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GOVERNMENT-SPONSORED RESEARCH AND DEVELOPMENT EFFORTS IN THE AREA OF INTELLIGENT TUTORING SYSTEMS

SUMMARY REPORT

Christine Youngblut

February 1995

Approved for public release, unlimited distribution: April 6, 1995.

IDA

INSTITUTE FOR DEFENSE ANALYSES
1801 N. Beauregard Street, Alexandria, Virginia 22311-1772

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PREFACE

This report presents an analysis of Government-sponsored research and development efforts in the area of intelligent tutoring systems (ITS). The work was performed as part of a Central Research Project, Information Technology for Education and Training. An earlier report, IDA Paper P-3003, *Government-Sponsored Research and Development Efforts in the Area of Intelligent Tutoring Systems*, contains the original data and was published earlier to make the data available in a timely manner to researchers in the field of ITS.

This paper was reviewed by the following staff members at the Institute for Defense Analyses: Ms. Anne A. Douville, Dr. John D. Fletcher, Dr. Richard J. Ivanetich, Dr. Michael R. Kappel, Dr. Dale E. Lichtblau, Dr. Richard P. Morton, and Mr. Michael S. Nash.

The author gratefully acknowledges the support provided by all those who took time from their busy schedules to discuss their work. In particular, special thanks go to the following people:

Dr. John Anderson
Mrs. Carol Barclay
Dr. Susan Chipman
Dr. Michael Cowen
Ms. Susan Dahl
Dr. Sharon Derry
Dr. Jack Dohme
Dr. Martha Evens
Mr. Jim Fleming
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EXECUTIVE SUMMARY

This report reviews the current research and development (R&D) activities of Government organizations in the area of intelligent tutoring systems (ITS) to provide information that can be used by decision makers in determining the composition of future ITS R&D programs.

In all, information was collected about 41 current and 6 planned ITS-related projects. These projects ranged from multi-million dollar, multi-year productization efforts to small-scale, six-month Small Business Innovation Research Phase I investigations of particular technical issues.

ITS R&D remains a small but active field. Based on the analysis of current and planned Government-sponsored R&D efforts, 10 findings have emerged:

- The Department of Defense (DOD) continues to be the major player, with the Air Force Armstrong Laboratory taking the leading role, in accordance with the Defense Science and Technology Reliance Initiative.
- Component and architectural ITS issues are stabilizing and there are some indications of a maturing technology. Currently, popular areas of research are student diagnosis, interactive dialogue, and virtual reality applications.
- There is evidence of a push towards ITS technology transfer, with the Air Force sponsoring two major efforts that correspond to roughly 12% of the total funding in the ITS area.
- For ITS intended for practical use, the predominant application domain remains troubleshooting of electronic devices. The range of application domains for proof-of-concept, prototype, and other research ITS is growing.
- ITS systems intended for practical use do not exhibit high levels of intelligence.
- Only in about one-third of the cases are ITS development efforts driven by predefined training requirements: these systems do not correspond one-on-one with systems intended for practical use.
- There is much development of ITS authoring systems, taking roughly one-third of total current spending in the ITS area.

- More attention is being paid to formally evaluating ITS effectiveness. Roughly one-third of ITS under development are planned for summative evaluation, but critical evaluation issues remain to be addressed.
- There are some small efforts looking at issues of cognition and pedagogy, and Armstrong Laboratory is in the early stages of establishing a laboratory for long-term investigation of pedagogical issues.
- Two groups are actively including teachers or instructors in their efforts. A few efforts are building capabilities in ITS that are designed to help teachers in their use of the systems. Nonetheless, there is a lack of understanding on how teachers need to be supported.

In light of these findings, the following recommendation are made:

Recommendation 1: More focus is needed on evaluation issues. The next several years should see summative evaluation of all ITS developed for practical use, while moving towards assessing the effectiveness of ITS technology in general.

Recommendation 2: The current level of effort in the area of authoring systems should not be expanded at the present time. While authoring systems can be valuable tools for researchers, many issues need to be addressed before more such tools are developed for use by the general educational community.

Recommendation 3: More effort is needed in investigating how to prepare and support teachers in their use of ITS technology.

Recommendation 4: The role of ITS in supporting new instructional approaches, such as learner control, collaborative learning, and situated learning, should be investigated in addition to virtual reality and learning.

Recommendation 5: Continued transition of the technology into practice use should be encouraged. Public awareness of the potential of this technology needs to be increased.

The importance of education and training is increasing, both in Government and industry. This is in response, in part, to such drivers as the increasing need for a flexible workforce and DOD downsizing. The data are not available to see how current levels of funding differ from spending in previous years, but declining Government and DOD budgets may lead to substantial ITS R&D funding reductions in future years. The potential of this slowly maturing technology must be realistically assessed so that appropriate continued R&D funding can be determined to ensure a worthwhile pay-off in future years.

1. INTRODUCTION

This report reviews the current research and development (R&D) activities of Government organizations in the area of intelligent tutoring systems (ITS) to provide information that can be used by decision makers in determining the composition of future ITS R&D programs. Specifically, it summarizes the current and planned activities of several Department of Defense (DOD) organizations, the Department of Education (DOEd), the National Aeronautics and Space Administration (NASA), and the National Science Foundation (NSF). The particular Government organizations that provided information for this report are identified in Figure 1.

- **DOD:**
  - **US Air Force Armstrong Laboratory (AL), Human Resources Directorate**
  - **US Air Force Human Systems Center (AF HSC), Human Systems Program Office**
  - **Army Materiel Command (AMC), Missile Command (MICOM)**
  - **Army Simulation, Training and Instrumentation Command (STRICOM)**
  - **Army Research Institute (ARI), Advanced Training Methods Research Unit (ATMRU)**
  - **Army Research Institute, Aviation R&D Activity (ARDA)**
  - **Defense Modeling and Simulation Office (DMSO)**
  - **Office of Naval Research (ONR), Science and Technology Directorate**
  - **Navy Personnel Research and Development Center (NPRDC)**
  - **Naval Air Warfare Center Training Systems Division (NAWCTSD)**
  - **Naval Surface Reserve Force (NSRF)**
  - **Space and Naval Warfare Systems Command (SPAWAR), Undersea Surveillance Division**
  - **Technology Reinvestment Project (TRP)**
- **DOEd, Fund for Improvement of Postsecondary Education (FIPSE) Program**
- **NASA, Johnson Space Center, Software Technology Branch**
- **NSF, Advanced Technologies Program**

Figure 1. Government Organizations Providing Information

In all, information was collected about 41 current and 6 planned ITS-related projects. These projects ranged from multi-million dollar, multi-year productization efforts to small-scale, six-month Small Business Innovation Research (SBIR) Phase I investigations of particular technical issues.

The next chapter of this report provides a quick introduction to ITS. The third chapter identifies the ITS-related R&D projects of the participating organizations, looking at both current and planned projects and summarizing the major focus of each effort. The fourth chapter presents the findings of the analysis based on the issues identified above. The report concludes with a set of recommendations pertaining to future funding in the ITS area.

2. BACKGROUND TO INTELLIGENT TUTORING SYSTEMS

Individualized tutoring has long been recognized as offering a two-standard deviation improvement in student achievement over what is achieved by traditional classroom teaching methods [Bloom 1984]. ITS are intended to make the advantages of individualized tutoring widely available through the use of modern computer technology. Essentially, an ITS is a computer-aided system that acts like a personal tutor in presenting instruction and remediation in a manner tailored to each individual, based on a gradual accumulation of knowledge about that individual.

The majority of early computer-aided instruction systems were either tutorial or drill-and-practice systems. In both these forms of computer-aided instruction, the student is led through the material to be taught, providing a response at every step. Based on these responses, the student is moved ahead to the next part of the material, or else the current part is reviewed until subsequent responses indicate correct understanding. The actions taken by the system to student responses are mostly preprogrammed. Researchers began investigating how to tailor instructional actions to individual students and this led to the type of computer-aided instruction systems called intelligent tutoring systems.

The definition of an ITS has changed little since the initial development of this technology three decades ago. As defined by Hartley and Sleeman [1973], ITS use three types of knowledge to support computer-aided instruction; that is, knowledge of the domain (expert model), learner (student model), and teaching strategies (tutor). The key characteristics that distinguish an ITS from other forms of computer-aided instruction are the following [Fletcher 1988]:

- ITS are information system oriented. The underlying structure of the system is based on a knowledge base of information about the subject matter, as opposed to preprogrammed blocks of static material [Carbonell 1970].
- ITS are generative. The ITS is capable of generating instructional material from the knowledge base, for example, to ask a question designed to resolve a student's misunderstanding.

- ITS provide for mixed initiatives, that is, either the system or the student can initiate an interaction.

(As a word of caution, the reader should note that not all the systems discussed in this report exhibit these characteristics. The systems included here are those put forward as ITS by their developers, or those commonly discussed in the literature as ITS.)

In the simplest terms, an ITS works by having a student solve problems. The student's performance is monitored by reference to an expert's behavior, and the system builds and maintains a dynamic model of the student's knowledge and skill. This model may use an overlay approach or employ misconception identifiers to capture information about student misconceptions. In the first case, the model just represents what a student does with respect to what an expert would do, treating the student's misconception as a hole in his knowledge. In the second case, the ITS tries to identify the cause of the misconception. In any event, the ITS uses the student model, and information on what the student needs to know, to determine what to teach next and how to present it.

Since the early years, the key research issues have related to both artificial intelligence (AI) technology and cognitive psychology. For AI, the bulk of the research focused on what knowledge should be captured in the different models, how to represent that knowledge, and how to diagnose and respond to student errors. The technology characteristics of some early military ITS have been reported Fletcher [1988] and are summarized in Table 1 to give a feel for the type of technology used in the 1980s. The typical application areas for these systems were maintenance and operator training.

The main thrust from the cognitive psychology side has been looking at how to involve a student more actively in the learning process and reflecting changes in popular pedagogy in ITS. One example of a pedagogy that has been employed is cognitive apprenticeship. This pedagogical approach is based upon allowing the student to experience the most difficult aspects of a cognitively intense task where assistance is available; in the case of an ITS, this assistance is provided by an intelligent coach. Another widely used pedagogy is guided discovery. Here, the student is provided with a simulated environment in which he can explore various concepts and conditions through the manipulation of objects at different levels of abstraction. The level of intelligent help provided may be minimal, such as a tutor that presents and guides the proofing of some hypotheses.

To date, only a small number of controlled experiments that attempted to assess the effectiveness of specific systems have been reported in the literature. Their results (summarized in Figure 2) indicate that ITS technology is a potentially valuable field.

Table 1. Characteristics of Military ITS in the 1980s

ITS	Knowledge Base	Student Model	Tutor
SOPHIE (Electronic maintenance)	Semantic network with mathematical model	Overlay onto model	Simulation with articulate expert
STEAMER (Steamship propulsion)	Mathematical model with procedural network	Overlay onto model	Graphically simulated environment with advisor
IMTS (Corrective maintenance)	General-purpose corrective maintenance network	Overlay onto hierarchical curriculum network	Simulation with human instructor interface and concept distance
CBMS (Memorization of hierarchical concepts)	Weighted semantic network	Overlay onto network	Hints linked by problem type
TRIO (Radar intercept officer tactics)	Rule-based representation with goal-oriented problem solver	Overlay onto expert solutions	Real-time simulation with articulate expert and voice interaction
QUEST (Operation/troubleshooting of electronic circuits)	Rule-based, "zero-order," and "first-order" qualitative models	Overlay onto progressively sophisticated model	Simulation with problem generator and explicit queries
SATS (Radar signal analysis)	Rule-based representation with ordered lists	Overlay onto rule-based representation	Rule-based simulation and metatutor with problem generator
MACH-III (HAWK missile maintenance)	Hierarchical network	Overlay onto practical doctrine	Simulation with articulate expert
INCOFT (PATRIOT missile engagement control)	Rule-based representation	Overlay onto expert solution	Real-time simulation with articulate expert

LISP Tutor	Tutors in the LISP programming language. On the final exam, tutored students scored 43% higher than those taught using traditional methods, about a 1 standard deviation improvement. Tutor yields two to three times in time savings when working through problems [Anderson, Boyle & Reiser 1985].
Smithtown	Tutors scientific inquiry skills, using the context of microeconomics. Students working with Smithtown for 5 hours achieved the same gains as those in a classroom group which had 11 hours of instruction [Shute, Glasner & Raghavan 1989].
Sherlock*	Tutors in Air Force avionics maintenance facilities. Twenty hours of tutor instruction was shown to be equivalent to four years on-the-job experience in terms of the attained level of diagnostic skill [Lesgold et al. 1990].
Bridge	Tutors in Pascal programming. Students using the tutor took a third of the time to learn the same material covered in a traditional classroom and laboratory environment [Shute 1991].
Stat Lady	Tutors in statistical procedures. Tutor allowed high-aptitude students to learn significantly more, while low-aptitude students made comparable achievements to students taught in a traditional classroom [Shute & Gawlick-Grendell 1993].
Geometry Tutor	Tutors in proving geometry theorems. Tutored students shows a 1 standard deviation improvement over non-tutored students [Schofield & Evans-Rhodes 1989].

* This evaluation was performed prior to that mentioned later in this report.

Figure 2. Results of Previous ITS Evaluations

3. STUDY DATA

While the study did not conduct an exhaustive survey of Government-sponsored ITS R&D efforts, it is believed that the majority of such efforts was identified, and this was enough to provide insight into activity in this area as a whole. A total of 47 projects, sponsored by 16 different Government organizations, were studied. These efforts addressed the development of 70 specifically identified ITS or ITS authoring environments.

Table 2 summarizes these projects. Grouped by sponsoring organization, this table identifies each project title, the duration of the effort, and the amount and type of funding. The different funding types are grants (either Air Force Office of Scientific Research (AFOSR), the DOEd Fund for Improvement of Postsecondary Education, or NSF), SBIR procurement contracts, Technology Reinvestment Project awards, and monies appropriated from Congress for R&D work (6.1 category for basic research, 6.2 category for concept development, 6.3 category for engineering development, or 6.4 category for productization.) For each project, the major R&D focus is described, and expected ITS-related products identified.

Further information on these projects can be found in a companion document [Youngblut 1994], with the exception of the NSRF-sponsored development of STEAMER-GT for which information only recently became available.

Table

Primary Sponsor	Project Title	Start/ End Years	Funding		F
			Type	$	
AL	Training Research for Automated Instruction (TRAIN)	91-97	AFOSR	$3.6M	Understand the relationship am ological variables, and instructi
	Fundamental Skills Training (FST)	90-96	6.2	$4.5M	Research, develop, evaluate, an schools and industry under Fed
	Intelligent Computer-Assisted Training Testbed (ICATT)	89-	6.3	$5.3M	Create, demonstrate, and evalu and deliver intelligent simulati related tasks
	Basic Job Skills (BJS)	90-95	6.2, 6.3	$4.5M	Develop technology and metho nents of skills that define high- accelerate skill acquisition and
	Intelligent Training Development Methodologies	93-95	6.2	$400K	Identify principles for merging and development tools for use i
	Improved Instructional Techniques for Intelligent Training Systems	**94-96**	**6.2**	**$3M**	**Support upward transition o prototype instructional syste**
	Virtual Interactive Technologies ITS Development System (VIVIDS)	**95-00**	**6.3**	**$5M**	**Extend findings in training p need to producing efficient tr systems**

Planned effort

le 2. Summary of ITS Data

Focus	ITS-Related Products	ITS and ITS Authoring System Details	
		Product Type	Target Domain
ımong automated pedagogies, person- ctional effectiveness	Human performance capabilities taxonomy, methods for instruction-targeted task analysis, automated instruction development guidelines	Not applicable	
	Mathematics Abstract Reasoning Tutoring Architecture (MARTHA)	Research	Algebra word problem-solving
	Puzzler Toolkits	Research	Scientific concepts
	Solver ITS	Research	Word problem solving
	Spreadsheet ITS	Research	Problem-solving with spreadsheets
	Virtual Interactive System for Training Applications (VISTA) Laboratory	Research	Console operations and spatial navigation
	Loader ITS	Research	Remote crane control arm operation
	Console Operations Tutor (COPTER) ITS	Research	NASA shuttle missions
	Phoenix ITS	Research	Instrument-only landing in the F-16 aircraft
and transfer ITS technology to public 'ederal technology transfer guidelines	Word Problem Solving Tutor	Prototype	Word problem solving
	Reading/Writing in a Supportive Environment (R-WISE) Tutor	Prototype	Basic writing skills
	Instruction in Scientific Inquiry Skills (ISIS) Tutor	Prototype	Scientific inquiry skills for biology
ıluate a capability to rapidly develop ıtion-based training for equipment-	Microcomputer Intelligence for Technical Training Writer (MITT) Authoring Shell	Practical use	Troubleshooting complex devices
	Rapid ITS Development System (RIDES)	Practical use	Interactive system behaviors
	STEP Writer Authoring Environment	Practical use	Procedural skills
hods to examine cognitive compo- h-tech maintenance expertise, and to ıd foster skill generality	Avionics Troubleshooting ITS (Sherlock II)	Research	F-15 navigation electronics troubleshooting
	F-15 Hydraulics ITS (HY-DRIVE)	Prototype	F-15 hydraulics troubleshooting
	F-15 Comm-Nav Penetration Aids ITS	Prototype	F-15 comm-nav penetration troubleshooting
	F-15 Radar ITS	Prototype	F-15 radar troubleshooting
ng principles of instructional design ɛe in VR-based simulations	Software Development Toolkit for Development of VR-based ITS	Prototype	Developing and delivery of VR-based ITS
	Orbital Mechanics ITS	Research	Orbital Mechanics
of TRAIN results by implementing tems in Air Force domains	**TBD**		
potential of VRs, while addressing training development and delivery	**VR-based ITS authoring shell**	**Prototype**	**Operation and maintenance of complex systems**
	Specification for operational VR-based shell	**Production**	**Operation and maintenance of complex systems**

Table 2. Summ

Primary Sponsor	Project Title	Start/ End Years	Funding		Fo
			Type	$	
AF HSC	Maintenance Skills Tutor (MST)	90-99	6.4	$2.5M	ITS productization
	ITS User Support	94 -	Not applicable		Review ITS development efforts and formulate cooperative effort
AMC, MICOM	ARPA Intelligent Tutoring System	93-94	SBIR Phase II	$489K	Investigate the use of a new faul more effective and efficient diag
	Neural/Expert Based Client-Server Architecture for Multi-Node, Task-Sharing, Expert-Instruction ITS	93-94	SBIR Phase I	$50K	Investigate the application of hy edge-based strategies to the prob
STRICOM/ ARPA	Simulator/Simulation-Based Intelligent Tutoring Systems	93-94	SBIR Phase I	$99K	Develop instructional framewor tion, elicitation-based assessmen
	Case-Based Reasoning for Simulation-Based Intelligent Tutoring	93-94	SBIR Phase I	$70K	Investigate the use of case-based sent the example problems and p
	Hybrid Simulator-Based Intelligent Tutoring System	93-94	SBIR Phase I	$50K	Investigate combining skill-base structured knowledge-based dia
	Icon-Based Intelligent Tutoring System Utilizing Fuzzy Expert Systems and Multi-Media Gaming Simulations	93-94	SBIR Phase I	$50K	Demonstrate feasibility of fuzzy dent performance, and gaming s
ARI, ATMRU	Visual Knowledge Representation in Multi-Media CyberSpaces	92-94	6.1	$500K	Investigate how VR technology immersion and applying results t
	Multilingual: Advanced Technologies for Mastering Foreign Languages	89-95	6.2	$2.5M	Conduct research in technology ing and extend understanding of

ary of ITS Data (Continued)

us	ITS-Related Products	ITS and ITS Authoring System Details	
		Product Type	Target Domain
	F-15 Avionics Off-Equipment Manual Test Stand ITS	Production	F-15 Avionics Off-Equipment Manual Test Stand Troubleshooting
	F-15 Pneudraulics ITS	Production	F-15 Pneudraulics Troubleshooting
	F-16 Pneudraulics ITS	Production	F-16 Pneudraulics Troubleshooting
	F-15 Avionics A Shop ITS	Production	F-15 Avionics A Shop Troubleshooting
	F-15 Avionics C Shop ITS	Production	F-15 Avionics C Shop Troubleshooting
	F-16 Avionics A Shop ITS	Production	F-16 Avionics A Shop Troubleshooting
	F-16 Avionics B Shop ITS	Production	F-16 Avionics B Shop Troubleshooting
	F-16 Avionics C Shop ITS	Production	F-16 Avionics C Shop Troubleshooting
	F-16 Engine ITS	Production	F-16 Engine Troubleshooting
	F-15 Environmental/Electrical Systems ITS	Production	F-15 Environmental/Electrical Systems Troubleshooting
	F-16 Environmental/Electrical Supply ITS	Production	F-16 Environmental/Electrical Supply Troubleshooting
explore additional applications, to satisfy mutliple training needs	Not applicable		
solation technique in providing osis of student deficiencies	ARPA ITS	Prototype	Avenger Table Top Trainer
id neural network and knowl- m of MITE system training	MITE ITS	Proof-of-concept	Task allocation for team members
with dynamic scenario regenera- multiple knowledge schemas	MOS 91B Technical Training ITS	Proof-of-concept	Trauma care
easoning to capture and repre- ovide student explanations	MOS 91B Technical Training ITS	Proof-of-concept	Emergency medical procedures
adaptive training techniques and osis and syllabus modification	MOS 91B Technical Training ITS	Proof-of-concept	Ground ambulance evaluation support
	MOS 63B Technical Training ITS	Proof-of-concept	Maintenance of 5-ton trucks
ogic paradigms in analyzing stu- ulation techniques for learning	Icon-based ITS with two data bases (63B and 91B)	Proof-of-concept	5-ton truck oil system repair, advanced first-aid skills
n be used as a tool for studying synthetic training environments	Authoring tools for construction of research VRs	Not applicable	
enhance foreign language train- oreign language skill acquisition	Military Language Tutor	Demonstration	C3I job-specific language skills

Table 2. Sum

Primary Sponsor	Project Title	Start/ End Years	Funding		F
			Type	$	
ARI, ARDA	Intelligent Flight Trainer for Initial Entry Rotary Wing Training	93-95	SBIR Phase II	$500K	Integrate ITS methods, adaptive thesis, and low-cost simulation
DMSO	Building Education and Training Technology on Commercial Software	94-94	6.3	$400K	Investigate the practical feasibil oping ESSCOTS applications
ONR	Computer Dialogue Generation to Support Multiple, Sophisticated Tutoring Tactics	93-96	6.1	$380K	Investigate how to produce inte dialogue that responds to user n
	Participating in Reflective Dialogues in a Complex, Real-World Domain	91-97	6.1	$370K	Investigate student needs for re egies for choosing what/how in
	Development and Assessment of Alternative Tutoring Strategies for an Intelligent Mathematics Tutor	93-96	6.2	$523K	Experimentally study effectiver strategies for schema-based sol
	Forecasting Training Efficiency and Transfer Effectiveness: An Automated Cognitive Approach	94-95	6.2	$160K	Investigate a cognitive analysis train and expected degree of tra
	How People Learn from a Tutor	**94-96**	**6.1**	**$290K**	**Develop an abstract model wl resultant cognitive processes**
	Utility of Coaching Models and Improved Measurement Systems in an ITS	**94-96**	**6.2**	**$298K**	**Determine whether measures can enhance student modelin computer-based training**
NPRDC	Complex Cognitive Skills: Objective 2	92-95	6.2	$375K	Determine the feasibility of usi appropriate mental models
	Linking Cognitive Styles to Instructional Strategies for ITS	93-94	SBIR Phase I	$50K	Develop empirically validated l instructional strategies, and info
	Damage Control Training in a Virtual Environment	**94-95**	**SBIR Phase I**	**TBD**	**Demonstrate techniques for t training in a virtual environm**
NAWCTSD	Low-Cost Knowledge-Based Tool for Rapid Prototyping and Development of ITS	93-93	SBIR Phase I	$50K	Demonstrate the feasibility of a ment of courseware exploiting
	Intelligent Tutor for Electronic Warfare (EW) Situation Assessment	93-94	SBIR Phase I	$272K	Develop a standard, modular ar ligent Embedded Trainers for sl
NSRF	Enhancing Naval Reserve Propulsion Engineering Training	93-95	NSRF funds	$600K	Converting STEAMER to simu
SPAWAR	Integrated Training Architecture in Support of Active Sonar Systems	92-94	SBIR Phase II	$555K	Design and demonstrate a pract applicable to all aspects of Surv tem (SURTASS) operator profi

ummary of ITS Data (Continued)

Focus	ITS-Related Products	ITS and ITS Authoring System Details	
		Product Type	Target Domain
ptive training techniques, speech syn- ion technology	Intelligent Flight Trainer (IFT)	Prototype	Initial Entry Rotary Wing (IERW)
sibility and cost effectiveness of devel- ns	ESSCOTS applications	Prototypes	TBD
intelligent computer-generated tutorial er needs	CircSim Tutor	Practical use	Negative feedback system controlling blood pressure
	A-Base	Practical use	Physiology of acid-base problems
r reflective dialogues, identifying strat- w information should be presented	Prototype explanation generator for Sherlock	Not applicable	
iveness of alternative instructional solving of algebra word problems	Tutoring in Problem Solving Tutor	Practical use	General problem-solving skills
ysis tool to support forecasting time to f training transfer	Extended Cognitive Analysis Tool	Not applicable	
l which relates tutorial actions to ses and learning effects in the student	**Model relating tutorial actions to resultant cognitive processes and learning effects**	**Not applicable**	
ires of what a trainee is looking at eling, and the value ITS compared to	**Computer Adaptive Testing-Armed Services Vocational Aptitude Battery (ASVAB)**	**Prototype**	**Diagnosis of system problems for test administrators**
using an ITS as a means of training	EW cognitive skills training tutor requirements and design specification	Prototype	EW cognitive skills
ted links between cognitive styles, information-presentation methods	Electronic Warfare Tutor	Prototype	EW tasks in Combat Information Centers (CICs) on Navy ships
or integrating damage control team onment	**ITS System Specifications**	**Prototype**	**Damage control teams**
of a commercial tool for rapid develop- ing both CBT and ITS technologies	ITS development tool	Proof-of-concept	Domain independent
	ITS development tool design specification	Prototype	Domain independent
r architecture for development of Intel- or shipboard EW operators	Electronic Warfare Intelligent Embedded Trainer	Proof-of-concept	EW situation assessment
imulate a LM-2500 gas turbine engine	STEAMER-GT	Production	Marine gas turbine propulsion
ractical application of ITS technology Surveillance Towed Array Sensor Sys- roficiency	Multistatic Acoustic Receiver System Trainer	Demonstration	SURTASS

Table 2. Sum

Primary Sponsor	Project Title	Start/ End Years	Funding		F
			Type	$	
ARPA/ Technology Reinvest-ment Program	Next Generation Authoring Tools and Instruc-tional Applications	94-97	TRP	$6M[a]*	Accelerate development of new applications
	Engineering Academy of Southern New England	94-96	TRP	$4M[b]*	Design, implement, evaluate, ar of education for engineers in th
	Retraining the Manufacturing Workforce for the Biotechnology and Biomedical Industries	94-97	TRP	$1M*	Develop a new generation of er facilitate transition of defense v ical engineering
DOEd	Computer Lessons for Written Harmony	91-94	FIPSE	$150K	Develop software for the cognit and analyze musical exercises i
	Computerized Sight-Singing Lessons with Intelligent Feedback	91-95	FIPSE	$135K	Develop a series of computer-b tional teaching in sight-singing
NASA	Conduct of Fire Trainer (COFT) Automation	93-94	6.2	$360K	Automate instruction functions (COFT) facility, develop tank c integrate with simulation
	Early Language Intervention	92-95	6.2	$290K	Adapt the Intelligent Physics Tı vention for children with disabi
	Horizontal Integration of Battlefield Augmentation	93-95	6.3	$1.1M	Develop an ICAT and associate to model battlefield informatior
	Assessing the Potential of Virtual Realities in Science Education	94-95	NSF Grant	$936K	Chart opportunities/challenges (cognitive trials to research how
	Authoring System Development	92-95	6.3	$110K	Develop an authoring environm and provide a tool that guides tl
	Advanced Training Technologies	87-96	6.3	$3M	Enhance effectiveness of NASA application of advanced technol
NSF	Methodology for Developing a Practical Algebra Tutor	92-95	NSF Grant	$790K	Define what is involved in takir and using it to implement a cou
	Using Automatic Speech Recognition To Improve Reading Comprehension	92-94	NSF Grant	$870K	Test feasibility of automatic spe comprehension, identifying wha
	Developing Flexible Explanation Generators for Intelligent Tutoring Systems	92-95	NSF Grant	$380K	Develop and evaluate a flexible cally generates user-tailored res
	Educational Support Systems Based on Com-mercial-Off-the-Shelf Software	**TBD**	**NSF Grant**	**TBD**	**Investigate theoretic and evalı based learning**

a. With matching funds from the contractor, East/West Consortium.
b. Universities and industries that belong to the Academy will provide an addition $8M in funds.
* Figure reflects funding for overall project, of which ITS effort is only a part.

Summary of ITS Data (Continued)

Focus	ITS-Related Products	ITS and ITS Authoring System Details	
		Product Type	Target Domain
›f new authoring tools and instructional	Intelligent Tutor Authoring Tools	Practical use	Customizable domain and teaching style
	Math Tutor	Practical use	Basic math operations to beginning algebra
ate, and disseminate an integrated system ; in the next century	Stamping Tutor	Practical use	Design for Manufacturing and Assembly
	Injection Molding Tutor	Practical use	Design for Manufacturing and Assembly
ı of engineering teaching environment to ense workers into biotechnology/biomed-	Retraining in Biotechnology/Biomedicine ITS	Practical use	TBD
cognitive skills needed to correctly write cises in four-part harmony	Written Harmony Tutor	Practical use	Four-part choral style
uter-based lessons to supplement tradi- nging	Sight-Singing Tutor	Practical use	Sight-singing
ctions of the Conduct of Fire Training tank commander and gunner system, and	COFT/ICAT	Prototype	M1A1 COFT for M-series and Bradley tank gunnery
sics Tutor to support early language inter- disabilities, and transfer to public sector	Early Language Intervention System (ELIS)	Prototype and production	Basic language and communication skills
ociated communication device emulators nation passing	InterVehicular Information System (IVIS)/ICAT	Prototype	IVIS interface operations and battlefield logistics
nges of VR for science learning, perform ı how VR can optimize learning	Virtual Physics Laboratory (VPL) II	Prototype	1-D, 2-D kinematics, statics, and dynamics
ironment derived from NASA's research ides the trainer modeling process	ICAT authoring environment	Prototype	Training based on simulating work environment and modeling a personal trainer
NASA training through development and chnology	ICAT applications, VR-training applications, and technology transfer to Mission Operations Directorate. Tools for building and maintaining ICAT systems and complex VRs. Shared VRs for collaborative training.	Details not available	
ı taking a cognitive tutor methodology a course	Algebra I Tutor	Prototype	Algebra 1
ic speech recognition to improve reading ıg what a reading coach should do	Emily Coach	Research	Reading
exible explanation facility that dynami- ed responses to unanticipated questions	Biology Tutor	Prototype	College-level biology
l evaluative issues underlying inquiry-	ESSCOTS Applications	Practical use	TBD

4. FINDINGS

It is clear that ITS R&D remains a small but active field. Current and planned programs are funded at a level of over $56M spread over a 14-year period from FY87 to FY00.[1] This figure only represents a snapshot of an ever-changing funding profile, however, since efforts completed prior to FY94 are not included and, presumably, additional efforts may be initiated.

As is often the case when investigating R&D efforts, it is impossible to quantify what has been accomplished in recent years. Even though a few ITS are coming into practical use, there is a current lack of data on their effectiveness. Nonetheless, the analysis identified several themes that serve to give a feel for the current state of the art and state of the practice.

4.1 Activities of Different Government Organizations

The DOD has led R&D in the ITS area since the inception of this technology and continues to be the major player within the Government. It is sponsoring the majority of current R&D efforts, both large and small. Using the snapshot of the current funding profile, the proportion of funding being provided by different Government organizations is shown in Figure 3, together with details of the breakdown of funding within the DoD.

Within the DOD, the Defense Science and Technology Reliance Initiative requires that related R&D efforts be consolidated and co-located at a single site [NPRDC 1993]. The Air Force has been given responsibility for R&D in Intelligent Computer-Aided Training, with its Armstrong Laboratory taking the lead for R&D in the ITS subarea. To help fulfill this responsibility, Armstrong Laboratory has developed a comprehensive research plan designed to:

- Progress from laboratory studies in artificial tasks toward field studies of fully implemented ITS for real-world tasks, and

[1] It should be noted that, although based on program funding profiles, the dollar amounts given in this section are intended only as rough approximations to give a feel for the level of effort involved in each case. For each program, funding is pro-rated over the duration of that effort.

- Use learning theory to drive further research, and use evaluation data to constrain that research.

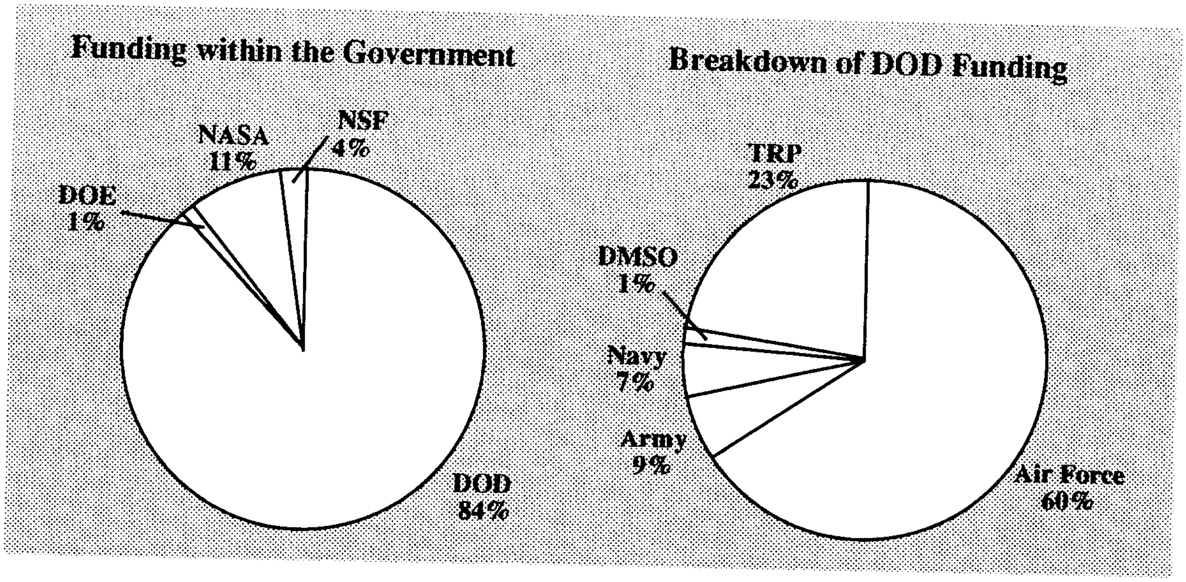

Figure 3. Funding by Organization

Armstrong Laboratory also is coordinating with the Air Force Human Systems Center to productize ITS for Air Force use. To increase efficiency and reduce overlap, the Reliance Initiative intends that other DOD groups only look at application of the technology with respect to their special concerns. Some groups are following this guidance, for example, ARI ARDA is investigating the development of an intelligent flight trainer. Others are looking at integrating ITS and other evolving technologies, for example, the focus of ONR's current ITS work is on integrating natural language interaction capabilities into ITS. Several other groups, however, are conducting what appears to be ITS basic research independent of Armstrong Laboratory, although none of the current efforts seem to be overlapping significantly and may provide useful technology advances [Youngblut 1994]. Together, Armstrong Laboratory and the Air Force Human Systems Center are responsible for approximately 60% of the ITS R&D funded by the DOD.

Another DOD initiative, the Technology Reinvestment Project, is also addressing ITS R&D. Here, ARPA is sponsoring three efforts that touch on ITS, exploiting dual use potential and promoting the transfer of the technology into specific practical applications.

Other than the DOD, there only are a few Government organizations active in this area. NASA is very interested in the technology, sponsoring several large efforts and promising to be a leader in the research into virtual reality ITS applications. As part of its

Advanced Technologies Program, the NSF is sponsoring a few, small-scale efforts, but ITS R&D is not a major area. The DOEd has two small efforts funded under its Fund for Improvement of Post-Secondary Education. In general, the DOEd has not funded software projects, and although this is planned to change in FY95, the DOEd expects to fund computer-aided instruction, rather than ITS, R&D at that time.

4.2 Advances in Basic Technology

Roughly one-third of the examined efforts are directly concerned with ITS basic technology development. (The term *basic technology development* is used to distinguish efforts looking at how to implement or extend ITS technical capabilities from those efforts primarily concerned with developing ITS authoring systems or bringing the technology into practical use.) These efforts have a current funding profile as shown in Figure 4. They cover the range from well-funded, multi-year projects to short, small-scale efforts. The majority, however, fall into the latter category.

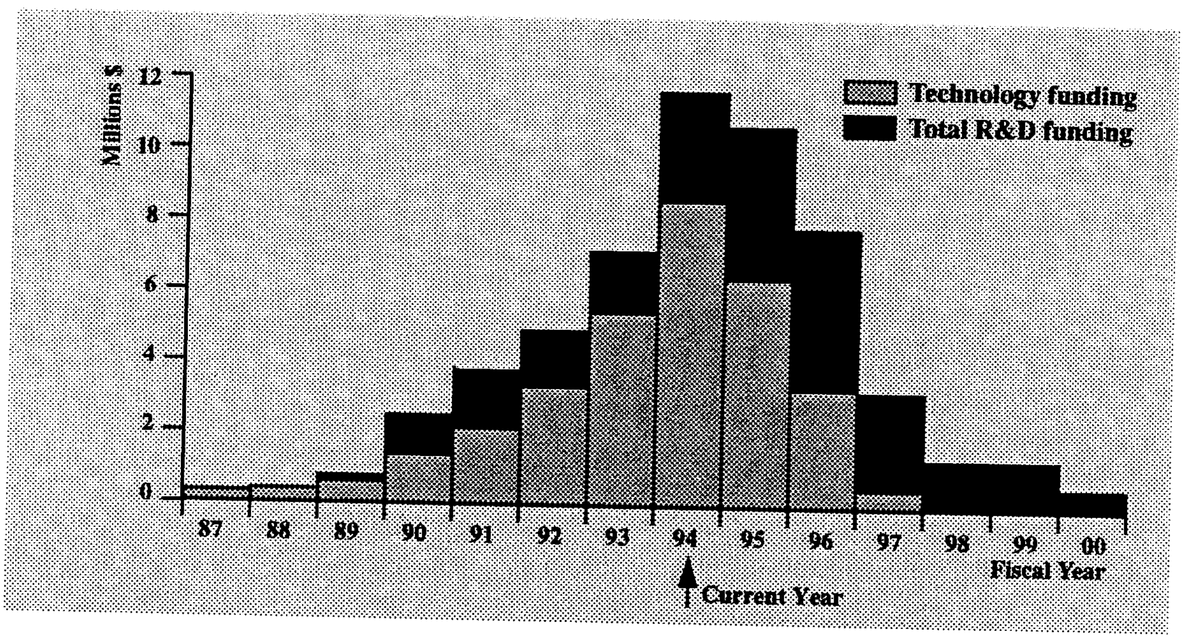

Figure 3. Funding for ITS Basic Technology Development

The issues being addressed range from investigation of dynamic scenario generation to investigation of the joint application of hybrid neural networks and knowledge-based strategies. However, there are two areas of popular interest. The first is the traditional area of student modeling and diagnosis of student deficiencies, the second is improving ITS communication with a student through interactive dialogue.

In the first case, in their Simulator/Simulation-Based Intelligent Tutoring System project, STRICOM and ARPA are sponsoring researchers to investigate student assessment based on elicitation techniques and to investigate integrating multiple knowledge representation techniques in an ITS. Other STRICOM- and ARPA-funded efforts are looking at using integrated neural network and expert system strategies for modeling and diagnosis, and at using expert systems analysis and control techniques and fuzzy logic in student modeling. AMC is funding an effort looking at diagnosing student deficiencies using innovative fault isolation techniques. A planned ONR effort is intended to determine whether measures of what a student is looking at can enhance student modeling.

Research into interactive dialogue between an ITS and student offers to improve system effectiveness and usability in several ways. There are three interesting projects in this area, with quite different focuses. First, ONR's Computer Dialogue Generation project is developing a capability whereby the CircSim Tutor can carry out several different types of interaction, involving questions, acknowledgments (positive, negative, or neutral), multi-part hints and explanations, and summarizing discourses. These can be used, for example, in providing directed lines of reasoning and in natural language dialogue where the tutor explores students' errors with them, probing for misconceptions. In a separate effort, ONR has funded researchers to investigate how to support reflective dialogues by identifying the types of questions students want to ask, identifying strategies for choosing the information to include in responses, and organizing and presenting the information in a useful way. The third effort is an NSF project in which the major focus is on providing a flexible explanation facility. The system, in this case the Biology ITS, will dynamically generate responses to unanticipated questions and tailor these responses to individual students; it will also allow the generation of what-if questions on the subject matter.

Of course, the efforts just discussed all use natural language processing technology. Other efforts are likewise exploiting this technology. ARI's Multilingual project is using it to develop skill acquisition in reading, writing, listening, and speaking in both Arabic and Spanish. The Emily Coach is using this technology to improve reading comprehension skills. These two efforts, and STRICOM's Icon-Based ITS, are the only ones actively using automatic speech recognition. From the ITS output perspective, ARI's Intelligent Flight Trainer and NASA's Conduct of Fire Trainer project are using speech synthesis to deliver coaching and advice to students.

A rather different area of research is being sponsored by DMSO (and, potentially, by NSF). Here researchers are looking at exploiting existing commercial-off-the-shelf

(COTS) software products for training aids. They are looking at how to add a software "wrapper" that turns the application into an education or training environment. This work is in its earliest stages, currently identifying which COTS can be used, identifying educational outcomes they can affect, developing broad principles, and identifying standards to guide the development of educational wrappers. Two COTS products that have been identified as prime candidates for use as the basis of an ESSCOTS are RDSS (a model of why groups revolt) and SIMHEALTH (a simulation for studying and designing alternative health systems).

Other topics being addressed by isolated efforts include dynamic regeneration of scenarios based on diagnosis of student knowledge, and the use of case-based reasoning to represent problems and structure learning.

In an effort to summarize the current state of the art, Table 3 presents the key characteristics of current prototype, demonstration, and practical use systems, where known. There are some indications of a maturing technology, in particular:

- A change in the focus of on-going work from ITS component and construction issues to specific technology-related topics. Comparatively few efforts are engaged in basic research into such topics as student and expert modeling; moreover, these efforts are all small scale. Instead, researchers are shifting their attention to topics such as interactive dialogue and wider tutoring concerns.
- Development of standard ITS architectures. Here one effort is developing an architecture for a specific domain (electronic warfare) and NASA is refining an existing general purpose NASA architecture.
- ITS systems and ITS authoring systems are being developed as research tools to support investigation into non-ITS issues. For example, in the first case, the Emily Coach is intended to support investigation into the technical feasibility of using automatic speech recognition to improve reading comprehension. In the second case, several tools are being developed that will rapidly generate ITS for experimentation in virtual environments.

Apart from the general change in focus, there are some new technology areas under investigation, primarily in the area of VR. Here researchers are attempting to lay the foundation for future work by investigating the training potential of virtual environments and developing guidelines for merging principles of instructional design and development tools for use in VR-based simulations. Although some four or five ITS efforts fall into this category, these efforts are small and do not represent large funding investments. Even so, this is an area likely to experience increasing attention in coming years.

On the whole, this is all good news. Further investigation of basic technology issues needs to wait on a better understanding of the capabilities of already developed technology. The researchers need feedback from the use of actual systems that will provide some measure as to the value and deficiencies of this technology: steps must be taken to ensure that this vital step occurs. Meanwhile, researchers are focusing on specific issues worthy of attention.

4.3 Push Towards ITS Technology Transfer

The Air Force is sponsoring two major technology transfer efforts, each of which has a formalized production approach. The Air Force Human Systems Center is focusing on introducing the technology into practical Air Force use, while Armstrong Laboratory's Fundamental Skills Training project is directing its work towards the public sector. Technology transition is expensive and current funding for these efforts represents roughly 12% of the total ITS funding, as illustrated in Figure 5.

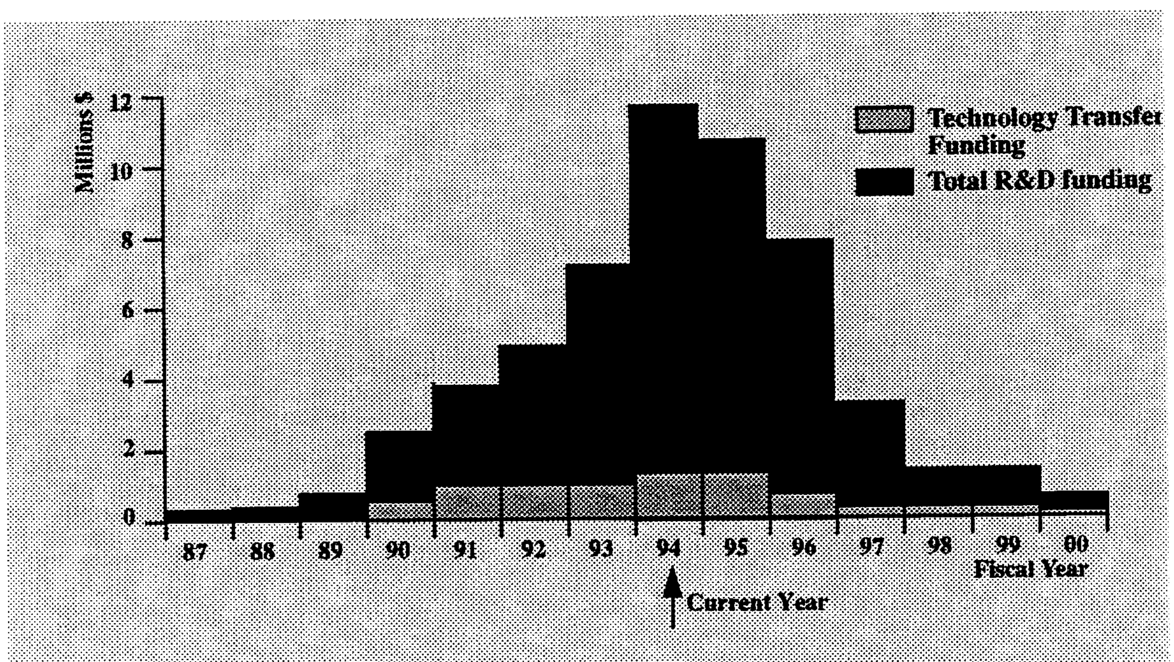

Figure 4. Funding for ITS Technology Transfer

Table 3. Char

ITS	Knowledge Representation	Student M
Word Problem Solving Tutor	Declarative and procedural representations	Separate declarative and pro tions
Reading/Writing in a Supportive Environment (R-WISE) Tutor	Semantic network using a system of nodes (containing both content and attributes) and links (typed to show relationships)	A rule-based model is used t A second model collects fine information on student activ
Instruction in Scientific Inquiry Skills (ISIS) Tutor	Knowledge is stored in the context of the simulation and text files for students to study	Endorsement-based student declarative and procedural r
Sherlock family	Object-oriented approach	Uses set of standards for eff ing, matching student behav
ARPA ITS	Production rule-based and dependency model-based approaches	Model is copy of domain hie training attributes, fault isol approach based on separate d testing with a sub-scenario
Multi-Node, Task-Sharing, Expert-Instruction (MITE) ITS	Integration of neural network and knowledge-based strategies	
MOS 91B Technical Training ITS (Simulator/ Simulation-Based ITS Project)	Integrated causal model knowledge structure (INKS) combining five representation schemas (scripts, object frames, semantic nets, production rules, mental models)	Assessment based on hybrid compiled into INKS framew
MOS 91B Technical Training ITS (Case-Based Reasoning for Simulation-Based ITS Project)	Object-oriented representation of cases with case-based reasoning supporting automatic knowledge acquisition and presentation	Contains student actions and principles, procedures, and t and those mastered
MOS 63B and MOS 91B Technical Training ITS (Hybrid Simulator-Based ITS Project)	Explicit cognitive models implemented by algorithmic, neural network, or expert system approaches	Cognitive model with "sites' ences with expert, structured diagnosis with deficiencies e rule-, or knowledge-based le cies model
Icon-based ITS (MOS 63B and MOS 91B)	Multi-media database, fixed expert rule set and data array, modifiable expert rule set and data array	Uses fuzzy logic expert syst niques. Supported by person data base.
Military Language Tutor	Rule-based	Rule-based model with bran remediation amount and lev
Intelligent Flight Trainer (IFT)	Hybrid algorithmic, neural net, expert system approach	Infers student proficiency on performance and known pilo
CircSim Tutor	Object-oriented knowledge base with three levels of detail	Combination of overlay and approaches to model knowle tions, certainty factor to mea

'haracteristics of Current ITS

ıt Model	Tutoring Strategy	Type of Simulation	User Interface
l procedural representa-	Coach practice environment	—	GUI
ɪed to drive the instruction. ; fine-grained, historical ıctivities for reporting	Acts as cognitive partner, using three separate tutors, hybrid paradigm combining adaptive tutoring and reification	—	GUI with animation
lent model using both ral representations	Cognitive apprenticeship	Ecosystem simulation driving scenario	GUI
: effective problem solv- ·havior against these	Cognitive apprenticeship through intelligent coached practice and intelligent reply, expert teaching specified by rules	Device simulation driving scenario	GUI with windows, interactive still video for equipment representation, hypergraphics, dynamically updated block diagrams
ı hierarchy annotated with isolation diagnostic ate deficiencies model and rio	Provides observation, diagnosis, and tutoring modes with scenario generation based on student performance	Weapon simulation driving scenario	GUI supported by intelligent UI design responsible for processing student inputs, and presenting scenario displays
Information not available			
brid elicitation techniques nework	Instruction driven by models of needed thinking skills. Dynamic scenario regeneration based on student knowledge	Human body simulation for examples/ exercises	Animation
and decisions, details of nd techniques presented	Presents examples, principles and methods, and compares student's solutions to stored solutions. Using student input to "learn" which examples are helpful	Human body simulation for examples/ exercises	Text and graphics with animation, video, pictures, hypertext
·ites" for capturing differ- ured knowledge-based ies evaluated in skill-, ·d level, separate deficien-	Skill-based adaptive training techniques driven by identified deficiencies	Vehicle simulation driving scenario	Object-oriented, menu-based GUI with virtual displays of controls and the HCI, visual, auditory, tactile, and proprioceptive interfaces, voice synthesis, multi-media
systems analysis tech- rsonal characterization	Three stages of learning based on gaming simulation techniques (tutorials and drill-and-practice, simulation, interactive educational gaming), with dynamic reconfiguration of gaming simulations, decision trees for tutoring strategies	Gaming simulation driving scenario	Menu-based with icons using graphics and multi-media presentation techniques, windows
ɪranching logic to control level	Lessons composed of exercises of 14 types	—	GUI with windows, supported by text-based natural language interactive dialogue, animation, sound
y on basis of observed pilot capabilities	Adaptive training techniques with evaluator/helper and aided control to fly simulator, and advice via synthesized speech output capabilities	Vehicle simulator driving scenario	Multi-modal cueing system (visual, motion, proprioceptive, auditory, tactile) for student, GUI for instructor
and bug library ɪwledge and misconcep- measure change over time	Dynamic multi-level planner, using hierarchically organized rules. Multi-part hinting and explanations, directed lines of reasoning, and other interactive dialogue, strategies under experimentation	—	Interactive natural language input/output, text-based, windows

Table 3. Characteris

ITS	Knowledge Representation	Student M
Tutoring in Problem Solving (TiPS) Tutor	Object-oriented database of problems and solutions using multiple schemas linked together	Incorporates fuzzy logic, loca dent actions using linked sch provides long-term picture of
Electronic Warfare Tutor		
Electronic Warfare Intelligent Embedded Trainer	Rule-based, including process model of inductive and deductive decision-making	Developed through monitoring use of interruption analysis
STEAMER-GT	Mathematical model interfaced with dynamic graphical objects	Not develo
Multistatic Acoustic Receiver System (MARS) Trainer Demonstration System	Tree-structure of related goals, concepts, procedures, etc.	Overlay on domain knowledge
Written Harmony Tutor	Rule-based using hypertext stack	Response matrix of questions a given
Sight-Singing Tutor	Rule-based using hypertext stack	Response matrix of questions a given
Conduct of Fire Training (COFT)/ICAT	Production rules	Descriptive approach based on hierarchically organized
Early Language Intervention System (ELIS)	Hybrid (production rules, decision trees and/or schemas	Descriptive approach based on hierarchically organized model teacher guidance
InterVehicular Information System (IVIS)/ICAT	Hybrid (production rules, decision trees and/or schemas	Descriptive approach based on hierarchically organized
Virtual Physics Laboratory (VPL) II	Production rules and mixture of other schemas	Descriptive approach based on solving procedures used by stu actions with patterns of actions (in)appropriate to indicate erro vide teacher guidance
Algebra I Tutor	Production rule model	Relates student behavior to so duction firings in the cognitive
Biology Tutor	Structured around viewpoints (descriptions of objects or processes) and models (built from viewpoints and supporting simulation and visualization)	Overlay subset of knowledge b around viewpoints and models

teristics of Current ITS (Continued)

nt Model	Tutoring Strategy	Type of Simulation	User Interface
:, local model records stu- d schemas, global model ure of student knowledge	Cognitive apprenticeship with three stages (demonstrator/ open system expert, collaborator/Socratic teacher, coach/ cheerleader), "look-back" facility	—	Menu-based graphics, windows, voice recording
TBD			
:oring student behaviors and is	Three modes: of operation: free-run, interactive training, training debrief	—	Graphics with digital maps
eveloped	Via associated workbooks	Marine gas turbine engine	GUI representing five primary control panels, supported by sound synthesis
ledge base	Cognitive apprenticeship with teachers by alternating between diagnostic and training processes	For MARS device	Text and graphical GUI
ions asked and answers	Progress through exercises based on student mastery, individualized multi-layer feedback for errors, exercise generator	—	Menu-based GUI, supported by sound synthesis
ons asked and answers	Progress through exercises based on student mastery, individualized multi-layer feedback for errors, exercise generator	—	Menu-based GUI, supported by sound synthesis and pitch detection for voice input
:d on historical modeling,	Based on "trainer-modeling" and just-in-time coaching, provides after-action reviews, and scenario generator	COFT simulator driving scenario, and simulations of crew members	GUI with virtual display of controls, etc.
d on historical modeling, odel used to provide	Initial screening of capabilities, then displays pictures and questions student about objects in the pictures	—	GUI with multi-media presentations, speech recognition/synthesis
d on historical modeling,	Based on "trainer-modeling" and just-in-time coaching	Communication device emulations	Menu-based, touchscreen monitor, animation and digitized panels to represent equipments, sound output
d on capturing problem- / student, patterns of ions classified as errors, model used to pro-	Intelligent coaching through experimentation, supported by visualization	For virtual laboratory environment and simulated work environment	VR interface providing visual and auditory displays, tactile/force feedback, motion tracking (uses eyephones, data glove, chair equipped with hand controllers for 3-D orientation and translation
o some sequence of pro- tive model	Model tracing approach and reification, ACT-R cognitive theory. Tutor is a learning environment in which helpful information can be provided and useful problems selected.	—	Text and graphics, employing spreadsheets, symbol manipulation packages and graphing routines
ge base, so structured lels	Answers questions with individualized, interactive dialogue	For biological processes	Text and graphics, initial use of still video and animation

To reflect the Navy's phasing out of steam ships, the Naval Surface Reserve Force is sponsoring NPRDC to convert STEAMER to support instruction in gas turbine propulsion. The resulting product, STEAMER-GT, will be based on the mathematical model of STEAMER but include additions such as linking to an Interactive Technical Manual. STEAMER-GT will be used to replace STEAMER at 60 sites, including the Gas Turbine School for Navy ratings. While not specifically addressing technology transfer issues, this effort is included in this category because it is directly concerned with bringing an ITS-related product into actual use.

NASA's Intelligent Physics Tutor has been licensed to a private company for commercialization. In addition, two of NASA's other R&D efforts are addressing technology transfer, though this is not the major focus of either of the programs concerned. Its Early Language Intervention Project plans to transfer NASA technology to the private sector. The Advanced Training Technologies Project is focusing on transferring technology within NASA, namely from the Johnson Space Center Software Technology Branch to the Mission Operations Directorate.

With the current state of ITS technology, this level of focus on technology transfer is probably appropriate. Hopefully, more data from formative evaluations of ITS effectiveness will become available in the near future to indicate what, if any, additional funding is required.

4.4 Popular Application Domains

For those ITS systems which are documented as under development for practical use, the predominant application domain remains troubleshooting of electronic devices. In the case of the 22 ITS cited as intended for practical use, 11 address troubleshooting. Of the four authoring systems cited as intended for practical use, only one is specifically intended for the development of ITS for troubleshooting electronic devices; most of these authoring systems, however, are intended to be produce ITS customized to various domains, and many of them could be used for the troubleshooting domain. Figure 6 identifies the intended application domains of all these systems under development for practical use.

Of the remaining proof-of-concept, research, and prototype ITS being developed, there are 34 with known application domains. These domains span a wide range. The most common domain is equipment operation and maintenance, followed by troubleshooting of electronic devices and mathematics (this category includes algebra word problem solving applications). More details about intended application domains are given in Figure 7. As appropriate for each application domain, target audiences range from first-grade school students to operators of complex equipment, such as pilots.

ITS:		Authoring Systems:	
Electronic device troubleshooting	11	Electronic device troubleshooting	1
Manufacturing and assembly	2	Procedural tasks	1
Music	2	Operating complex systems	1
Biology/biotechnology	2	Unclassified	1
Mathematics	2	Total	4
Gas-turbine propulsion	1		
Early language intervention	1		
Medicine	1		
Total	22		

Figure 5. Application Domain Counts for Practical Use Systems

ITS:		Authoring Systems:	
Equipment operation & maint.	8	VR-based research	2
Electronic device troubleshooting	4	Unclassified	2
Mathematics	4	Operating complex systems	1
Electronic warfare	3	Total	5
Emergency medical care	3		
Basic reading/writing	2		
Biology/biotechnology	2		
Battlefield logistics	1		
Damage control	1		
Military languages	1		
Orbital mechanics	1		
Physics	1		
Problem diagnosis	1		
Spatial navigation	1		
Task allocation	1		
Total	34		

Figure 6. Application Domain Counts for Proof-of-Concept, Research, and Prototype Systems

Judging from this data, it appears that researchers are starting to exploit results from the last 30 years of investigation into electronic troubleshooting ITS and to develop systems for practical use. Meanwhile, attention is turning to a broad range of additional domains. These trends are encouraging, providing some evidence of a maturing technology.

4.5 Intelligence of ITS Intended for Practical Use

An interesting question is how much intelligence those ITS under development for practical use exhibit. Over half are derivatives of the Sherlock intelligent coached practice environment. Sherlock is not as driven by a dynamic student model as most of the ITS discussed in this work. Its intelligence primarily is used to respond to student requests, rather than to intervene directly.

Of the non-Sherlock based ITS under development for practical use, information was not available for ONR's A-Base tutor, or for those funded under the Technology Reinvestment project. Like its predecessor STEAMER, STEAMER-GT is a smart simulation that, currently, does not use intelligence in the traditional ITS sense (NPRDC researchers hope to include a coach in STEAMER-GT in the future, but such an effort is currently unfunded). The remaining systems to consider are ONR's CircSim and Tutoring in Problem Solving tutors, and NASA's Early Language Intervention System, all of which provide the traditional types of cognitive diagnosis and adaptive remediation. Only CircSim goes further. The focus of this effort is on providing additional "intelligence" through interactive natural language dialogue in which the system can explore their errors with students and discuss issues in the instructional material and approach.

Finally, while intelligence is not a question pertinent to ITS authoring systems themselves, it would be useful to note how intelligent the ITS developed by these authoring systems will be. Unfortunately, this information is not available.

4.6 Role of Training Requirements

Another issue is how ITS developments are addressing specific training requirements. Presumably all those ITS under development for practical use are intended to meet a specific training requirement. In general, however, training needs are being met in one of two ways: (1) there is a particular training need that has driven the ITS R&D effort, or (2) a training requirement has been chosen primarily to provide an application domain in which to conduct R&D. Categorizing the ITS systems in this way is a subjective matter, but roughly a third of the systems fall into the first category, predominantly the Sherlock family of tutors and STEAMER-GT, with the remaining two-thirds being in the second category.

It is interesting to note, however, that those cases where the training requirement can be said to largely drive the research do not correspond one-to-one with systems intended for practical use. This arises because a few systems developed as research vehicles have come into practical use, and because some efforts intended to develop practical use systems are building generic ITS systems (these are not full authoring systems, they are a general-purpose ITS systems which can be supported by different knowledge databases). Of course, it is to be expected that meeting a specific training requirement is not the primary driving force where ITS are developed as research vehicles for investigating particular technology issues.

It is important to note that only Armstrong Laboratory, the Air Force Human Systems Center, and NASA appear to be specifically trying to identify the training needs in a broad domain and look at how ITS could meet these needs.

4.7 Development of Authoring Environments

Another relatively new area of investigation, and one that seems likely to continue to experience growth, is that of ITS authoring environments. These are systems that can be used to build a new ITS from scratch, defining both instructional approaches and content material. Here again, the funding for a relatively few efforts represents a significant portion of the ITS total (very roughly, 11% of efforts are allocated 32% of the total funding). Figure 8 shows how current and planned funds are distributed over time.

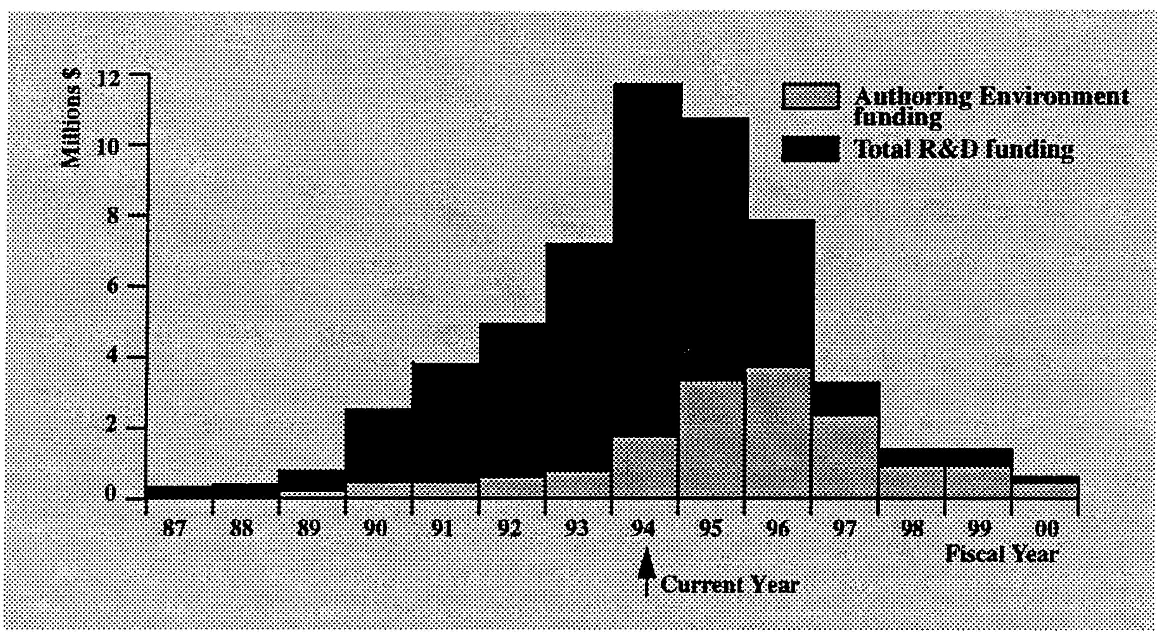

Figure 7. Funding for ITS Authoring Environments

Authoring environments are largely seen as a mechanism for reducing ITS development costs and transitioning the technology into practice. For example, Armstrong Laboratory reports that a "typical" ITS development effort takes three years and costs around \$1M, and its Intelligent Computer-Assisted Training Testbeds project has the goal of reducing tutor development time by 80% and reducing tutor development cost by up to 95%. As yet, no data on the actual cost-effectiveness of authoring environments has been reported. In only one case, Microcomputer Intelligence for Technical Training Writer, has the product of an authoring system been evaluated. Here, an instructional designer and subject matter experts used Microcomputer Intelligence for Technical Training Writer to develop a tutor to train students in troubleshooting the AN/UGC-141 Teletypewriter. This tutor would be used to supplement classroom instruction. In a controlled experiment, researchers found that students who used the tutor performed significantly better in a paper and pencil test than those that did not use the tutor. (On average, the control group mean score increased 23% while the treatment group mean score increased 47% [Parlett 1994].)

It is also interesting to note that authoring environments under development are split almost equally between prototypes or research tools, and those intended for practical use. In view of the lack of data about the benefits of these environments, this is evidence of a very quick move into the development of practical use systems.

Of the nine authoring systems identified, three are intended to support research activities. These activities fall into the following areas: (1) investigating the merging of principles of instructional design and development tools, (2) looking at how to best exploit the capabilities of virtual reality technology for effective training of cognitively complex tasks, and (3) determining the effect of immersion on training. Three more authoring systems are essentially packaging of traditional ITS approaches.

The remaining three, Armstrong Laboratory's Rapid Intelligent Tutoring System Development System, the Technology Reinvestment Project's Next Generation authoring system, and NASA's Intelligent Computer-Assisted Training authoring system, provide more insight into the approaches being used to develop authoring systems. All are intended to develop ITS for customized domains, although the Rapid Intelligent Tutoring System Development System is constrained to situations where the learner can benefit from interaction with complex computer-based graphical models. It is not clear how much flexibility of teaching style these systems will support, although the Rapid Intelligent Tutoring System Development System allows both automatic generation or custom-authoring of required instruction and the developers of the Technology Reinvestment Project authoring system are emphasizing a customizable teaching style yet to be determined. These systems all provide the user with graphical editors for ITS construction, but provide different paradigms for use of the editors. The Rapid Intelligent Tutoring System Development System approach is based on the concept of objects and their behaviors. Though the full process can be shortened, ideally the Rapid Intelligent Tutoring System Development System usage starts by defining a set of learning objectives. The user then develops a preliminary design of the instruction units that will attain the objectives, an interactive graphical model of the domain of concern, and browsable knowledge units. Finally he completes the instructional units. The Technology Reinvestment Project authoring system essentially operates as a knowledge acquisition shell for representing and rapid prototyping of domain and tutoring knowledge. With its Intelligent Computer-Aided Training and Tutoring metaphor, the NASA approach is much different. Here, developing an ITS consists of building a simulated work environment and providing a personal trainer that uses this environment to instruct the student. Consequently, the authoring system integrates a simulation package for work environment construction with a tool that guides trainer modeling, that is, overlaying a simulated work environment with lessons and providing remediation to the student.

To date, the authoring systems only have been used for the development of prototype ITS, not practical use ITS. The Microcomputer Intelligence for Technical Training Writer has received the greatest usage, with nine prototype ITS being developed for applications ranging from acute care liver transplants to a cryptographic unit.

The expectation that authoring systems will help to transition ITS technology into practice is based on the premise that teachers, and instructional developers, will be more likely to use ITS that they themselves have developed and/or customized. So far, there is no evidence of teacher involvement in authoring system development, even for those authoring systems intended for practical use. Unless the proper consideration is paid to the needs of teachers, authoring systems will not help to transition the technology.

4.8 Evaluation of ITS Effectiveness

While the results of ITS evaluations to date (see Chapter 2) seem promising, there has been insufficient experimentation to develop any general conclusions about ITS effectiveness that can be used to guide ITS usage or further development. Without question, this has been a major shortcoming in the ITS field. There are some difficult issues to be addressed. For example, an ITS is a complex interaction between computer-based technologies (such as artificial intelligence, human-computer interaction, and language processing), pedagogy, cognitive science, and subject matter. How can, and should, the effect of these different concerns be addressed? How can actual training effectiveness be assessed?

Basic questions as to what should be measured and how to measure have yet to be answered.

Armstrong Laboratory is conducting a project that places a major focus on investigating these issues. The goal of this project, the Training Research for Automated Instruction, is to understand the relationship among automated pedagogies, personological variables, and instructional effectiveness. It has built a computer laboratory (called the Cooperative Lab, or Co-Lab) to serve as a national testbed for instructional theory, and as a resource that can be used for evaluating ITS in a controlled laboratory setting. The Training Research for Automated Instruction project is also developing and promoting widespread use of a standard set of criterion tests that are designed to allow benchmarked comparisons of instructional approaches and so help diverse researchers share data. Other projects that include some (smaller-scale) investigation of how to assess ITS instructional effectiveness are Armstrong Laboratory's Basic Job Skills project, the ARI's Intelligent Flight Trainer project, and the NPRDC's Complex Cognitive Skills project. Additionally, investigating ITS effectiveness in training transfer is one of the goals of NASA's Intelligent Computer-Assisted Training Testbeds Program.

About a quarter of those efforts developing an ITS have performed, are performing, or plan to perform, formal evaluations of their products (see Table 4). Here again, it is interesting to note that there is not a direct correspondence between effectiveness evaluation and systems intended for practical use, although the majority of such systems are expected to be formally evaluated. The primary results reported from completed evaluations are as follows (information on evaluation results was not available for Reading/Writing in a Supportive Environment):

- Word Problem Solving tutor—A large-scale field evaluation showed that students exposed to traditional instruction improved their word problem-solving performance by 17% over a school year, while students exposed to Word Problem Solving tutor improved by 26% over the same period [Parlett 94].
- Sherlock—Initial field testing showed that 20 to 25 hours of Sherlock training produced learning equivalent to about four years of on-the-job experience. More recent evaluations, performed with a criterion of real-world performance of the most difficult part of the job, and with blind scoring of performances, report experimental versus control effects of two standard deviations [LRDC 1993].

- Algebra Tutor—Using the Iowa Algebra Aptitude Test, ITS-tutored students' scores were 33.5, as contrasted to non-ITS users' scores of 30.5. Using Scholastic Aptitude Tests, the average score of ITS-tutored students was 410, compared with an average of 380 for non-ITS users [Anderson et al. 1994].
- Emily—Early pedagogical tests showed assisted students gained a reading level higher than their independent reading level by an average of 0.6 years. Subjects misread only 2.6% or the given words, as opposed to 12.3% when no assistance had been used [Mostow et al. 1994].
- Virtual Physics Laboratory, Physics Tutor—Initial evaluations found high levels of student satisfaction with the tutor. Evaluations of tutor effects on course achievement were inconclusive, but, at the end of the training period, tutored students had the highest scores for problem-solving strategies [Ross and Casey 1992].

Table 4. Efforts Looking at Effectiveness of ITS Products

ITS	Evaluation Status
Word Problem Solving Tutor	Ongoing
Reading-Writing in a Supportive Environment Tutor	Ongoing
Science Tutor	Planned
Sherlock	Ongoing
Intelligent Flight Trainer	Ongoing
CircSim Tutor	Ongoing
Computer Adaptive Testing-Armed Services Vocational Aptitude Battery Tutor	Planned
Electronic Warfare Tutor	Planned
Sight-Singing Tutor	Ongoing
Written Harmony Tutor	Ongoing
InterVehicular Information System/Intelligent Computer-Assisted Training	Planned
Early Language Intervention System	Planned
Virtual Physics Laboratory	Ongoing
Algebra Tutor	Ongoing
Emily Coach	Ongoing
Biology Tutor	Planned

The types of experiments that have been conducted vary widely in scope. For example, a pilot evaluation of the Word Problem Solving tutor employed some 350 subjects, whereas early Emily evaluations have been limited to 12 subjects. The systems for which evaluation data is available vary widely; this, together with the lack of common evaluation paradigms, means that results are not comparable across systems.

Two of the efforts developing ITS authoring systems are also planning formal evaluation of training effectiveness, specifically the efforts underway by Armstrong Laboratory and the Technology Reinvestment Project Next Generation Authoring Tools. The project plans for several other efforts cite plans for some informal evaluation, but this evaluation is likely to be more in the nature of the small-scale test and evaluation routinely required on any system development effort, rather than addressing the particular concerns of ITS technology.

This evidence of increased attention on the evaluation of ITS effectiveness is encouraging. Since most evaluation activities have yet to be fully defined and conducted, it is too soon to say whether enough attention is finally being paid to evaluation issues.

4.9 Focus on Pedagogy

It is encouraging to note that several efforts are looking at pedagogical issues. There are no major trends to report, but rather a diffusion of attention across a range of concerns. Some of this work is closely linked with the technological research underway, as discussed previously in Section 4.2, in particular, ONR's efforts investigating the use of reflective dialogue. Others are studying particular pedagogic strategies, notably cognitive apprenticeship and inquiry-based learning, and one effort has the stated purpose of conducting experimental studies of alternative strategies. There are four efforts focusing on cognitive issues: (1) identifying stereotypical patterns of cognitive processes, (2) looking at linking an individual's cognitive style with methods for organizing and presenting information, (3) relating tutoring actions to resultant cognitive processes and learning effects, and (4) building tools for analyzing cognitive skills and mental models. Only ARI's Multilingual project work with pedagogy is primarily driven by an application domain. While application domain is of course a factor for the other efforts, it does not appear to be the driving factor behind the work.

Armstrong Laboratory and NASA have a couple of efforts working at a higher level, endeavoring to assess the potential that VR technology has for instruction. This is a popular area, not only within the ITS community but the computing community in general.

While the majority of the current projects in this area are small, short-term efforts, there is some reason to hope that this focus on pedagogy will continue. For example, Armstrong Laboratory's Co-Lab intends to look at how to implement and assess emerging knowledge about pedagogical strategies, and it has another large, multi-year project investigating the relationship between automated pedagogies and instructional effectiveness.

4.10 Support for Teachers

Two groups are actively including teachers, or instructors, in their work. Supported by NSF, John Anderson has been working closely with teachers in Pittsburgh, Pennsylvania, to support the Pittsburgh Urban Mathematics Projects. As part of its Fundamental Skills Training project, Armstrong Laboratory has also built and maintained strong ties with local schools, involving teachers in ITS development efforts and using several schools as test and evaluation sites.

Some other efforts are looking at how to support teachers in their actual use of an ITS. NASA's previously developed Physics Tutor introduced a Teacher's Window application that uses the underlying student model to provide guidance to teachers in the selection and use of ancillary instructional aids. A similar capability is being developed for NASA's ongoing Early Language Intervention Project. The TRP authoring tools project (Next Generation Authoring Tools and Instructional Applications) is proposing to enable instructors to monitor the internal state of the tutor. SPAWAR's Multistatic Acoustic Receiver System Trainer Demonstration System will provide various reports on individual and group performances, giving access to student-generated comments and performance-based parameters. Additionally, this ITS can generate reports that reflect on the strengths and weaknesses of the content material.

A third, and final, type of support being provided to teachers is the provision of special editors and tools that enable them to prepare their own lesson materials. (These are not full authoring environments as discussed previously, but do allow some customization and extension of instructional content.) Included in this category are the Multistatic Acoustic Receiver System Trainer Demonstration System, the Sight-Singing and Written Harmony tutors, and the Military Language Tutor.

Nonetheless, the critical issues in how ITS technology should best support teachers have not yet been systematically identified, much less understood. This area requires further attention. If ITS technology is to mature appropriately and come into widespread practical usage, the special needs of teachers must considered as an integral part of any development effort.

5. RECOMMENDATIONS

ITS technology has been under development for three decades and there are signs that it is starting to emerge from the laboratory and come into practical use. While there still are technology issues to be addressed, the emphasis of researchers is appropriately starting to shift to issues pertaining to ITS use.

The early focus on general ITS components and construction issues is changing. Today, technology-related R&D is looking at specific topics, such as flexible explanation generation and dynamic scenario generation. Several of the efforts are looking at advancing those parts of the technology whereby an ITS exhibits intelligence. Apart from the general change in focus, there are some new technology areas under investigation, primarily in the area of VR. On the whole, activity in this area seems promising and should continue. Higher levels of funding for basic technology R&D need to wait on a better understanding of the capabilities of already developed technology. The researchers need feedback from the use of actual systems that will provide some measure as to the value and deficiencies of this technology.

Recommendation 1: More focus is needed on evaluation issues. The next several years should see summative evaluation of all ITS developed for practical use, while moving towards assessing the effectiveness of ITS technology in general.

Questions such as *What is the potential of this technology?* and *How best can it be used?* have yet to be answered. To date, there has been a lack of formal, or even informal, evaluations that work toward answering these questions, so it is encouraging to note that a number of current efforts seem to be addressing this need. This trend should be encouraged. A single organization (in view of the Defense Science and Technology Reliance Initiative, probably Armstrong Laboratory) should be given the responsibility to collect and consolidate evaluation data produced by the ITS community as a whole, and to make this information readily available to feedback into new development efforts.

Recommendation 2: The current level of effort in the area of authoring systems should not be expanded at the present time. While authoring systems can be valuable tools for researchers, many issues need to be addressed before more such tools are developed for use by the general educational community.

The question of support for the development of authoring systems is less clear cut. The value of such tools for bringing ITS into widespread use will be substantial, but is the time right? Authoring systems can already serve as valuable tools for developing ITS that will themselves be used as research vehicles. Without more data on the general effectiveness of ITS, however, the current level of effort may be premature. Assuming that researchers do establish that ITS are a cost-effective way to deliver instruction, will the typical end user be able to use an authoring system to produce an ITS as effective as one developed by experienced researchers? Is there any way in which the quality of the products of an authoring system can be predicted, without necessitating formative evaluation of each individual product? To date, authoring systems only have been used to development prototype ITS, so it is disturbing to note that half the authoring systems under development (or planned for development) are intended for practical use by end users such as subject matter experts, instructional developers, and teachers.

Recommendation 3: More effort is needed in investigating how to prepare and support teachers in their use of ITS technology.

As this technology continues to mature, it is increasingly important that the needs of teachers are understood. This includes looking at what ITS products teachers actually want, preparing teachers for the use of these products, and ensuring that the ITS provide the types of information teachers need to help student in the learning process. Should teachers receive formal training prior to their use of an ITS, a practical demonstration of the system, or just an instruction manual? What role should teachers play in formal evaluations of ITS? What types of special editors and tools for customizing lesson content are best suited to teachers' use? These are just a few examples of the many issues to be investigated. Without due consideration of teachers' needs, ITS products are likely to end up as shelfware.

Recommendation 4: The role of ITS in supporting new instructional approaches, such as learner control, collaborative learning, and situated learning, should be investigated in addition to VR and learning.

A related issue that needs studying is how ITS technology can support the changing vision of the classroom. Although learner control, collaborative learning, situated learning, and virtual reality and learning have been identified as key ITS topics for the 1990s [Shute and Psotka 1994], the only topic receiving significant attention from researchers in the identified efforts is virtual reality and learning. While this research needs to be continued, the other topics merit attention.

> **Recommendation 5:** Continued transition of the technology into practice use should be encouraged. Public awareness of the potential of this technology needs to be increased.

The focus starting to be placed on transitioning ITS technology into practical use should be encouraged. Such efforts would serve multiple purposes. As well as providing needed instructional tools, increased practical use of ITS would provide data to support assessing the effectiveness of this technology and help in identifying the key issues involved in better supporting teachers in their use of the technology. Moreover, some transition activities should be selected as demonstration activities used to raise public awareness of the potential of ITS technology. In developing products for practical use, care must be taken to select applications where this technology is appropriate and to satisfy real training requirements.

The importance of education and training is increasing, both in Government and industry. This is in response, in part, to such drivers as the increasing need for a flexible workforce and DOD downsizing. The data is not available to see how current levels of funding differ from spending in previous years, but declining Government and DOD budgets are likely to lead to substantial funding reductions in future years. The potential of this slowly maturing technology must be realistically assessed so that continued R&D funding can be appropriately allocated to ensure a worthwhile pay-off in future years.

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LIST OF ACRONYMS

1-D	One Dimensional
2-D	Two Dimensional
3-D	Three Dimensional
AF	Air Force
AFOSR	Air Force Office of Scientific Research
AI	Artificial Intelligence
AL	Armstrong Laboratory
AMC	Army Materiel Command
ARDA	Aviation Research and Development Activity
ARI	Army Research Institute
ASVAB	Adaptive Training Armed Services Vocational Aptitude Battery
ATMRU	Advanced Training Methods Research Center
BJS	Basic Job Skills
CAT	Cognitive Analysis Tool
CBMS	Computer Based Memorization System
CBT	Computer-Based Training
CIC	Combat Information Center
COFT	Conduct of Fire
COPTER	Console Operations Tutor
COTS	Commercial off the shelf
DMSO	Defense Modeling and Simulation Office
DOD	Department of Defense
DOEd	Department of Education
ELIS	Early Language Intervention System

EW	Electronic Warfare
FIPSE	Fund for Improvement of Postsecondary Education
FST	Fundamental Skills Training
FY	Fiscal Year
GUI	Graphical User Interface
HCI	Human-Computer Interface
HSC	Human Systems Center
ICAT	Intelligent Computer-Aided Training
ICATT	Intelligent Computer-Aided Training Testbeds
IERW	Initial Entry Rotary Wing
IFT	Intelligent Flight Trainer
IMTS	Intelligent Maintenance Training System
INCOFT	Intelligent Conduct of Fire Trainer
INKS	Integrated Casual Model Knowledge Structure
ISIS	Instruction in Scientific Inquiry Skills
ITS	Intelligent Tutoring System
IVIS	InterVehicular Information System
MACH-III	Maintenance Aid Computer for HAWK—Intelligent Institutional Instructor
MARS	Multistatic Acoustic Receiver System
MICOM	Missile Command
MITT	Microcomputer Intelligence for Technical Training
MST	Maintenance Skills Trainer
NASA	National Aeronautics and Space Administration
NAWCTSD	Navy Air Warfare Center Training Systems Division
NPRDC	Navy Personnel Research and Development Center
NSF	National Science Foundation
NSRF	Naval Surface Reserve Force
ONR	Office of Naval Research

QUEST	Qualitative Understanding of Electrical Systems and Troubleshooting
R&D	Research and Development
R-WISE	Reading/Writing in a Supportive Environment
RIDES	Rapid Intelligent Tutoring System Development System
SATS	Signal Analysis Tutoring System
SBIR	Small Business Innovation Research
SOPHIE	Sophisticated Instructional Environment
SPAWAR	Space and Naval Warfare Systems Command
STRICOM	Simulation, Training and Instrumentation Command
SURTASS	Surveillance Towed Array Sensor System
TiPS	Tutoring in Problem Solving
TRAIN	Training Research for Automated Instruction
TRIO	Trainer for Radar Intercept Operations
TRP	Technology Reinvestment Project
UI	User Interface
VISTA	Virtual Interactive System for Training Applications
VIVIDS	Virtual Interactive Technologies Intelligent Tutoring System
VR	Virtual Reality
WPS	Word Problem Solving

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
February 1995

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
Government-Sponsored Research and Development Efforts in the Area of Intelligent Tutoring Systems: Summary Report

5. FUNDING NUMBERS
IDA Central Research Program (CRP) 9001-504

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Institute for Defense Analyses (IDA)
1801 N. Beauregard St.
Alexandria, VA 22311-1772

8. PERFORMING ORGANIZATION REPORT NUMBER
IDA Paper P-3058

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Institute for Defense Analyses
1801 N. Beauregard St.
Alexandria, VA 22311-1772

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, unlimited distribution: April 6, 1995.

12b. DISTRIBUTION CODE
2A

13. ABSTRACT (Maximum 200 words)

The U.S. Government has been sponsoring efforts in the development of intelligent tutoring system (ITSs) for over 20 years. Information on current ITS-related R&D activities was collected from various organizations within the Department of Defense, Department of Education, National Aeronautics and Space Administration, and National Science Foundation. Based on the information acquired, this report provides insight into the current state of the art in the ITS area. It discusses research trends, characteristics of today's ITS, and efforts to move ITS technology into widespread practical use.

An earlier report, IDA Paper P-3003, Government-Sponsored Research and Development Efforts in the Area of Intelligent Tutoring Systems, contains the original data and was published earlier to make the data available in a timely manner to researchers in the field of ITS.

14. SUBJECT TERMS
Intelligent Tutoring Systems, Computer-Assisted Instruction, Human-Computer Interface (HCI), Graphical User Interface (GUI), Training, Software Tools.

15. NUMBER OF PAGES
60

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR