring Systems

Intelligent tutoring systems contain some measure of expertise which is useful in the educational process. This class of programs is closely related to expert systems in that they include extensive knowledge of an expert domain. Intelligent tutoring systems and the use of AI techniques in educational software is also termed Intelligent Computer Aided Instruction (ICAI). The goal of ICAI systems is to assume some of the duties of an instructor. The systems include instructional as well as subject matter expertise.

GUIDON is a well publicized example of an ICAI system which uses the knowledge from an expert system, MYCIN, to instruct medical students. MYCIN itself is a medical expert system which provides anti-microbial therapy for bacteremia and meningitis. GUIDON is a case-method tutor which leads a student through a case already solved by MYCIN. GUIDON uses tutoring rules to select discourse procedures, choose domain knowledge, and update the student model (Clancey 1982).

# CHAPTER 4

# TRAINING NEEDS ADDRESSED BY AI

## The Challenges in Military Training

There is a continuing need for improved training of military personnel, especially in critical skills associated with the operation and maintenance of complex military systems. With the increased sophistication of technologies supporting weapon systems, the use of complex, high-technology equipments requires an increasing flow of highly skilled, specialized operators and technicians. The military services, however, have experienced a decline in trained personnel. This is in part due to personnel attrition caused by an emigration to private industry, which offers more attractive work benefits. Military training programs produce individuals with expertise that is in great demand by the private sector.

The shortage of expertise also results from the continuing evolution of system complexity, which creates a demand for personnel with the knowledge to understand and the skills to work with equipment that is increasingly complicated and technical.

The services' goal of insuring that their people have the expertise to accomplish peacetime and wartime missions continues to be resolved through training programs. The shortage of expertise is at the heart of a conflict between the training and field missions within all branches of the military. Since the services want to provide quality instruction, the instructors are usually the most experienced people, i.e. the experts. However, when the expert is instructing, he or she is not performing his/her primary job in the field. The field feels a shortage of trained personnel and needs the graduates of training programs to be trained to a higher technical caliber, but this in turn robs the field of its most highly trained people, i.e., the instructors.

For these reasons, it is generally agreed that present methods of training development and delivery need improvement, whereby people are trained more effectively, more quickly, and at lower cost. The challenge is to maximize the competence that results from training, while minimizing the amount of resources spent. Training effectiveness has of course long been a goal for the military services, and progress is continuously being made.

## Technology Solutions

Emerging technologies in combination with new training methodologies do offer the potential for increased training effectiveness. One way to more effectively utilize experienced people is by allowing the computer to perform some of the training. The cost of personnel is increasing, while computers are becoming less expensive and more capable.

New developments in computer hardware, particularly microcomputer-based systems, offer potential benefits for training. These systems represent increased computational power in a smaller, portable configuration at lower cost (Kelly 1985).

There is also the potential of applying training methodologies in combination with cognitive science. Cognitive science takes an information processing approach to the study of human cognitive processes. Of particular interest to trainers is the recent focus on the nature of expertise, including expert versus novice, mental models, and problem solving in technical domains. The possibility exists for a training device that can interactively model a trainee's current knowledge and problem-solving strategies, compare this with what an expert would do, and in real time, design (!) and deliver instruction.

AI techniques, too, can provide approaches to increased training effectiveness. Those discussed in this report may be applied to either the in-residence (school house) or on-the-job (OJT) training environments. Because in-residence training emphasizes classroom sized groups of students, applications of AI may be most appropriate in the OJT environment where training is more structured around the individual.

## AI and Training Needs

Appropriateness of the subject matter for the use of AI is an important consideration in the application of AI to solve training problems. The selected application must be able to reflect an advantage from utilizing the new technology. AI will be beneficial in domains that have a significant cognitive component. Representative cognitive activities are problem formulation, searching for problem solutions, diagnosis, and decision making. These activities require representation of knowledge and inferential reasoning about that knowledge. There are two relevant domains for a training system: the knowledge content of the technical specialty being taught, and the instructional knowledge of methods, strategies and procedures.

Simulators are typically designed to develop and extend knowledge and skills that are impractical, expensive, or impossible to exercise within operational environments. Often simulators provide practice on the target task, but little or no instructional feedback on trainee performance, skill deficiencies, or coaching on correct behavior. Human instructors must therefore observe trainee performance and provide appropriate instructional interventions. In many cases skilled instructors are in short supply relative to the number of trainees. This problem could be alleviated by intelligent simulators with "surrogate instructor" capabilities. These are capabilities in addition to simulation of operational equipment and situations. Such augmented training capabilities could extend the availability of individualized instruction. Because instructors are a critical resource in short supply, automating the instructor's role in the training system is highly desirable.

In a tactical training system, the instructor may have several distinct roles. In addition to monitoring the trainee, the instructor may also play the role of an adversary, as well as a fellow team member (Moreno 1984). In such a training environment, the instructor has a demanding and complex job. AI technology could be applicable to an environment where the instructor has multiple responsibilities.

Singer and Perez (1986) identified the lack of training developers' expertise as a training related problem. Training developers are not typically expert in the training device literature and in the many factors and interrelationships to be considered when prescribing training device features such as functional and physical fidelity, instructional features, and training effectiveness. The potential exists for applying an expert system to the ill-defined area of training system design. An AI-based decision support system could effectively assist in making choices concerning the kind of training device required to train specific tasks, and how that training device is most effectively used in training.

The next chapter describes how current AI-based systems address these problems and challenges. The solutions focus on automated artificial expertise in the design and delivery of instructional capabilities.

# CHAPTER 5

# CURRENT AI-BASED TRAINING SYSTEMS

The systems to be described are representative of the current state-of-the-art in working applications of AI to military training. These systems are of a prototype nature: they are operational in the sense that they could become useable products in a real educational situation without significant conceptual changes to the design. All of them are microprocessor implementations, and thereby further advance the ultimate goal of inexpensive portable computer-based trainers that would greatly increase the amount of practice and quality of training available to military personnel.

## Propulsion Engineering Training System

STEAMER is a computer-based simulation of a Navy 1078-class frigate propulsion plant. It has a color graphics display for inspecting and controlling the simulation, and a black and white display to exercise other features in the system. The color screen shows dynamic graphic displays of different views of the plant, such as gauges, pumps, and valves, while the black and white screen is for typing commands. Students use a mouse to manipulate the simulated steam plant by pointing at displayed valves and other components, and causing them to be adjusted, opened or closed, or to be turned on or off. A trainee can simulate a casualty, such as a stuck valve, and look at its propagation through the system by selecting other views of the plant (Stevens and Hutchins 1983).

STEAMER was designed to incorporate an intelligent tutorial component capable of providing students with guidance in plant operating procedures, instruction in basic operating principles, and explanations of component and subsystem operations. The intent of the STEAMER project was to develop advanced knowledge-based techniques for use in computer-based training systems. Research and development was conducted under a Navy contract with Bolt, Beranek and Newman, Inc., and a series of eight reports describe the developmental efforts for the automated tutor. Components include a procedures tutor that monitors student procedures and displays them on the black and white screen, an explanation module for the operation of a feedback system, and a set of minilabs for teaching basic principles needed to understand the plant. The designers claim that although STEAMER was developed for the specific domain of propulsion engineering, a large part of the system is generic; i.e., its graphics system, graphics editor, tutorial capabilities, and user interface have all been designed to work with other simulation models.

The prototype STEAMER system has been evaluated by users. It was installed at the Surface Warfare Officers School in Newport, Rhode Island and made available for use by Propulsion Plant Trainer instructors. They felt that the STEAMER system could make a valuable contribution to propulsion training. In order to evaluate the system's instructional potential for enlisted personnel, it was also installed at the Engineering Systems School, Naval Training Center, Great Lakes, Illinois. There, the system was used to instruct both those with experience in steam propulsion and those who had no prior exposure to the subject. Results of these efforts were not available through the literature search.

## Tactical Action Officer Training Systems

The Navy developed a computer-based memorization system for training tactical action officers (Crawford and Holland 1983). A tactical action officer (TAO) is that individual on watch who is designated to take direct defensive action using the ship's weapons and electronic countermeasures. The TAO, who is directly responsible to the commanding officer for his decisions and actions, should be experienced in tactical decision making in a Naval environment, with knowledge of anti-air, anti-surface, anti-submarine, amphibious and electronic warfare. The TAO should also be familiar with the available intelligence on potential enemy tactics, and be knowledgeable about capabilities and limitations of enemy hardware, including weapons platforms and anti-ship cruise missiles.

The TAO training is conducted at the Fleet Combat Training Centers (Pacific and Atlantic) and at the Surface Warfare Officer School. Students master information on enemy platforms, weapons, electronics, and surveillance capabilities. The six-week course has lectures and simulation exercises. The information taught to TAOs is hard to acquire and difficult to maintain unless continually used. A portable training system would facilitate the initial learning of this material, and could also provide some means of refresher training.

The Navy's automated tutoring system was implemented on a small, stand-alone computer. It has a data base of all Soviet threat information taught in the TAO course, structured as a semantic network containing several thousand representations of facts. Software in the system consists of a series of interactive games that quiz the student about various aspects of knowledge in the data base. These games are separate from the knowledge base so that they can run with any other knowledge base represented in the semantic network. In quizzing the students, the gaming software selects items randomly from the data base and generates questions, examples, or graphics. Unlike previous computer-based training, these exercises are not specifically pre-programmed.

Four systems were installed for student use at the Fleet Combat Training Center, Pacific. At the time the referenced report was published, system evaluation had not been completed.

Zivovic (1986) describes an early prototype expert system for the training of tactical action officers, based on a generic model of the TAO decision making process. The system analyzes the environment and determines the appropriate course of action for the TAO. All pre-planned responses for the events covered by the prototype are contained in a set of production rules. An illustrative example of such a rule is as follows:

```
IF threat is a MISSILE
     and contact movement is inbound or closing

THEN engage with PHALANX     -probability = 10/10
     and fire CHAFF          -probability = 10/10
     and engage with 5/54    -probability =  6/10
```

Built with the EXSYS expert system development tool, this prototype is designed to run on the IBM PC. It was tested by a limited number of TAO qualified officers and professors at the Naval Postgraduate School in Monterey, California. The designer believes that the system demonstrates a new way to transfer knowledge and "know-how" acquired by experts over the years to inexperienced personnel, without the need for the expert to be physically present during training. This could have a significant impact in the Navy because experienced personnel are often transferred to another command and the operating ships must continually train their own TAOs.

## Signal Analyst Tutoring System

The Signal Analyst Tutoring System (SATS) is an ICAI system designed to instruct newly assigned personnel in radar principles. SATS leads an Air Force trainee through a series of lessons on radar concepts, asking questions throughout the lessons to test the student, find out why he made an error, and then correct the error. If the trainee answers correctly, SATS instructs the next concept. If the answer is incorrect, SATS attempts to determine why the answer was not correct and then provide additional training information and remedial tutoring. After correcting the problem, SATS continues to lead the student through the lesson (Melvin 1986).

SATS incorporates three components of an ICAI system: problem solving expertise, a student model, and tutoring strategies. These are further divided into eight knowledge bases which contain facts and rules used by the expert instructor. During operation the databases interact with one another. A prototype of this system was under development using M.1, an expert system building tool available for the IBM PC.

The following knowledge bases have been defined:

1. CONTROL -- directs the consultation.

2. PRESENTATION -- leads the student through the lesson.

3. LESSON -- contains the text and graphics for concepts to be presented.

4. STUDENT MODEL -- contains information on the student, such as level of experience and knowledge.

5. QUIZZING -- updates the student model knowledge base.

6. DIAGNOSTICS -- deduces causes of student error.

7. META-TUTOR -- decides on the best approach for remedial tutoring.

8. TUTOR -- presents remedial tutoring information to the student.

## ICAI Authoring System

Authoring is the creating of computer-aided instructional material (courseware). Authoring is similar to computer programming. Programs associated with courseware may be highly interactive with the student and may even have to operate in real time. As courseware authors are typically unskilled in traditional programming languages, they are candidate users of authoring languages and systems, and in this context, knowledge-based tools that increase an author's productivity in developing computer-aided instruction and procedural training simulation. Interactive computer based training (CBT) procedural simulations are representative of a class of training applications with a large potential payoff in the courseware development process. Applications that simulate instrument panels which students learn to operate or maintain is a good example.

Freedman and Rosenking (1986) developed Object-Based Intelligent Editor-1: Knowledge Based Editor (OBIE-1: KNOBE), a knowledge-based tool for the authoring of CBT material. The tools of this prototype CBT authoring system execute on a Symbolics 3600 LISP Machine. The three component tools are a graphics interface editor, a cognitive connection editor, and a panel sequencing editor.

The system was demonstrated in a typical application to a 40-minute procedural training session on the use of the LTN-72 aircraft inertial navigation system (INS). In that session, the student views a set of simulated devices and relationships, panels of interrelated devices, and regions of the screen with text. Student input is by mouse and keyboard. One of the procedures in the INS training session is longitude/latitude modification. If not followed exactly, the aircraft is in danger of being off course.

The complete authoring of the 40-minute INS training session required about 10 hours. The OBIE system has the advantage of a knowledge-based approach to authoring. The designers claim that OBIE-authored CBT sessions for procedural simulation can be produced in less time than with conventional authoring methods.

# CHAPTER 6

# POTENTIAL APPLICATIONS IN MILITARY TRAINING

## Electronics Troubleshooting

The use of simulators for maintenance training is not a new idea. However, AI and associated developments in cognitive science are leading to a different view of the role and potential of simulation in technical training. Research in cognitive science indicates that experts in technical fields view problems in their domain in terms of abstract entities and principles that are not immediately evident from the physical characteristics of the problem. This abstraction provides the memory structures for expansion of the cognitive resources needed in successful problem solving. From this it follows that simulators may well function more efficiently if they were to incorporate explicit representations of abstract entities and provide views of the domain which promoted the development of the knowledge structures needed for effective problems solving (Halff 1984).

People use mental models as a basis for predicting outcomes and for planning and reasoning. An Army Research Institute project is examining how mental models of electronic circuits influence the learning of troubleshooting strategies. The goal is to find some combination of models and strategies that results in flexible and effective troubleshooting behavior (Pliske and Psotka 1985).

The development of an Adaptive Computerized Training System (ACTS) is another Army project which combines AI with other techniques for teaching electronics troubleshooting procedures. This system simulates the electronic malfunction with no actual equipment required. It constructs mathematical models of both the student and the expert performer. A multi-attribute utility decision model captures circuit troubleshooting behavior independent of circuit type, thereby providing a generalized behavioral representation. This model can be used to represent generic troubleshooting strategies (Boyd, Johnston and Clark 1983).

An expert system based tool for maintenance training offers great promise in the achievement of weapon system support and readiness objectives. Military programs for expert diagnostic systems are already under way (Pipitone 1986). These systems could be expanded to an intelligent machine assistant and tutor combination in an integrated maintenance job performance aiding/on-the-job training (JPA/OJT) system (Thomas and Sykes 1985). This expert system would handle the dual role of job performance aid and intelligent tutor, with an explanation facility as a key component through which the underlying reasoning of the system can be imparted to the technician. The basic objective of the OJT component would be to build the conceptual knowledge of the technician rather than having him/her simply execute instructions.

The Air Force is developing the technology for intelligent maintenance advisors. An intelligent maintenance advisor (IMA) is a computer-based device which enables unskilled technicians to perform as if they were skilled, tutors technicians who need further development in their technical skills, and works cooperatively with skilled technicians to capture diagnostic insights for the benefit of their peers and successors. The Air Force IMA project has been focusing on knowledge engineering techniques and user interface development (Richardson and Jackson 1986).

A suitcase IMA and knowledge base was demonstrated in the fall of 1985 at Cannon Air Force Base, New Mexico, an operational intermediate level repair facility for F-111s with a significant number of test stations and both experienced and novice personnel. A suitcase IMA is a portable briefcase-sized unit for flight-line maintenance, where the job aid must be self-contained, compact, light weight, and rugged. This aspect of the IMA project shares many similarities with the Tri-Service Portable Electronic Aid to Maintenance (PEAM) and the Navy's Stand-Alone Maintenance Aid (SAMA).

## Air Traffic Control

Tasks in which verbal responses are a significant portion of the task behavior are candidates for the development of voice-based automated trainers. Examples of speech based military job assignments include Ground Controlled Approach Radar Controller, Landing Signal Officer, and Air Intercept Controller. Prototype training systems that utilize computer speech recognition to capture the voice behavior of trainees have already been developed. These voice-based training systems were interfaced with standard technologies for teaching and performance assessment.

Investigations have been further extended into an examination of the possibility of enhancing their pedagogical potential through AI. Chatfield, Klein and Coons (1983) investigated the potential use of a computer resident automated instructor (CRAI) in voice-based training systems. The Intelligent Nascent Simulated Trainer for Research on Utterance Capability Trainers (INSTRUCT) implements their CRAI ideas as a test bed for those ideas. The components of the CRAI include a knowledge base in which procedural as well as factual knowledge is represented, a model of the student which would incorporate a representation of the student's evolution from novice to expert in both knowledge and processing skills, a performance measurement or monitoring component, a diagnostic component capable of deducing the state of covert student processing and knowledge levels from overt student action, and a curriculum driver that could use the student model to determine the tutorial function or adaptive task scenario that would optimize the student's learning. In addition, a natural language interface is included which would be useful in providing the student with a means for initiating information requests, in allowing the system to refine its diagnosis of student problems by interrogating the student, and provide the human instructor with convenient access to the system's data base on student performance and its pedagogical rationale.

The system includes a simulated student that interacts with the CRAI in the training of a task which is a simplified representation of speech-based air traffic controller type tasks in current Navy training system development programs. INSTRUCT's simulated student represents a theoretical model of both human task performance and human task learning. The simulated student allowed the researchers to examine the application of AI techniques to modeling student behavior. The INSTRUCT system demonstrated that state-of-the-art psychological theory and AI techniques are sufficiently developed to implement a small simulation package.

Trainer for Radar Intercept Operations (TRIO), another demonstration system, also incorporates AI methods and speech recognition into an air traffic control type trainer. TRIO is an expert system for training F-14 intercept radar operators in the basic tactics of high speed air intercepts. TRIO supports simulations of aircraft radar flight dynamics/control and missile weapons models (Feurzeig, Ash and Ricard 1985). The system task environment provides dynamic displays of heading, bearing, displacement vectors, radar screens, intercept parameters, missile envelopes and interceptor/target aircraft ground tracks. It also incorporates speech synthesis and continuous-speech recognition subsystems, the former used by the articulate expert program to give spoken directions and explanations to a student, and the latter used by the pilot simulation program to let the student speak exactly as he would to the pilot.

The articulate expert is the major AI component of TRIO. The expert is designed as the integration of a production-rule system with a goal-oriented (means-end-analysis) problem solver. Interplay between production rules and goals proved effective in capturing the tactical doctrine elicited from expert radar intercept instructors. The system was implemented with the Interlisp programming language.

## Strategic Warfare Planning

War gaming has long been an accepted practice in the mental preparation of military officers. With the introduction of computers, strategic planning and wargaming exercises have become increasingly sophisticated. White (1986) proposed an AI approach to the TEMPO force planning war game currently used by the Air Force at its Squadron Officers School. TEMPO is a small scale force planning simulation designed to teach the importance of comparing the values of different weapon systems in order to obtain maximum effectiveness per dollar. It is played between two opposing sections of approximately 12 people each.

White's thesis (1986) involved the development of a special version of TEMPO in which a computer expert system takes the place of one of the sections, and an intelligent computer instruction system takes the place of the instructor. The research demonstrated that it is possible to implement a useful war game on a microcomputer, making it available to a larger segment of the officer corps. The demonstration system was implemented on an IBM PC.

## Tactical Warfare Operations

Daniel (1985) identified a number of potential AI roles in warfare operations related training. These operations all involve eight fundamental steps in information handling/processing in a Naval combat environment:

1. Sense/Acquire
2. Transfer
3. Store and Retrieve
4. Process
5. Present
6. Decide
7. Act
8. Assess

The eight steps are required in support of the following warfare operations:

- Surveillance and Information Distribution
- Multisensor Correlation and Detection
- Threat Assessment and Prioritization
- Weapons Assignment/Optimization
- Resource Management/Allocation/Sharing
- Tactical Assignment Recommendations
- Stores Management
- Information Display (alerts based on intelligent assessment)

The potential for AI technology applications to support training in these areas is considered high because the current trend toward cooperative battle group team operations, the complexity of modern weapons/sensors, and the availability of extensive combat information make active pursuit of automated decision support systems imperative, and effective training systems to provide indoctrination and practice in the use of these support systems are likewise considered essential. In addition, the warfare functions identified above are critical to successful execution of missions, and the need for continued and effective training in these areas is well established.

Johnston and Obermayer (1985) describe a low-cost test bed for examining technologies which will allow the introduction of advanced automated instructional features to teams of individuals applying tactical decision-making skills in military environments. An anti-submarine warfare (ASW) simulation with a Combat Information Center environment has been implemented for extracting the essence of ASW interactions for a team of three members: an operations coordinator, an aircraft controller, and a fire control officer. A computer model was created to replace one of the team members, the fire control officer. The model is an expert system that runs in real time along with the simulation. It was developed in the Prolog programming language.

Replacing the human by a model enables training efficiency by reducing the need for manpower in training simulations. In addition, using an expert system approach, the player model may serve as a knowledge base for automated instructional features.

## Air Combat Training

Air Force Human Research Laboratory (AFHRL) ongoing research in air combat tactics and training provides an opportunity for AI applications. One potential application relates to the incorporation of training capabilities into operational aircraft systems. Concepts of embedded training typically focus on an operational aircraft being used to aid in the training of the aircrew. On-board simulation and embedded training involve taking the training program out of the synthetic training environment and integrating it into the operational system. The aircraft would thus be turned into a simulator.

A typical scenario involves loading a different software package into existing onboard computers. The package would allow the aircrew to practice air-to-air combat, air-to-ground weapons delivery, navigation, route planning, and mission rehearsal. Enabling the aircraft's avionic and weapon systems to be exercised (for training) by pilots and aircrew while the aircraft is on the ground or during periods such as transit to/from operations would significantly increase training opportunities and enhance operational readiness (Golovcsenko and Balazs 1985).

In a typical training setting the instructor would have control over the stimuli or problem being presented to the student, and access to the student's responses. The student feedback would allow the instructor to choose the sequence of material presented. In an operational setting, however, the instructor may not have control over the problems faced by the user, nor have the opportunity to select the most appropriate sequencing technique to support learning and retention. Expert system technology could potentially overcome this problem. An expert system could be designed to use the individual's responses to real problems as the basis for identifying missing skills that led to a less than acceptable performance; i.e., surrogate expert instruction (Riner 1985).

CHAPTER 7

# DESIGN AND SYSTEM INTEGRATION ISSUES

## Knowledge Base Acquisition

The development of intelligent computer-based instructional systems requires the acquisition of extensive knowledge about the target task and about trainees' behavior when learning the task. This knowledge is what the expert instructor brings to bear during training. Constructing such knowledge-intensive expert systems requires a methodology known as the knowledge engineering process. This process is in general distinguished by repeated interactions between a domain expert and a highly trained system developer who elicits and encodes the expert's knowledge about task performance and training procedures. The knowledge engineer attempts to "pick the brains" of the expert. This requires a great deal of time for both the expert and the knowledge engineer, which is due in part to a conceptual as well as a procedural knowledge gap between them. Someone trained in computer science conceptualizes a problem much differently than a domain expert such as an electronic warfare analyst.

The shortage of experienced knowledge engineers and the difficulty of bringing knowledge engineers and domain experts together for extended periods of time points to the need for automated tools for knowledge acquisition. These tools could interact directly with domain experts and reduce the involvement of knowledge engineers. Such a system would interact directly with the expert, seated at a terminal, presumably in natural language, and extract the required rules. The most successful results to date have been with systems that extend or modify a fairly mature knowledge base. TEIRESIAS, for example, allowed new rules to be added to the MYCIN knowledge base. The main limitation of the TEIRESIAS approach is that a great deal of existing knowledge is required to direct the acquisition of new knowledge (Westcourt and Thorndyke 1983).

Knowledge acquisition must be made more efficient if expert systems are to become widely used in training simulators. Automated tools could facilitate the more rapid and widespread development of advanced training systems that have intelligent instructional features. However, the usefulness of tools for automated knowledge acquisition is limited by fundamental issues yet to be resolved. Most of the available AI systems to date have been experimental in nature. The representation of knowledge has been influenced significantly by the peculiar encoding schemes preferred by the knowledge engineer. The choice of one scheme over another has often been a matter of speculation and not the result of rigorous and systematic analysis.

Knowledge-based systems technology is still immature, lacking in the breadth and depth of applicability needed for the emergence of systematic, general methods. As a result, the knowledge engineering process is iterative and incremental, with the experience gained early in the process used in subsequent stages to refine and revise system objectives and behavior. The iterative, incremental nature of knowledge engineering implies that knowledge acquisition cannot be isolated from other objectives by automation without interfering with the knowledge engineer's pursuit of those other objectives.

The technology for engineering knowledge based systems has not progressed to a stage in which relationships among domain characteristics, system objectives, and knowledge representation requirements are well understood. This lack of understanding limits the generality of system architectures and any potential aids for the system building process. The power of aids already developed, such as TEIRESIAS, is inversely proportional to their generality.

## Knowledge Representation

A central issue to all AI-based systems is how to best represent the different kinds of knowledge. Three kinds of knowledge must be integrated in an intelligent simulation system: problem-solving or task oriented expertise, instructional strategies, and a student model which reflects the level of student understanding. Military competence is characterized by goal-oriented practical thinking in the accomplishment of operations and maintenance tasks. The decomposition of complex military and technical skills yields according to Gott, Bennett and Gillet (1986) three basic elements: procedural content, conceptual knowledge, and critical mental models.

Procedural skills are observable in operations and methods that serve specified goals. Procedural knowledge may be either rote or conceptually deep wherein procedures are supported by conceptual understanding. Conceptual knowledge consists of explicit task structure knowledge, background knowledge such as scientific laws and principles, and contextual knowledge which involves knowing about the larger supporting context of a task.

Mental models constitute the road maps for problem solving activity. Initially, as a trainee begins to develop a technical skill, a model influences problem representation as a template with which the problem solver organizes a set of stimuli. It is the model that determines which stimuli are encoded, and how. For example, people often view the flow of electric current as analogous to "flowing water." This model may be used initially to support the application of troubleshooting strategy to different problems, although it may produce different patterns of errors about electric circuits.

Rasmussen (1983) proposed an information-processing type representation of human cognition. It is a generally descriptive model of mental processes based on the assumption that the mind is a processor and transformer of information. Rasmussen's model can contribute to defining the components of cognitive demand, and it can guide the choice of alternatives in rating levels of cognitive demand. Table 1 illustrates the distinction among high, moderate, and low rating levels. These distinctions can be valuable in the derivation of cognitive components for a particular skill. With a careful analysis of a complex skill it may be possible to address the formulation of representations which describe skilled performance. Such cognitive representations are necessary to make explicit the particular sub-skills that are important targets of instruction. Results from such analyses could provide a basis for instructional systems that contain intelligence about ideal and less-than-ideal performance, and intelligence about effective instruction to reduce the distance between the two.

Choosing a set of representations for problem solving expertise that maps onto trainees' existing knowledge structures appears to be the key to more efficient and enduring learning. This knowledge representation must encompass different media and sensory domains (vision, touch, kinesthesia, and hearing), and its structures should be accessible and modeled in forms compatible with existing misconceptions and "flowing water" theories that trainees might have (Gray, Pliske and Psotka 1985).

## Modular Architecture

GUIDON, the ICAI program for teaching diagnosis, illustrates the principle of domain independence. In addition to being able

TABLE 1

CATEGORIES OF COGNITIVE DEMAND

| OPERATOR PERFORMANCE LEVEL | PROCESSING REQUIREMENT | INTERNAL REPRESENTATION | HOW INFORMATION IS PERCEIVED | SAMPLE TASKS |
|---|---|---|---|---|
| Skill-Based | Requires operator to perform a highly routine and habitual action with minimal conscious control | Large repertoire automated subroutines | "Signals," continuous quantitative sensory input data | Dissassembly of a piece of equipment |
| Rule-Based | Operator must recognize the need to invoke a procedural rule associated with a particular system or task | Stored rules which control sequencing of subroutines | "Signs," indicators of a state in the environment which serve to activate or modify stored patterns of behavior | Using voltage and ohm-meters effectively |
| Knowledge-Based | Requires identification and categorization of an unfamiliar situation for which no proven rules are available, and a conscious choice among alternative plans to guide the selection of tasks | Goals, plans for reaching goals, mental model of the system's internal structure | "Symbols," abstract constructs defined by by the internal representation which is the basis for planning and reasoning | Fault isolation in digital equipment |

to use the teaching procedures to tutor different cases, GUIDON can provide tutorials in any problem area for which a MYCIN-like knowledge base of decision rules and fact tables has been formalized. Clancey and his research associates held the knowledge base constant while considering the additional knowledge about teaching that would provide a good tutoring system (Clancey 1986). Their research set out to demonstrate the advantages of separate, explicit representations of teaching knowledge and subject material. GUIDON's teaching knowledge is separate from the medical knowledge, so that it is reusable and adaptable to new applications.

As a result of the experimental nature of work in the area of intelligent training systems, no clear general architecture for such systems can be identified as yet. However, a review of the current literature on research findings in this area indicates somewhat of a concensus on the general components of an intelligent training simulator. These components are as follows:

a). DOMAIN EXPERT. This module is capable of actually solving problems in the domain of expertise. It contains knowledge of the task domain, and may also be referred to as the ideal student model. The domain expert module contains the material for the student to learn. An intelligent training system uses this representation of the content domain both to provide content for instruction and to evaluate the learner's responses.

b). INSTRUCTIONAL KNOWLEDGE. Separate from the domain expert knowledge base, this is a control module which actually operates on the content. This module contains strategies used to teach the domain knowledge. Rules for how to teach, when to help, how frequently and in what form, are incorporated into this component. Instructional strategy determines why a student makes an error and how to correct it. Ideally, this module considers both the instructional objectives and the student model.

c). STUDENT MODEL. An intelligent training system maintains a global perception of the learner through this module. The student model contains information on the individual student's familiarity with the subject domain as well as his/her past performance. It is updated by learner responses, provides diagnostic analysis, and is used to advise the instructional strategy component of its next appropriate action.

d). USER INTERFACE. The module which administers teaching interaction between the instructional system and the student. It implements the instructional strategy, and it includes an explanation facility for communicating tutorial information and remedial discourse to the student.

e). TRAINING SIMULATION. This is a computer model of an actual system and the synthetic replication of a real world task environment in order to create a realistic training situation. In general, the simulation replicates the interface between the student and the actual equipment, its systems and its environment.

# CHAPTER 8

# RESEARCHERS' FINDINGS AND CONCLUSIONS

Because of the amount and variety of training regularly performed for military needs, advances in the application of AI to military training would be advantageous. However, few products are currently available. Prototypes and demonstrations tend to involve so many components unique to the subject matter that little building on old systems has occurred. There is no emergence of standard architectures for systems.

This chapter outlines several research findings and conclusions regarding concepts of potential value in the eventual formulation of a useable standard architecture. The first concept relates to the systematic development of intelligent instructional systems through a TriService approved design methodology. The second concept is a total training model which could be a basis for integrating several training related application areas into a formal integrated system. The third concept addresses the potential development of class-generic AI-based training systems. From an integrated system viewpoint, each of these concepts is a valuable contribution to the emergence of a standard architecture which could serve as the foundation and framework for future research and development.

## Instructional System Design

Researchers at the University of California conducted a retrospective analysis of two existing intelligent CAI systems in order to identify future strategies that could enhance the general usefulness of ICAI technology for Army training problems (Center for the Study of Evaluation, UCLA 1986). Analyzing the development strategies for WEST and PROUST, two intelligent tutoring programs, the researchers observed that the developers of these programs appeared at least equally interested in exploring the limits of technology as in devising an effective program which was to meet particular outcomes. Because developers were not from a field where learning and instruction are of paramount interests, they may have neglected important research principles that have emerged in such fields. Incorporating lessons learned from instructional technology and learning psychology might well have increased the instructional effectiveness of both WEST and PROUST. In order to increase the effectiveness of future ICAI products, the researchers recommended a more systematic development process that draws on the available knowledge from the fields of education and the psychology of learning and instruction. They suggested a team approach which includes persons with expertise in instruction in addition to those who are expert in computer technology, human factors and artificial intelligence.

Lessons learned from the front-end analysis leading to the Navy's VTX undergraduate pilot training system suggested that considerable effort must be expended on the development of learning objectives, conditions and standards prior to media selection and lesson specification. Improper media selection and poor lesson specifications due to incomplete instructional system development (ISD) could lead to functional specifications which do not address actual training requirements. Furthermore, simulation engineers are hardware specification oriented, and it was difficult to communicate training requirements to the engineers due to the lack of hardware definition. This was overcome by a detailed description of the instructional features needed to meet the VTX training requirements (Punches 1982).

ISD encompasses many activities in addition to training device design. Tasks must be analyzed, training needs established, instructional media selected, programs of instruction established, and training effectiveness assessed. From a system perspective, all of these activities are equally as important as the design of training device characteristics. A change in the output from any ISD stage will affect all others since they form an interdependent system. Likewise, the research issues which provide data for training device design may also provide necessary data for other ISD activities.

The systematic nature of the ISD process forces training program developers, administrators and researchers to view training system issues as completely interactive and interdependent. According to Cormier et al. (1983), very little progress can be made in the investigation of training systems and training device issues if one maintains an isolationist point of view.

## Total Training Model

Training, performance assessment and job performance aids (JPAs) are interrelated pieces of the total Air Force training model. They are neither separate nor independent Air Force activities (Richardson 1983). Training provides the basis for job performance expertise, which in turn is augmented and developed by OJT. The effectiveness of training is assessed through some from of performance measurement. JPAs support the knowledge and skills of personnel by providing procedural aids for operations and maintenance tasks. Numerous trade-offs are required among: (a) which knowledges and skills should be taught formally in residence training, (b) which should be gained through OJT, and (c) which need not be specifically taught because technical manuals and other JPAs are available.

A common denominator among the three areas is the task analysis: it is the basis for training, evaluation and JPAs. 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 JPAs.

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. Richardson examined the challenges within each, and analyzed potential applications of AI in meeting these challenges. The technology of AI is based on specific knowledge representations and sets of procedures that act on those representations. Job task analysis is the means of providing a representation that can be processed by intelligent 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 AI technology, it appears that AI provides a unique opportunity to develop and validate representations that can serve as task analyses. These representations can be used to simulate intelligent behavior, as for example performing the job task of interest, or to provide instruction in the job task of interest.

AI provides a basis for integrating the three application areas into a formal integrated system. Furthermore, doing it computationally provides the foundation of an automated, computer-based system which will aid the increase of productivity and effectiveness in training, performance measurement and job performance aiding.

In the maintenance task area, expert systems are anticipated to handle the dual role of job performance aiding and intelligent tutoring, and it is anticipated that the separation between maintenance actions and maintenance training will eventually become less distinct. Consequently, maintenance training equipment as we know it today can be expected to be gradually superseded by some form of intelligent maintenance assistant.

## Class-Generic Knowledge

Westcourt and Thorndyke (1983) concluded that future research should focus on the problem of characterizing and representing class-generic knowledge necessary to capture training expertise in a variety of domains. This promising idea entails the development of systems for the acquisition of knowledge in a variety of domains with a single conceptual class. The notion of a class may be defined as a set of domains that share a significant number of concept abstractions among their bodies of knowledge and that could be taught by a single training system with a fixed set of instructional features. Such classes within the Navy include sonar and radar system operations, system maintenance, and platform level combat tactics. The skill of troubleshooting a class of machines such as helicopters may be a candidate for a generic trainer. The basic troubleshooting methodology could be embodied in a generic training system for how to diagnose and solve problems on a specific type of helicopter.

"Telescoping task hierarchy" (Richardson 1983) can be a useful concept in the development of class-generic systems. Telescoping refers to increasing the level of generality from the very specific to the very broad and general. For example, telescoping task hierarchy for troubleshooting and diagnosis tasks can mean a representation capability for: the troubleshooting process involved in a particular system (e.g., F-111 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).

Generic training systems could facilitate the rapid development of new trainers for updated military equipment or for teaching changes in military procedures. These systems are beyond the current capabilities of expert systems technology. Further research into knowledge acquisition may provide insight into the fundamental components of generic training systems. This insight may include not only knowledge about specific training domains, but general methodological principles of training system design as well.

# CHAPTER 9

# SUMMARY

The term artificial intelligence refers to the study of computer-based techniques which allow machines to perform tasks which were previously performed by humans. Major technical areas in AI include natural language processing, computer vision, robotics control, and expert systems. A knowledge-based expert system incorporates, inside a computer, the rules of action or thought a human expert has on a well-defined domain of knowledge or skill.

Relatively little is known about how to use AI/expert system technology for training highly practiced skills such as flying airplanes. However, emerging technologies make the time ripe for applying AI approaches to the military services' severe training and instructional program requirements. One major development is the rapid improvement of computer hardware capabilities at lower costs. Personal computers will soon have the power of mainframes. A second development is in the area of cognitive science, which together with the psychology of human learning allows the modeling of student and instructor characteristics (i.e., mental processes) in a machine.

The review of current and potential AI-based systems has revealed a variety of applications for intelligent training simulation, instructor support aids, and training systems design. Applications include knowledge and skills training for teams and individuals, in strategic planning, in tactical warfare, in sensor analysis, in equipment operations and in electronics maintenance.

How much of the human instructor's traditional role will be taken over by computer-based instructional systems? It is possible to develop AI techniques using natural language processing/voice and expert systems technologies to provide substitutes for many instructor functions. Effective training requires a series of instructor tasks ranging from instructor preparation for the training session to record keeping of training events. Charles (1982) suggested that a training device should provide support to each of the instructor's functions, especially to student briefing, simulator initialization, simulation control, proficiency evaluation, student debriefing, and training scenario generation.

Instructional support features of training simulators are those features specifically designed to facilitate the instructional process. These features are the capabilities which transform a simulator from simply a practice device into a flexible element of the total training system. Automated instructional support features could improve instructor productivity and reduce instructor manning requirements.

Candidate subcomponents for the insertion of machine intelligence include:

- automated demonstrations
- programmable malfunction control
- automated cueing and coaching
- surrogate ground controllers
- computer controlled adversaries
- quantitative performance measurement
- adaptive training

Implementing an intelligent training system requires a great amount of knowledge to be represented in the instructional software. The acquisition of knowledge for the purpose of building an intelligent software system is recognized as a serious problem. Whereas assessment of many operational performance tasks is straightforward, e.g., tracking with a CRT cursor, assessing decision-making does not yield to traditional automated approaches. Much research will have to be accomplished for the long-term objective of automating the knowledge acquisition from subject matter experts.

Extensive research is also required for the long-term goal of developing authoring tools which would enable intelligent training simulator and ICAI software to be built more easily by non-programmers. Curriculum designers find most computer tools too inaccessible. The design of systems without some programming is not feasible in the near future, but it may be possible that some limited instructional domains will be simple enough that special purpose design environments can be created.

Long-term as well as some of the more immediately realizable short-term research goals constitute the topic of discussion in the next chapter.

# CHAPTER 10

# FUTURE RESEARCH DIRECTIONS

## Fundamental Research

Reitman et al. (1985) noted that often research on an intelligent CAI system has necessitated that the project involve some research in knowledge representation, natural language processing, or expert systems. Consequently, the subject matter and style of ICAI goals is heavily dependent on advances in these other areas of AI, and ICAI in general is not likely to succeed without fundamental breakthroughs in basic AI research. The gaps where research must be pushed include:

- expert systems, natural language processing, and knowledge representation: these provide the technological base upon which intelligent simulation systems are based

- modeling student misconceptions, i.e., the identification and definition of classes of errors: this is labor intensive but critical for successful computer coaching

- knowledge acquisition tools: software to bridge the gap between curriculum designer and AI programmer is a fundamental need

- programming languages, tools, and techniques: important in the task of building the system

## Applied Research

To facilitate the parallel development of fundamental research and practical development, Bankes (1985) recommends selecting key applications for actual system development, and to avoid costly failures, suggests that an evolutionary strategy be employed. As with any novel technology, there is the potential for initial disappointments. Until the technology is more mature and better tested, it is best that applications be carefully chosen. The gradual refinement of techniques can be encouraged by sponsoring projects which enhance capabilities but which are not critical to the success of some greater enterprise. It is best that all initial problems be well defined and bounded, and that knowledge-based systems be designed with the purpose of augmenting human capabilities, not of replacing personnel.

Care must be exercised in choosing the application to be addressed in near-term knowledge-based research projects. The domain should be restricted so that the body of knowledge required for competency in this domain may be manageable. Another requirement for success is that there be an accessible source for the needed knowledge. The experts' ability must be expressible in some concrete form and the knowledge must be in a form for which a known representation method is applicable. Yet another general feature of a good problem for research is that it possess a large economic leverage. The best candidates are problems where even a small improvement over current approaches would be important.

## Prototype System Requirements

Today's applications promise of AI is real, but past overzealousness has taught the lesson that principles of practical and achievable project management must be followed. Richardson provided specific practical recommendations for research and development programs in the application of AI technology to training. The recommendations focus on the development of a single, integrated, intelligent, computer-based system. This system would have application to the three facets of the total training model, i.e., training, performance measurement and job performance aiding. The same system should support in an integrated fashion the design, development, delivery and evaluation of each facet. This integrated 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. A master plan specifying the basic functions of the system should be developed and used to prioritize its own implementation. This insures that the task analysis representations are developed first and that all project efforts can be integrated within the larger system.

Furthermore, the central knowledge bases should include: (a) a procedural representation of the tasks, both operations and maintenance, (b) an explicit body of procedural knowledge relating the curriculum sequencing and pedagogical interaction, (c) a "how it works" hierarchy regarding the device's functionality and structure, and (d) an explicit model of the interrelationships between training, measurement and job performance support and evaluation for the chosen career specialty.

## The Next Research Milestone

It is suggested that the next research milestone is a system which incorporates all of the basic AI techniques in an integrated fashion in a single domain. Such a milestone signifies a major step forward in the usefulness of intelligent training systems technology and demonstrates a previously unachievable level of performance. The key to the effort is to integrate modeling, coaching, problem solving, inquiry teaching, explanation, etc. into an effective learning environment. The architecture of this system would be a key research result, although aspects of the design could be very subject specific.

## General Areas for Research

The investigations of Chatfield and Klein (1983) regarding AI in voice-based training systems led to the view that a system's ability to talk with the student, as a human instructor would, opens up a new resource of information that training systems from a wide spectrum of applications could use. They outline general areas for additional research that would facilitate implementation of specific future environments.

First is the area of further developing the requirements for a curriculum driver in intelligent automated instruction. The curriculum driver utilizes the adjusted student model to direct search through possible approach scenarios to select the one which should yield the greatest improvement in student learning. Implementation would require that it be able to start with training strategies that are at least reasonably effective for training the skills in question. It would also be desirable for the curriculum driver to have the ability to gradually develop more efficient strategies through the knowledge it gains from interacting with students.

A second area for further general research would be that of the diagnostic function and the attendant natural language interface. The diagnosis function directs the process of inferring the state of a student's covert cognitive component from the student's overt responses. Natural language provides the capability of discourse with the student for diagnostic purposes. General research can be directed at more fully developing an inference engine and natural language interface adapted for diagnostics use. General development could be done using existing training domains as baseline references for an expanded hypothetical task. The general development would require little additional effort to modify the data base and make minor adjustments for implementation in a particular training environment.

A third recommendation concerns the creation of functional specifications for the type of information needed and the organization required in the implementation of an intelligent trainer. This includes design guides for the representation of basic cognitive processes and structure for use in an intelligent system, and would require a broader and more systematic approach to extend initial concepts and ideas already identified through exploratory research.

## Parallel Research Directions

In summary, research must continue on several levels.

a). Basic research into fundamental issues of AI. These research areas have very long time to fruition. This category includes natural language processing, knowledge representation and research of long-range knowledge engineering issues.

b). Development of tools to assist in the construction of voice-based and knowledge-based instructional systems. This may include special hardware, programming languages, authoring development systems, programmer aids, and decision support systems.

c). Preliminary studies in the design of intelligent training systems for actual use, including human interface design.

d). Developing a prototype simulator for military use. The prototype integrates all key components of an AI-based system in a standard architecture and it represents a major step forward in the usefulness of intelligent training technology.

e). General areas of additional development which would facilitate implementation in specific environments.

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