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Computer-Based Aids for Learning, Job Performance, and Decision-Making in Military Applications:
Emergent Technology and Challenges

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Technology-based systems for education, training, and performance-aiding (including decision-aiding) may pose the ultimate test for validating approaches to integrate humans with automated systems. These systems need to model students and users. The models they generate, as well as the interactions based on them, must adapt to the evolving knowledge and skills of individual students and users. Evaluation findings suggest that such adaptations are feasible, worthwhile, and cost effective. Data drawn from many evaluations of technology-based education and training indicate overall that these systems can reduce costs by one-third and that they can also either reduce the time to achieve instructional objectives by one-third or increase achievement (holding time constant) by one-third. The likely impact on military readiness and effectiveness suggested by these findings is significant. Evaluations of technology-based performanceaiding systems have suggested similar results of increased personnel effectiveness and cost-savings. They suggest a need to determine and readjust the balance between resources allocated to training and resources allocated to performance-aiding systems. Development of sharable, reusable objects and capabilities for assembling these objects on demand and in real time will substantially increase accessibility and will reduce costs of education, training, and performance-aiding while making them asynchronously and continuously available? regardless of distance and time. Specifications and capabilities for such objects are the goals of much current research and development (R&D).

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PREFACE

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EXECUTIVE SUMMARY

Continuous adult learning is the hallmark of establishing and maintaining competence and expertise in the military occupations. This learning environment relies increasingly on technology to be continuously accessible to learners and other users. Because of the autonomous nature of technology, such learning environments will place on the developers an enormous responsibility to design and implement materials from the learner's perspective.

Technology-based systems for education, training, and performance-aiding (which includes decision-aiding) may pose the ultimate test for validating approaches to integrate humans and automated systems. These systems need to model students and users. The models they generate and the interactions based on these models must adapt to the evolving knowledge and skills of individual students and users. Evaluation findings suggest that such adaptations are feasible, worthwhile, and cost-effective. Data drawn from many evaluations of technology-based education and training indicate that these systems can reduce costs by one-third and that they can also either reduce the time to achieve instructional objectives by one-third or increase achievement (holding time constant) by one-third. The likely impact on military readiness and effectiveness suggested by these findings is significant.

Evaluations of technology-based performance-aiding systems have resulted in similar findings regarding increased personnel effectiveness and cost-savings. These evaluations suggest a need to review and readjust the balance between resources allocated to training and resources allocated to performance-aiding systems. The development of sharable, reusable objects for the generation of instructional (or decision-aiding) presentations and the capabilities for assembling these objects on demand and in real time will substantially increase accessibility and reduce costs of education, training, and performance-aiding while making them asynchronously and continuously available regardless of distance and time.

Specifications and capabilities for such objects are the goals of much research and development (R&D). Some of these goals are discussed under the systems engineering categories of analysis, design and development, delivery and management, and evaluation. North Atlantic Treaty Organization/Partnership for Peace (NATO/PfP) participation would

substantially enhance this research agenda. This participation might include the development of a NATO/PfP directory of databases that would permit wide dissemination and sharing of techniques and findings and the development of NATO/PfP common practices for developing sharable objects and guidelines for their use.

COMPUTER-BASED AIDS FOR LEARNING, JOB PERFORMANCE, AND DECISION-MAKING IN MILITARY APPLICATIONS: EMERGENT TECHNOLOGY AND CHALLENGES

A. INTRODUCTION

Continuous adult learning is the hallmark of establishing and maintaining competence and expertise in the military occupations. This learning environment relies increasingly on technology to be continuously accessible to learners and other users. Because of the autonomous nature of technology, such learning environments will place on the developers an enormous responsibility to design and implement materials from the learner's perspective. Education, training, and performance-aiding systems may be the ultimate test bed for validating technological approaches to accommodate humans in automated systems.

Automated instructional systems must address several variables, including the method of instructional delivery, desired learning objectives, and learning environment (see Figure 1). Figure 1 illustrates these elements in three dimensions:

- The "Complexity of Technology & Technique" axis provides a continuum of technical difficulty beginning with computer-aided instruction (CAI) and progressing in difficulty to a virtual reality (VR) distributed simulation. Educational objectives and the availability of required equipment determine the level of technology required for instruction.

- The "Level of Learning" axis concerns the level of knowledge required by the task(s) to be performed. Benjamin Bloom's taxonomy offers a convenient framework for defining levels of learning—from basic knowledge to the more involved process of evaluation (Bloom, 1956). These levels suggest the instructional techniques to be used and affect the training time needed to reach them.

- The "Environment" axis denotes where the information learned will be used, ranging from a familiar simple environment (e.g., the office) to the unfamiliar, complex environments characteristic of military operations (e.g., the battlefield). The environment determines what training devices will be available and helps set priorities for instructional objectives.
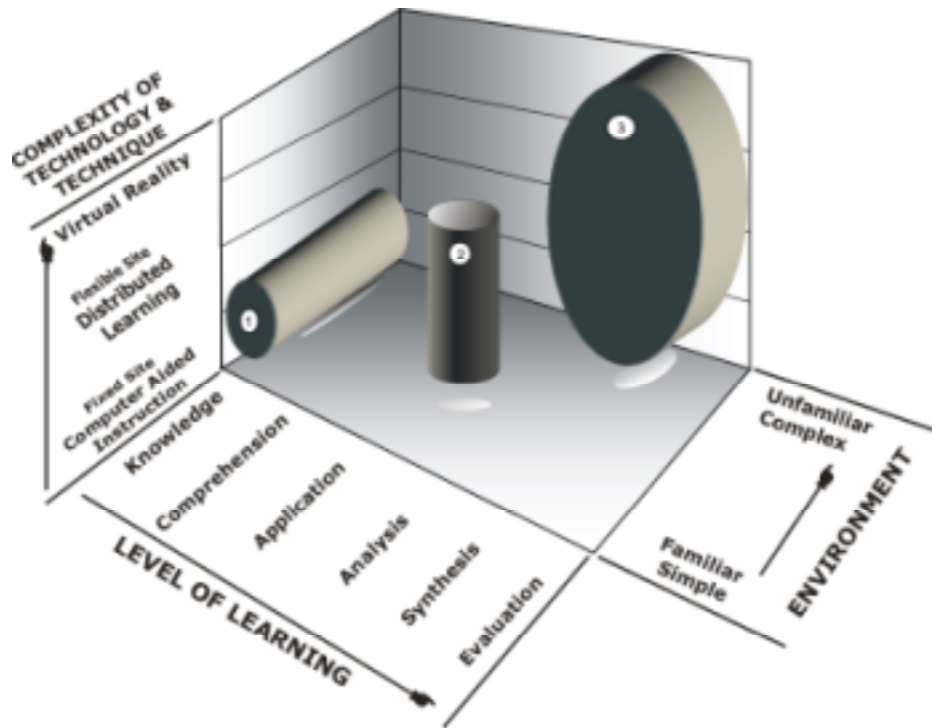
Figure 1. Dimensionality of Human Roles in Training Systems

A key point emphasized in this document is that each human will play many roles in his/her interactions with any system, including (as Figure 1 suggests) training systems. This figure suggests that these roles must evolve along with the level of learning achieved by individuals. Capable systems (notionally, the numbered items in Figure 1) must accommodate these levels of learning dynamically as users achieve them—adjusting the complexity of technologies, the techniques they employ, and the environment they present to the learners. To be effective in providing continuous adult learning, both the system and the users must change their behavior. Both must adapt and learn.

Can we expect this to happen? Will technology, specifically computer technology, adapt to its users in much the same way that users today must adapt to it? The technology is certainly becoming more powerful. After almost 40 years, Moore's law (e.g., Service, 1996) still holds. In 1965, Gordon Moore[1] noted that engineers were doubling the number of electronic devices (basically transistors) on chips every year. In 1975, he revised his

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[1]   Gordon E. Moore is currently Chairman Emeritus of Intel Corporation. Moore co-founded Intel in 1968, serving initially as Executive Vice President. He became President and Chief Executive Officer in 1975 and held that post until elected Chairman and Chief Executive Officer in 1979. He remained CEO until 1987 and was named Chairman Emeritus in 1997.

statement to say that this doubling was occurring every 2 years. If we split the difference and predict it will occur every 18 months, our expectations fit reality quite closely.

One consequence of Moore's law is that significant computational power and functional capacity are found in today's desktops and laptops for less than $1,000 per system. Moore, however, did not predict the pace of progress in human-centered design of computer software interfaces or in software applications. Raymond Kurzweil discussed this rapid increase in electronic capability [10 years ago in the *The Age of Intelligent Machines* (1992) and, more recently, in *The Age of Spiritual Machines* (2000)]. Kurzweil predicted that a $1,000 unit of computing would equal the computational capability of the human brain by the year 2019—and exceed it thereafter. Whether this $1,000 unit will be "intelligent" and have functional capability adaptively centered on the human user can be debated, but the rapid expansion of computational capability into many areas of human cognition seems undeniable.

The pervasive nature of automation technology and applications to military enterprises seems equally undeniable. It is present not only in our offices, schools, and homes, but it has also become an essential enabling capability for our military operations. We seem inexorably borne on a rising crest of digital applications in command and control (C2), communications, modeling and simulation (M&S), sensors and surveillance, and, notably, in such human-intensive activity as decision-making, education, training, and performance-aiding. These latter applications and their inherent technology challenges are the topic of this document, which addresses the following questions:

- **Is it worth it?** What do we know about the value of technology applications in learning (education and training) and performance-aiding (decision-making and job-task enhancement) and what are the challenges if we want to realize the full value?

- **Where do we want to go?** What are promising technological opportunities and directions for these applications and how might we best employ them to support military operations and activities?

- **How should we get from here to there?** How can science and engineering advance the state of the art and the state of our practice in performing military operations?

B. IS IT WORTH IT?

We will argue "yes." Scientists and engineers have been pursuing research and development (R&D) on and assessments of computer applications in education, training,

and performance-aiding for more than 45 years (Fletcher and Rockway, 1986). Much, possibly most, of this work in the United States has been funded by the military (Congress of the United States, Office of Technology Assessment, 1988) and is intended to enhance military capabilities. This pattern of funding support may also be true for other countries (Chatelier and Seidel, 1993; Seidel and Chatelier, 1995). It is not surprising, then, to find that data on the effectiveness and cost benefits of these applications have been accumulating. We might wish for more data, particularly in the area of cost benefits; however, the weight of evidence makes it much easier to argue (on the basis of existing, empirical data) for the value of these applications rather than against them. These data are reviewed in the following sections on education and training applications, human instructors in the loop, and performance-aiding applications.

1.   Education and Training Applications

Suppose we could reduce by 30 percent the time that military personnel need to reach a given level of training. We would then expect to see reductions in expenditures for instructor pay and allowances, student pay and allowances, temporary duty costs, training equipment costs, and installation support costs—among the measurable items. Not surprisingly, we find that savings from the reduction of training time can be substantial—a "value" that may go beyond the measurable (e.g., flexibility in the reuse of the recovered or "saved" time).

For instance, the U.S. military spends about $4 billion a year on specialized skill training. This is the training required after "basic" or accession training to qualify personnel for the many technical jobs (e.g., wheeled vehicle mechanics, radar operators, avionics technicians, medical technicians) needed to conduct military operations. It does not include the cost of aircraft pilot training, which comprises a separate cost category. Figure 2 shows the annual reductions in costs that would result if instructional time were reduced by 30!percent for 20, 40, 60, and 80 percent of the U.S. military personnel who complete specialized skill training each year. For instance, if the United States military were to reduce by 30!percent the time to train 20 percent of the personnel undergoing specialized skill training, it would save over $250 million per year. If it were to do so for 60 percent of the personnel undergoing specialized skill training, it would save over $750 million per year, an appreciable amount by almost any standard.
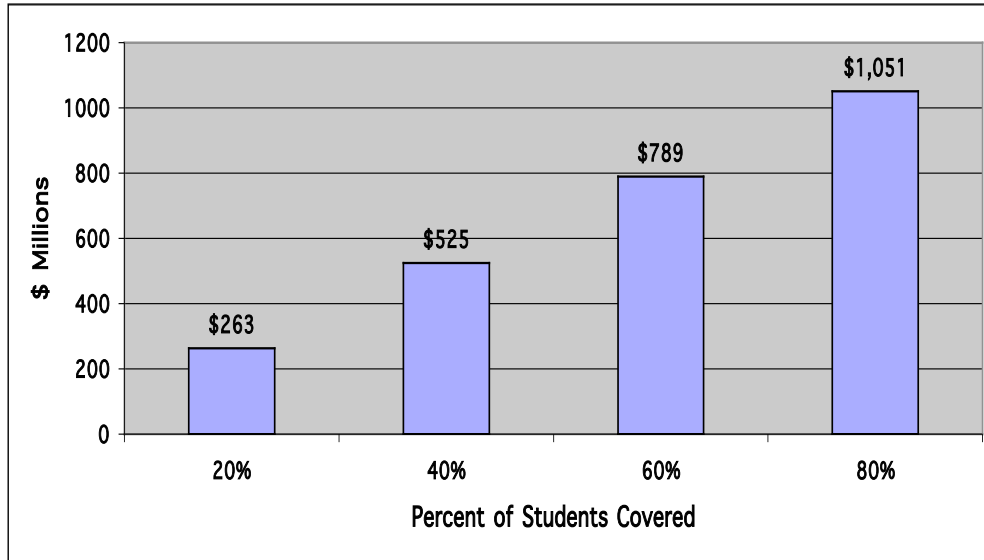
Figure 2. Monetary Savings in Specialized Skill Training With a 30-Percent Reduction in Training Time

Time savings of 30 percent are used here for a reason. As Table 1 suggests, savings of about this magnitude in training time are frequently found in reviews of instructional technology. Orlansky and String (1977) reported that reductions in time to reach instructional objectives averaged about 54 percent in their review of technology used in military training. Fletcher (1991) found an average time reduction of 31 percent in 6!assessments of interactive videodisc (IVD) instruction applied in higher education. Kulik (1994) reported time reductions of 34 percent in 17 assessments of technology used in higher education and 24 percent in 15 assessments of adult education. All these reviews were independent in that they reviewed different sets of evaluation studies. On this basis, it does not seem unreasonable to expect instructional technology applications to reduce the time it takes students to reach a variety of given instructional objectives in military education and training by about 30 percent.

Table 1. Percent Time Savings for Technology-Based Instruction

Study (Reference)	Number of Studies Reviewed	Average Time Saved (Percent)
Orlansky and String (1977)	13	54
Fletcher (1991)	8	31
Kulik (1994) (Higher Education)	17	34
Kulik (1994) (Adult Education)	15	24

For that matter, 30 percent is a conservative target. Commercial enterprises that develop technology-based instruction for the Department of Defense (DoD) regularly base their bids on the expectation that they can reduce instructional time by 50 percent (Fletcher, personal communication). Noja (1991) has reported time savings as high as 80 percent through the use of technology-based instruction in training operators and maintenance technicians for the Italian Air Force.

a.   Where Do These Time Savings Come From?

To a large extent, these time savings may be accounted for by individualization of pace—the speed with which students move through instructional material and reach instructional objectives. Even the most rudimentary of technology-based instruction systems adjust pace for individual students.

b.   Does the Capability To Adjust Pace Matter?

Many classroom instructors have been struck by the differences in the pace at which their students learn, and research confirms their observations. For instance, consider the following findings on the time that different students take to reach the same instructional objectives:

- Ratio of time needed by individual hearing-impaired and Native American students to reach mathematics objectives: 4 to 1 (Suppes, Fletcher, and Zanotti, 1975; 1976)

- Overall ratio of time needed by individual students to learn in grades K–8: 5 to 1 (Gettinger, 1984)

- Ratio of time needed by undergraduates in a major research university to learn features of the LISt Processor (LISP)2 programming language: 7 to 1 (Private communication, Corbett, 1998)

We may not be surprised to discover differences among students in the speed with which they are prepared to learn, but the magnitudes of the differences do seem surprising. As we might expect from Gettinger's 1984 review, a typical Kindergarten through Grade 8 classroom will have students who are prepared to learn in one day what it will take other students in the same classroom 5 days to learn. This difference does not seem to be mitigated by more homogeneous grouping of students based on their abilities. The students in

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2   LISP is generally regarded as the language for artificial intelligence (AI). LISP was formulated by AI pioneer John McCarthy in the late 1950s.

Corbett's (1998) research university are highly selected, averaging well above the 80th percentile on their admission tests, yet the differences in time they require to learn a modestly exotic programming language remain large.

The differences in the speed with which different students reach given objectives may be caused, initially, by ability, but this effect is quickly overtaken by prior knowledge as a determinant of pace (Tobias, 1989). This is likely to be particularly true of students in military education and training who bring a wide variety of backgrounds and life experiences to the classroom.

The challenge this diversity presents to classroom instructors is daunting. How can they ensure that every student has enough time to reach given instructional objectives? At the same time, how can they assist those students who are ready to surge ahead? The answer, of course, despite heroic efforts to the contrary, is that they cannot. Most classrooms contain many students who, at one end of the spectrum are bored and, at the other end, are overwhelmed and lost. Technology allows us to alleviate this difficulty by adjusting the pace of instruction to the needs and abilities of individual students. They can proceed as rapidly or as slowly as needed. They can easily skip what they already know or have mastered and concentrate on what they have yet to learn.

c. Do These Savings in Time Come at the Expense of Instructional Effectiveness?

The data suggest the opposite (i.e., the use of technology decreases instruction time and increases instruction effectiveness). Noja's 1987 findings are not uncommon. For the Italian Air Force technicians, in comparing conventional instruction in electronics with technology-based instruction, he found the following:

- A reduction in training time of 3 weeks (from 8 weeks to 5 weeks)
- Equivalent student achievement for electronic theory
- Substantial improvements in student achievement for electronic applications.

One study does not provide final answers, but many studies can be aggregated to suggest conclusions. This aggregation is usually done using "meta-analysis" (analysis of analyses), with an estimation of effect sizes. Roughly, effect sizes are normalized measures of standard deviations found by subtracting the mean from one collection of results (e.g., a control group) from the mean of another (e.g., an experimental group) and dividing the resulting difference by an estimate of their common standard deviation. Because effective sizes are normalized, they can be averaged to give an overall estimate of effect from many

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separate studies undertaken to investigate the same phenomenon or treatment. Figure 3 shows effect sizes from several collections of studies that compared conventional instruction with three types of technology-based instruction.
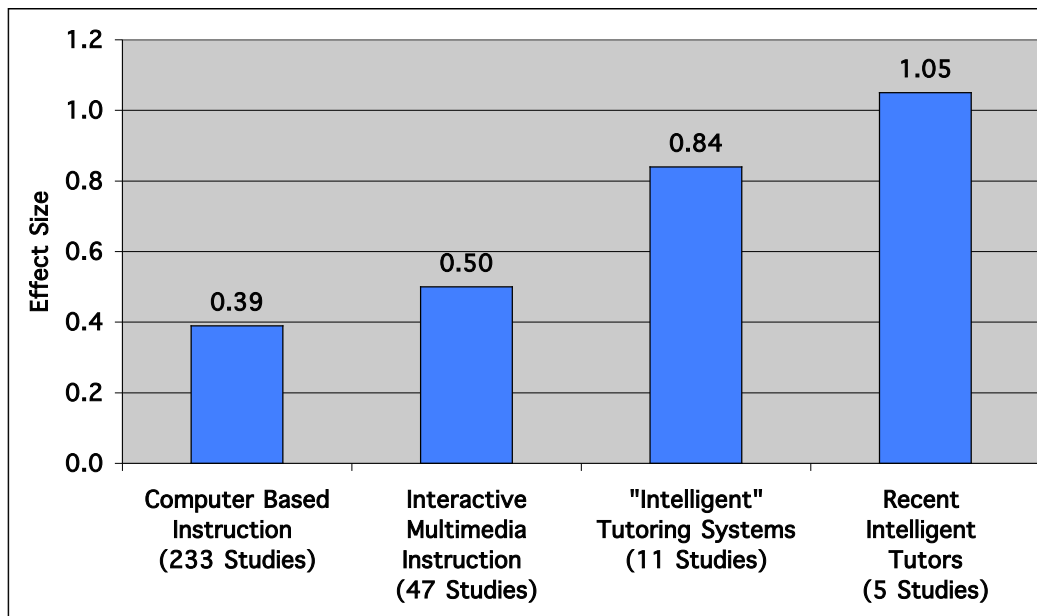
Figure 3. Some Effect Sizes for Studies Comparing Technology-Based Instruction With More Conventional Approaches

In Figure 3, "Computer-Based Instruction" (CBI) summarizes results from 233!studies. These studies involved straightforward application of computer presentations that used text, graphics, and some animation—as well as some degree of individualized interaction. The effect size of 0.39 standard deviations suggests, roughly, that the perform-ance levels of 50th percentile students improved to the performance levels of 65th percentile students.

"Interactive Multimedia Instruction" involves more elaborate interactions adding more audio, more extensive animation, and (especially) video clips. Greater achieve-ment—an average effect size of 0.50 standard deviations compared with an effect size of 0.39 for typical CBI—may compensate for the added cost of these capabilities. An effect size of 0.50 for interactive multimedia instruction suggests that the performance levels of 50th percentile students improved to the performance levels of 69th percentile students.

"Intelligent Tutoring Systems" (ITSs) involve a capability that has been developing since the late 1960s (Carbonell, 1970) but has only recently been expanding into general use. In this approach, an attempt is made to mimic directly the one-on-one dialogue that

occurs in tutorial interactions. The key component is that computer presentations and responses are generated in real-time, on demand and as needed or as requested by learners. Mixed-initiative dialogue in which either the computer or learner can ask or answer open-ended questions is supported. These interactions are generated as required. Instructional designers do not need to anticipate and pre-store them. This approach is computationally more sophisticated, and it is more expensive to produce than standard CBI. However, its costs may be justified by the increase in average effect size to 0.84 standard deviations, which suggests, roughly, that the performance levels of 50th percentile students improved to the performance levels of 80th percentile students.

Some later ITSs (Gott, Kane, and Lesgold, 1995) were considered just to see how this approach is progressing. The average effect size of 1.05 standard deviations for these recent applications is promising. It represents, roughly, that the performance levels of 50th percentile students to the performance levels of 85th percentile students.

The more extensive tailoring of instruction to the needs of individual students that can be obtained using generative ITSs can only be expected to increase. Such systems may raise the bar for the ultimate effectiveness of technology-based instruction. They may make available far greater efficiencies than we can now obtain from other approaches, but they will require instructional and computational capabilities that today are only partially in hand. They will need a full range of subject matter expertise and sufficient insight to present it to students. A mathematical model of a system will help, but it will not suffice. These generative ITSs will have to "know" what they themselves know and what the user does not. They will need an unobtrusive assessment capability that allows them to model dynamically what students have learned, have not yet learned, and have misunderstood. Very probably, these systems will need to communicate with their human users through natural (human) language, which implies not just speech-fragment recognition, but also comprehensive language and discourse understanding. We will need the intelligent, if not spiritual machines, Kurzweil has said that we can expect in 17 years or so.

2.   Human Instructors in the Loop

In the interim, and doubtless after that, we will need human instructors in the loop. How best to use these human instructors is a perennial issue in the design and implementation of technology based instruction. Finding the right balance is important. In preparing technicians of the Italian Air Force, Noja (1991) has attributed much of his success to achieving a reasonable balance of effort between technology and human instructors.

In the United States, as in perhaps many countries, the loss of military experts (e.g., through retirement, vocational burnout, and similar factors) in critical areas has combined with drastic reductions in live training experiences (because of costs, range, and environmental restrictions, greater reach of weapons, and so forth) to increase the need to make the best use of remaining military expertise. One significant way to do this is to support experts who are performing instruction, namely, by providing technology-based displays that are intimately linked to the subject matter being presented and the enabling knowledge and skills that students need to master it. The Interactive Multi-sensor Analysis Training (IMAT) system developed by the U.S. Navy to support training for antisubmarine warfare sensor operators is an example of such a capability.

IMAT provides training in sensor deployment, adversary detection, and undersea warfare tactical battlespace "sensemaking" (e.g., environmental analysis, sensor selection and placement, search rate and threat detection, multi-sensor crew coordination, and multi-sensor information integration) to compensate for the diminishing number of opportunities to develop and sustain these skills in formal training, on-the-job training (OJT), and fleet exercises. IMAT integrates models of the physical phenomena and innovative visualization techniques to demonstrate relationships among threats (submarines and their weaponry), the undersea environment, and anti-submarine systems. It combines analytic and instructional design technologies and advanced computer-based graphics to promote rapid acquisition of the cognitive visualization capabilities sailors need to understand structural and spatial interrelationships among sensors, platforms, and submarine systems.

The combination of instructor-led, IMAT-supported training has not only raised performance against established instructional objectives, but it has also raised the level of objectives set for training. It helped sailors achieve levels of competence that simply were not available without it. Notably, IMAT fulfills most of the training capabilities suggested by Figure 1. It allows training to be ported from basic to complex operational environments. It allows training environments to use human instructors and advanced technology together to achieve more high-level (transferable, abstract, problem-solving) objectives than were attainable using traditional training approaches, and it does so at easily affordable costs. It supports training in familiar, relatively simple environments while being scaleable to environments characteristic of "live" military operations. In short, IMAT training allows students to accomplish far more than either instructors or technology, working separately, can achieve.

3. Performance-Aiding Applications

Problem-solving is required when an individual or a group must achieve a goal but is uncertain how to do so (Baker and Mayer, 1999; Mayer and Wittrock, 1996). It requires ingenuity and creativity to manipulate and transform the knowledge and skills that problem-solvers possess into paths of action leading to the goal. It is a necessary and integral component of human performance in all sectors, and it is a critical component in every military operation. Difficulty in making problem-solving decisions is exacerbated by the frequency with which we are confronted with too much data, too many options, and unknown levels of risk. These matters have been the object of systematic study by both past (James, 1890/1950) and present (Edwards and Fasolo, 2001) researchers.

Given the complexity of real-world decision-making and the range, both descriptive and prescriptive, of its theoretic underpinnings, seeking assistance from technology does not seem unreasonable. Such applications involve tightly integrated interactions between humans and automated systems. They raise some of the most interesting issues for R&D in determining the role of humans in the use of intelligent and automated systems.

Not enough studies of the effectiveness and cost-benefits of these applications exist to permit a meta-analytic assessment of their impact. However, systematic and comprehensive assessment of technology-based performance-aiding can be found in the collection of studies covering the Integrated Maintenance Information System (IMIS), an automated, hand-held, flight-line avionics maintenance aid. Tomasetti et al. (1993) documented a thorough cost analysis of IMIS. Thomas later (1995) reported results from an empirical investigation of IMIS effectiveness. Teitelbaum and Orlansky (1996) summarized results from these studies, combined them into a more complete cost-effectiveness assessment, and discussed the implications of these findings.

Thomas (1995) compared the performance of 12 Avionics Specialists and 12 Airplane General (APG) Technicians on 12 fault-isolation problems concerning 3 F-16 avionics subsystems: fire control radar, heads-up display, and inertial navigation. Within each of the two groups of subjects, six of the fault-isolation problems were performed using paper-based task orders (TOs) (from Air Force technical manuals), and six were performed using IMIS. Training for APG Technicians includes all aspects of aircraft maintenance, only a small portion of which concerns avionics. In contrast, Avionics Specialists receive 16!weeks of specialized training in avionics maintenance. Table 2 shows the results of the study.

Table 2. Maintenance Performance of 12 Air Force Avionics Specialists and 12 APG Technicians Using TOs and IMIS

Technicians/ Performers	Correct Solutions (Percent)		Time to Solution (Minutes)		Average Number of Parts Used		Time to Order Parts (Minutes)	
	TOs	IMIS	TOs	IMIS	TOs	IMIS	TOs	IMIS
Avionics Specialists	81.9	100.0	149.3	123.6	8.7	6.4	19.4	1.2
APG Technicians	69.4	98.6	175.8	124.0	8.3	5.3	25.3	1.5

Observations that might be made from these results include the following:

- **Avionics Specialists using TOs compared with those using IMIS**. The Avionics Specialists using IMIS found more correct solutions in less time, used fewer parts to do so, and took less time to order these parts. All these results were statistically significant. The number of parts required may deserve brief comment. Savings in spare-parts inventory and transportation were by far the largest factors in the Tomasetti, et al. (1993) analysis of costs. The parts reduction exerted considerable leverage on the overall cost savings reported by Teitlebaum and Orlansky (1996). The reduction in time to order parts is to be expected because IMIS automates much of this process. Notably, the time taken by technicians to complete the paperwork in the absence of IMIS could be used elsewhere, with substantial productivity gains and cost savings if IMIS, or a similar capability, performs these paperwork chores.

- **APG Technicians using TOs compared with those using IMIS**. Thomas (1995) found similar results in these comparisons. APG Technicians using IMIS performed more correct solutions in less time, used fewer parts to do so, and took less time to order these parts. As with Avionics Specialists, all these results were statistically significant.

- **APG Technicians using IMIS compared with Avionics Specialists using TOs**. APG Technicians using IMIS found more correct solutions in less time, used fewer parts to do so, and took less time to order these parts than did Avionics Specialists using paper-based TOs. All these results were statistically significant. This result suggests that it is feasible and desirable to replace some of the extra training required by specialists with on-the-job, just-in-time decision aids, such as IMIS, supplied to nonspecialists.

- **APG Technicians using IMIS compared with Avionics Specialists using IMIS**. In these comparisons, APG Technicians performed about as well as Avionics Specialists and even slightly better in the number of parts used. None of these comparisons were statistically significant, and none appear to be

practically significant. These results again suggest the feasibility of replacing some number of specialists, who require greater training costs, with general technicians supplied with on-the-job, just-in-time decision aids. They also suggest the desirability of doing so because of the greater costs to train the specialists—even though the resulting performance on the job, where it counts, is the same in both cases.

The promise suggested by these results could well vanish if the costs to provide the decision aid (IMIS) exceed the costs they otherwise save. However, using two sources of data [i.e., the costs and benefits analysis by Tomasetti et al. (1993) combined with the empirical results reported by Thomas (1995)], Teitelbaum and Orlansky (1996) were able to estimate reductions in depot-level maintenance, organizational-level maintenance, and the maintenance and transportation of inventories of spare parts. Teitelbaum and Orlansky estimated that annual savings from the use of IMIS would be approximately $38 million for the full Air Force fleet of about 1,700 F-16s. Their analysis also considered the costs to develop and maintain IMIS. Assuming an 8-year useful life for IMIS, they arrived at a figure of about $18 million per year to maintain IMIS (including its databases) and to amortize its development costs. The result is about $20 million per year in net savings.

This figure of $20 million is conservative. Focusing only on cost may underestimate the total "value" of this technology. It does not include

- Savings that would result from a reduction in Air Force requirements to recruit and train specialized personnel such as the Avionics Specialists in Thomas's study

- Savings in training that would accrue from the use of IMIS as a decision aid and as a training device

- Savings in the costs to print, distribute, and, especially, update paper technical manuals

- Savings (of about 50 percent) in time to debrief pilots about maintenance problems.

Most important, these benefits do not include those arising from increased sortie rates and enhanced operational readiness and effectiveness resulting from the substantially improved problem-solving competencies of maintenance personnel.

As with training systems, performance-aiding will benefit from what appears to be the inexorable march of technology. However, significant technology challenges remain. Performance-aiding systems will require interactive, advising, decision-aiding, and computational capabilities that today are only partially in hand. Just like training systems, they will

need a full range of subject matter expertise and sufficient insight to present it to users. They will have to "know" what they themselves know and what the individual user does not know so they provide assistance in ways that the user is prepared to understand and act on. To do this, they will need an unobtrusive assessment capability that allows them to model dynamically what users know, do not know, and misunderstand. Very probably, they will need to communicate with their human users using natural (human) language involving comprehensive language and discourse understanding. They too will need the "intelligent" capabilities for interacting with humans that is foreseen by Kurzwiel (and others) and that researchers developing ITSs are creating. These systems are discussed in the next section.

4.   Is It Worth It? A Summary

Given the weight of data presented here and elsewhere, accelerating the research, development, and implementation of computer technology in military education, training, and performance-aiding seems reasonable. However, resources for such a pursuit are finite and, most likely, cannot support all that remains to be done. Thus, some consideration of technology opportunities and priorities driven by operational requirements seems in order. We should decide where we want to go before trying to get there.

C.   WHERE DO WE WANT TO GO?

One prominent and promising vision for the future is captured by the notion of asynchronous, continuous learning—which is education, training, and performance-aiding that is available anytime, anywhere to whomever needs it. Such a vision capitalizes on the development of the World Wide Web (www) (or whatever the global information grid of the future will be), generative CBI, unobtrusive assessment of users' intentions and needs, ITSs, natural language understanding, the development of educational objects, and, of course, the continuing advancements in computation and computer technology. Figure 4 captures this vision roughly.

This vision anticipates a future in which everyone will have access to an *electronic personal learning associate*. This device will assemble learning or decision-aiding presentations on demand and in real-time—any time, anywhere. The presentations will be tailored exactly to the needs, capabilities, intentions, and learning state of each individual or group (e.g., crew, team, or staff). Communication with the device will be based on natural
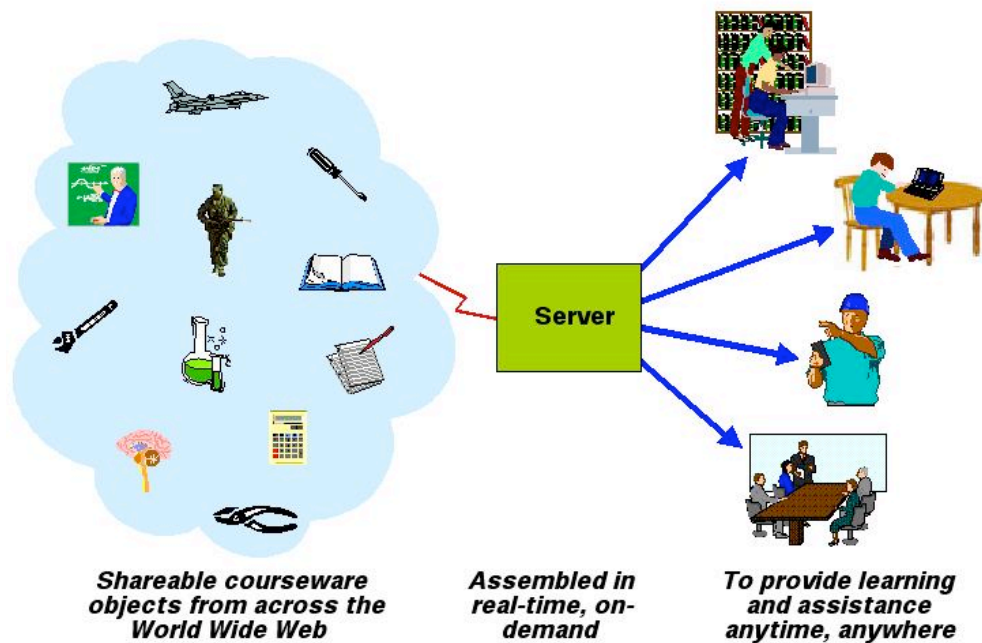
Figure 4. Asynchronous, Continuous Learning: A Vision for the Future

language dialogue initiated either by the device or by its users. The device will small enough to be carried in a shirt pocket, or it will be wearable. It will be used by individuals learning by themselves, in groups, or in classrooms. It will, of course, be wireless.

Most of the technology needed to build such a device exists now. Although we cannot yet fit it into a shirt pocket, creative engineering should take care of that. What is especially needed for instruction and decision-aiding is *content* in the form of instructional objects, which we are calling shareable instructional objects. These objects, shown in the cloud on the left side of Figure 4, must be readily accessible across the World Wide Web or whatever form our global information network takes in the future.

Once these objects exist, they must be identified, selected, and assembled in real time, on demand and then handed to the personal learning associates, which provide the instruction or decision-aiding. This work of identifying, selecting, and assembling objects is the job of the server, the box in the middle of Figure 4. By importing "logic" or instructional strategy objects, the server, which today might be called a learning management system, can acquire the capabilities of an intelligent tutoring system. This vision is keyed to the development and implementation of intelligent instructional systems. These systems must be scaleable and adaptive to military personnel "occupational specialties," the variety

of instruction venues, and the operational domain(s) addressed by the application (see the mapped with notional numbered examples in Figure 5).
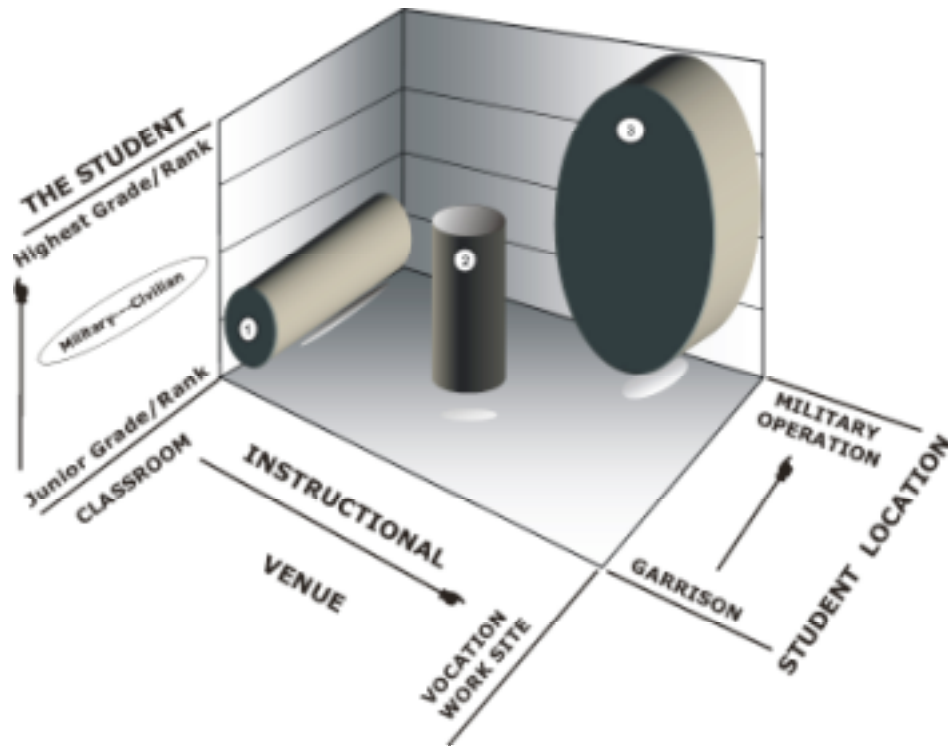
Figure 5. Dimensionality of Instructional Systems

Figure 5 represents the challenge to designer and developers of military instructional systems along three dimensions:

> The "Student" axis concerns the type of student, coupled with the roles and responsibilities of the student. These roles and responsibilities suggest targeted levels of expertise, abstraction, and objectives. This axis points to the need for dynamic adaptability of the instructional system.

> The "Instructional Venue" axis reflects where the instruction will occur (e.g., in the classroom, the work environment, duty station, garrison, home, or some combination of these). This axis points to the need for curriculum design and the instructional infrastructure flexibility and its required characteristics.

> The "Student Location" axis identifies where the knowledge gained will be used (e.g., in locations ranging from garrison and depots, to field combat command centers, to the battlefield). It determines the application environment for the knowledge and skills gained and their criticality.

Figure 5 suggests the kinds of intelligence that an automated instructional system must possess to operate effectively on behalf of its human user. It also suggests dimensions

for validating instructional and performance-aiding systems to ensure that the instruction and information they convey can be trusted. R&D along these dimensions will directly impact what are commonly called intelligent tutoring systems or ITSs.

1. Intelligent Tutoring Systems (ITSs)

It may be best to note the features that "ordinary" CBI provides. It can

Accommodate an individual student's rate of progress, allowing as much or as little time as each student needs to reach instructional objectives

Adjust the sequence of instructional content to each student's needs

Adjust the content itself so that different students can receive different content, depending on what they have mastered and what they have yet to learn

Make the instruction as easy or as difficult as necessary

Adjust to the learning style (e.g., verbal vs. visual) that is most appropriate for each student.

These capabilities have been available and used in CBI from its inception in the 1950s (Fletcher and Rockway, 1986). Those who promote systems with these features, touting them as indicators of newly developed "intelligent" capabilities, may be missing some history. They are using the term "intelligent" in ways that differ from the historical objectives of ITS—objectives that have been pursued since the late 1960s.

What are these objectives? What is left for ITS to provide? What can we get from them that is not otherwise available? Two functionalities deserve mention:

1. The ability to allow either the computer or the student to ask open-ended questions and initiate instructional, "mixed-initiative" dialogue as needed or desired

2. The ability to generate instructional material and interactions on demand rather than require developers to foresee and pre-store all the materials and interactions needed to meet all possible eventualities.

The first functionality requires the ITS to understand and participate in mixed-initiative interactions with the student. It requires mutual understanding of a language for information retrieval, decision-aiding, and instruction that is shared by the ITS and the student/user. Natural language has been a frequent choice for this capability, but the language of mathematics, mathematical logic, and electronics have also been used (e.g., Suppes, 1981; Sleeman and Brown, 1982; Psotka, Massey, and Mutter, 1988; and Farr and Psotka, 1992). Whatever form mixed-initiative dialogue takes, a key feature of one-on-one

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tutorial instruction is dialogue in which either the student or the instructor can initiate interactions (e.g., Graesser and Person, 1994). Such a capability has been a long-standing goal of intelligent tutoring systems (Carbonell, 1970).

The second functionality requires ITSs to devise on demand—not retrieve from storage—interactions and presentations for individual students. This capability involves more than generating elements to fill in blanks in a template. It means generating interactions and presentations from information primitives using an "instructional grammar" that is analogous to the deep structure grammar of the transformational-generative linguists of a generation ago. This functionality harkens back to the roots of ITS development as (again) can be seen in the volumes edited by Suppes (1981), Sleeman and Brown (1982), Psotka, Massey, and Mutter (1988), and Farr and Psotka (1992).

Motivations for both these functionalities can be found in basic research into human learning, memory, perception, and cognition. Findings from this research have led us to view all cognitive processes as constructive and regenerative. They have caused general theories of perception and learning

- To evolve from the fairly strict logical positivism of behavioral psychology (which emphasized the study of directly observable and directly measurable actions) to a greater consideration of internal, less observable processes that are assumed to mediate and enable human learning

- To produce the directly observable behavior that is the subject of behaviorist approaches.

The keynote of these conceptions of cognition may have been struck by Ulric Neisser, who stated, "The central assertion is that seeing, hearing, and remembering are all acts of *construction,* which may make more or less use of stimulus information depending on circumstances" (1967, p. 10). However, these ideas have been part of the fabric of scientific psychology since its inception (e.g., James, 1890/1950).

This point of view suggests that the generative capability sought by the vision presented by Figure 4 is not something merely nice to have, but is also essential if we are to advance beyond the constraints of the prescribed branching, programmed learning, and ad-hoc principles currently used to design technology-based instruction. A generative approach may be essential if we are to deal successfully with the immensity, extent, and variability of human cognition.

The key defining characteristic of ITSs then is not the application of computer techniques from artificial intelligence (AI) or knowledge representation or the specification of

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sharable instructional objects, important as these may be. Rather, it is the functional capability to generate in real time and on demand instructional interactions that are tailored to student requests and/or needs. This generative capability motivated DoD to invest in the development of these systems in the first place (Fletcher and Rockway, 1986). At that time, the motivation was to reduce or eliminate the high costs of foreseeing or predicting all possibly needed materials and interactions, programming them, and pre-storing them into CBI. Today, this motivation remains fundamental to R&D in intelligent systems intended to augment the learning and performance of human beings.

2.   An Example of an ITS at Work

An example of these capabilities at work can be found in the student-computer, mixed-initiative dialogues supported by the Sophisticated Instructional Environment (SOPHIE), an early and seminal ITS (Brown, Burton, and DeKleer, 1982) that would fit in Figure 5 at the lower front left. SOPHIE used a general-purpose electronic simulator to represent an electronic power supply and create a reactive, tutorial environment for training in electronic troubleshooting. The underlying simulator allowed faults introduced into the system by an (human) instructor or by SOPHIE to be propagated throughout the (simulated) power supply in a realistic fashion. SOPHIE employed a semantic network of information about the power supply, one of the most sophisticated natural language understanders ever built into an ITS, and an articulate, expert troubleshooting capability that could not only solve arbitrary faults introduced by students or instructors, but also explain to the student how it solved them.

SOPHIE's reactive environment responded in a realistic fashion to the actions and decisions of a student engaged in practical problem-solving. It employed strategies that shadowed those used by the student to make inferences about the circuit based on the student's measurements. SOPHIE could thereby determine which deductions the student was using, construct a model of his/her state of knowledge, and use this model to generate explanations in terms that the student was prepared to understand. SOPHIE highlighted the need for ITSs not only to solve arbitrary problems, but also to do so in a way that can be explained to students and be understood by them. It pioneered capabilities currently lacking in many information acquisition and retrieval systems.

The following is a student-computer dialogue adapted from SOPHIE:

Student: *What is the base emitter voltage of the voltage-limiting transistor?*

SOPHIE: The base emitter voltage of Q5 is -.037 volts.

The first student-SOPHIE interaction in this example is a straightforward question and answer. SOPHIE has introduced a fault into the simulated power supply and the student is trying to locate and repair it.

Student: *What about for the current limiting transistor?*

SOPHIE: **The base emitter voltage of Q8 is .349 volts.**

The second student-SOPHIE interaction is a little less straightforward because, in addition to simulating the faulted power supply, SOPHIE must be able to parse the dialogue sufficiently to know that the student is asking for the base emitter voltage of transistor Q8. The meaning of the student's question depends heavily on the context established by his/her prior question.

Student: *What should it be?*

SOPHIE: **In a working circuit, the base emitter voltage of Q8 is .593 volts.**

The third student-SOPHIE interaction continues its dependence on SOPHIE's understanding of context and, in addition, requires SOPHIE to extract the answer by simulating both the faulted power supply and one that is operating correctly.

Student: *Replace Q8.*

SOPHIE: **I am going to ask you some questions about how Q8 is faulted. Are any junctions shorted?**

The fourth student-SOPHIE interaction indicates a clear step beyond what Brown, Burton, and DeKleer (1982) described as a knowledgeable system to what they considered to be an intelligent system. SOPHIE has progressed from a knowledgeable parsing of its dialogue with the student and simulation of various states of the power supply to a system exercising tutorial intelligence. It shadowed the student's solution path, modeled the student's troubleshooting hypotheses, determined that they are incorrect, elected to capture the dialogue initiative back from the student, and is undertaking a series of tutorial interactions intended to lead the student back to a more correct approach to the problem.

It is difficult to imagine any practical way to achieve this level of functionality without the generative capability and mixed-initiative dialogue that distinguishes ITSs from other forms of CBI. Such functionality is as applicable and essential to performance-aiding as it is to instruction.

3.   Where Do We Want To Go? A Summary

To this point, we have described a vision of CBI in a general training or education application, which, in a military context, is the foundation for developing domain expertise in military specialties. Can this vision be applied to the adult learning, occupational training domain that is the foundation of military effectiveness?

The answer should be "yes," but that "yes," as suggested earlier in this document, is limited by the instructional, performance-aiding, and computational capabilities available today. We have speech recognition, but the levels of language and discourse understanding we need have to be developed. We have valid models of military systems, but we lack the "executive functions" that will allow automated instructional and performance-aiding systems to map the expertise represented by these models onto human users and match their presentations to individual user's needs. We have authoring systems, but they need additional development to reduce to an acceptable level the costs and time required to produce instructional and performance-aiding systems. Above all, we lack a comprehensive set of empirically based design principles to support an engineering of instructional and performance-aiding systems that would lead reliably to the achievement of given instructional outcomes and substantially reduce the time to produce human expertise and competence, or even, as IMAT does, produce levels of expertise in military personnel that currently do not exist. The next section addresses what is needed to produce such capabilities.

In brief, the vision depicted in Figure 4 and applied in the dimensions portrayed by Figure 1 and Figure 5 implies several key goals:

- The product of this R&D must be capable of generating presentations on demand, in real time.

- Content analysis (e.g., cognitive task analysis) must be able to be conducted by trainers and educators ubiquitously.

- Its presentations must be tailored in content, sequence, level of difficulty, level of abstraction, style, and so forth to users' intentions, backgrounds, and needs. Neither students nor problem-solvers will benefit from a device that does not provide information they are capable of understanding. Efficiency in learning and performance also demands such tailoring to user needs and capabilities.

- It must be used equally well to aid learning or performance.

- It must accommodate mixed-initiative dialogue in which either the technology or the user can initiate or respond to inquiries in natural language.

- It will benefit greatly from a supply of sharable instructional objects readily available for the generation of instructional (or decision-aiding) presentations.

These goals suggest requirements for R&D—requirements that must be met if we are to get from here (now) to there (where we want to be).

D. HOW SHOULD WE GET FROM HERE TO THERE?

1. Overview

Much has to be done before we will achieve the vision presented in this document for education, training, and performance-aiding. However, accomplishing some R&D goals will result in products that can be used immediately, and these goals might be achievable in the short term.

A DoD workshop on continuous learning systems held in October 1999 laid the foundation for these recommendations. This workshop was motivated in large part by the recognition that military readiness and effectiveness are keyed not just to the supply of systems and personnel, which are commonly measured in U.S. assessments of readiness, but also to the cognitive capabilities of military personnel—to what might be described as their cognitive readiness (Etter, Foster, and Steele, 2000).

Table 3 is a summary and an elaboration of findings from this workshop. It is roughly organized into the standard system engineering categories of analysis, design, and development; delivery and management; and evaluation.

Table 3 lists and briefly describes potential elements of a research agenda for the development of technology-based aids for education, training, performance-aiding, and decision-making in military applications. These elements do not comprise a formally established research agenda, but they suggest the breadth of R&D that must be undertaken to capitalize on the promise offered by our new technologies for education, training, and performance-aiding. The elements suggest opportunities for cooperative, international development undertaken by North Atlantic Treaty Organization/Partnership for Peace (NATO/ PfP) countries.

Table 3. Capabilities, Goals, and R&D Requirements for the Development of Technology in Education, Training, and Performance-Aiding

Capability	Description/Goal	Requirements/Gaps
Analysis		
Instruction Analysis: Cognitive theory	Accurate and comprehensive representation of cognitive skill and cognitive skill development to include such "higher order" capabilities as decision-making, problem-solving, meta-cognition, pattern recognition, critical thinking, situational awareness, and teamwork.	New concepts and theories of cognition based on new measurement capabilities, especially those available from technology-based assessment; representation of expertise in complex, ill-structured environments.
Instruction Analysis: Training analysis	Efficient, comprehensive, and accurate analysis of military needs for command, job, and task performance.	Automation of processes for performing front-end analysis, cognitive analysis, and cognitive readiness assessment; comprehensive and accurate representation of individual and crew, team, and unit expertise, capabilities, and performance; principles for determining relevant task characteristics for instructional design and selection of instructional strategies.
Instruction Analysis: Integrated human performance system	Training analysis, design, and selection of objectives integrated with the full range of alternatives used to ensure human competence in military operations.	Comprehensive principles for optimal, cost-effective, and balanced adjustment of tradeoffs between all elements (e.g., selection, personnel classification, training, ergonomic design, job design) used to ensure the presence of human competence when and where it is needed.
Instruction Analysis: Technology-based knowledge representation	Verified and validated representations of expert solutions, capabilities, and behavior.	Automated capture of expertise; self-generating, self-modifying databases built from cases and examples of successful problem-solving and decision-making.
Instruction Analysis: Assessment of learner potential	Ability to use computer technology to develop more comprehensive and accurate models of human cognition and potential; ability to identify potential "aces" in specific militarily relevant areas.	New forms of computer-administered assessment items using the full display and timing capabilities of technology.

Table 3. Capabilities, Goals, and R&D Requirements for the Development of Technology in Education, Training, and Performance-Aiding (Continued)

Capability	Description/Goal	Requirements/Gaps
Design and Development		
Instruction Design and Development: Instructional objects	Wide availability of accessible, portable, reusable instructional components or "objects"; fully developed infrastructure to support their use.	Object-oriented programming for instruction, models, and simulations; standards for developing sharable instructional and simulation objects.
Instruction Design and Development: Management of student progress	Comprehensive engineering of instruction that links instructional design and presentations to targeted instructional outcomes (e.g., speed of response, accuracy of response, retention of knowledge and skills, motivation to continue learning).	Principles of design and presentation that can be automated as needed to ensure reliable achievement of instructional outcomes by individuals, crews, teams, and units.
Instruction Design and Development: Cognitive readiness development	Development of comprehensive techniques for measuring and enhancing cognitive readiness.	Principles for the development of higher level cognitive skills (e.g., creativity, intuition, pattern recognition, transfer of know-ledge and skills, problem-solving, and situational awareness).
Instruction Design and Development: Human-behavior representation	Verified and valid representation of individual and group behavior for virtual team members, adversaries, friendly forces, noncombatants, and organizational behavior for C2, and nongovernmental organizations.	Principles for developing physically and cognitively realistic avatars; principles for matching the level of realism in human behavior and depiction to training objectives; accurate and facile interchange of real and virtual participants; development of sharable, reusable human behavior objects; capabilities that allow dynamic control of avatars by either human instructors or automated tutors.
Instruction Design and Development: Representation of knowledge and skill	Automated representation of both subject matter expertise and misconceptions.	Comprehensive computer representation of human knowledge and skill; capabilities for automated development, verification, and validation of these representations.
Instruction Design and Development: Articulate expertise	Ability to inform students and aid problem-solvers in terms they are prepared to understand.	Ability to assemble objects and prepare presentations that are tailored to dynamic representations of the student or problem-solver.

Table 3. Capabilities, Goals, and R&D Requirements for the Development of Technology in Education, Training, and Performance-Aiding (Continued)

Capability	Description/Goal	Requirements/Gaps
Instruction Design and Development: Natural language understanding	Ability to engage in natural language dialogues with students and problem-solvers.	Speech recognition; ability to parse natural language; ability to parse dialogues; adequate grammar for natural language and natural language dialogue.
Instruction Design and Development: Authoring tools	Fully developed capability for automated development of instructional and performance-aiding materials and optimally efficient tools for human use when automation is not practicable.	Comprehensive capability for generating instruction and performance-aiding materials on demand, in real time, tailored to the specific needs of individuals, crews, teams, and units; ability to generate instruction and performance-aiding automatically from computer-aided design and computer-aided manufacturing databases.
Delivery and Management		
Instruction Delivery and Management: Assessment of learner/user knowledge	Ability to assess automatically and unobtrusively student/user knowledge, skills, and needs from routine interactions with software.	Computer representation of user knowledge skills, and needs; generation of valid, unobtrusive near-real-time assessment from interactions of individuals, teams, crews, and units with the learning or performance-aiding environment; automated techniques for creating and assessing the shared mental models of crews, teams, and units.
Instruction Delivery and Management: Collaborative team, crew, and unit learning	Ability to foster optimal learner-to-learner collaboration and learner-to-instructor interaction.	Comprehensive representation of collaboration and interaction in teams, crews, and units; principles for establishing and supporting collaboration in distributed learning environments; capabilities to support in-route mission rehearsal despite physical separation of participants.

Table 3. Capabilities, Goals, and R&D Requirements for the Development of Technology in Education, Training, and Performance-Aiding (Continued)

Capability	Description/Goal	Requirements/Gaps
Instruction Delivery and Management: Self-management of instructional progress	Trainable techniques for developing meta-cognitive capabilities; comprehensive tools for supporting learner-directed instruction and learning-to-learn.	Comprehensive understanding of meta-cognition and its development; comprehensive understanding of incentive management for distributed learning; technology-based tools that allow distributed learners to manage their progress.
Instruction Delivery and Management: Security maintenance	Multiple levels of security provided reliably and as needed across a network of distributed instruction and performance-aiding based on a pervasive security policy and technical strategy that addresses pan-network, pan-organizational, authentication, and data access and security.	Reliable learner/user identification, authentication, and authorization; standard format for acquisition, storage, maintenance, retrieval, and application of knowledge bases; ability to access both secure and nonsecure sources transparently within the same network for training and performance-aiding purposes.
Instruction Delivery and Management: Integration of approaches	Integration of continuous, asynchronous instruction with current classroom, instructor-led approaches.	Principles for combining technology-based with human-based instructional resources and approaches; development of effective organizational structures.
Instruction Delivery and Management: Instructional management	Ability to optimize student progress toward achieving instructional or performance goals.	Ability to match instructional or problem-solving goals with current state of the student or user and generate or select optimal tutorial and/or problem-solving strategies.
Evaluation		
Instruction Evaluation: Cost and effectiveness analyses	Fully developed system for cost-effectiveness assessment of education, training, and performance aids at all levels to include user satisfaction, achievement of objectives, improvement in performance at duty stations, and enhancement of readiness and effectiveness.	Comprehensive models for both costs and effectiveness of education, training, and performance-aiding; techniques for linking education and training to duty station performance; verified and valid capabilities to assess the military value of education, training, and performance-aiding in enhancing military readiness and effectiveness.

2. How Should We Get From Here To There? A Summary in a NATO/PfP Research and Technology Context

Table 3 suggests a great many specific efforts that could—and, in fact, may—be undertaken cooperatively by the NATO/PfP community. In the space available here, we can only refer the reader to Table 3 as a list of possibilities. Nonetheless, two broad areas that offer specific and tangible opportunities deserve mention. They concern the sharing of information through a commonly accessible database and the development of guidelines and standards for technology-based education, training, and performance-aiding.

a. NATO/PfP Database

Some of the efforts suggested in Table 3 may already be underway and are being pursued separately and independently by different countries. Even though these efforts may be independent, much can be gained by sharing experiences and findings across all countries that have a stake in their outcomes.

Creating a NATO/PfP directory of databases would be a good first step (Fletcher, Alluisi, and Chatelier, 1993). This database would point to data elements that can be found in relevant databases elsewhere and include with information about how each can be accessed. Users would use an on-line inquiry to focus searches on the specific information required and the identification of which (if any) existing databases might have the information for which they are looking. Retrieving the information would remain in users' hands.

The NATO directory would identify what data elements are available and how these data elements might be accessed, but the next steps taken would be up to the users. This approach would describe access to all data elements in all accessible databases, the data in the data elements would be kept up to date by those who "own" the database, and the expenses for setup and maintenance would be minor. This approach is not the most efficient that could be imagined, but it represents a beginning. Also, because of its low cost and high feasibility, it might increase communication and the demand for more efficiently available information.

b. NATO/PfP Common Practices

The second opportunity is the development and the establishment of common practices (if not standards) for developing sharable objects and guidelines for their use in instructional systems. The objects would be intended to be accessible on the global information grid (today, the World Wide Web) and used in devising military education,

training, and performance-aiding presentations. This work has already been pursued by organizations in the United States, Europe, and the Pacific Rim. Much of it has coalesced under the DoD's *Advanced Distributed Learning Initiative*, which has been developing the Sharable Courseware Objects Reference Model (SCORM) (www.adlnet.org). Much, however, remains to be done.

Currently, efforts have focused on the software engineering needed to create objects that are accessible, durable, portable, and reusable. Not only have these efforts been successful, but their prescriptions are also likely to last. These objects have been developed with the direct support of business and industry sectors who are most likely to be affected by them but who were actively seeking a catalyst (in this case the DoD) to act as a honest broker in organizing, extracting, and documenting a set of compromises that would result in the standard practices they needed if the market for their software tools were to grow. This work produced the SCORM model.

How are these objects likely to be used in real-world applications now that they are becoming available? Guidelines for purchase agents, designers, implementers, evaluators, and even classroom instructors are needed. These guidelines must be produced and are just now emerging. To some extent, the guidelines will respond to the unique needs of those who develop them. However, to another, much larger extent, standardization in these guidelines will improve efficiency, reduce costs, and enhance effectiveness as much for military organizations as they will for the market sought by business and industry. Such standardization, in practice, seems a natural and achievable goal for the NATO/PfP community.

E.   A FINAL WORD

Human competence is an essential part of every military system and every military operation. Its presence will not guarantee the full performance expected from every military system or success in every military operation, but its absence is an often-noted cause of failure.

Few activities are as important in ensuring the availability of human competence when and where it is needed as are education, training, and performance-aiding. The application of human-centered technology, with its promise for reducing costs and increasing operational effectiveness, seems to be an economic and a military imperative. The NATO/PfP research and technology community has the opportunity and an obligation to lead its members into the future promised by these technological applications.

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GLOSSARY

AFB	Air Force Base
AI	artificial intelligence
APG	Airplane General
C2	command and control
CAI	computer-aided instruction
CBI	computer-based instruction
DoD	Department of Defense
DTIC	Defense Technical Information Center
ICAI	intelligent computer-aided instruction
IEEE	Institute of Electrical and Electronics Engineers
IMAT	Interactive Multi-sensor Analysis Training
IMIS	Integrated Maintenance Information System
IMS	Integrated Management System
IVD	interactive videodisc
M&S	modeling and simulation
NATO	North Atlantic Treaty Organization
NTIS	National Technical Information Service
OSUSD(S&T)	Office of the Deputy Under Secretary of Defense for Science and Technology
OJT	on-the-job training
PfP	Partnership for Peace
R&D	research and development
SCORM	Sharable Courseware Objects Reference Model
SOPHIE	Sophisticated Instructional Environment
TO	task order
VR	virtual reality
www	World Wide Web

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14. ABSTRACT

Technology-based systems for education, training, and performance-aiding (including decision-aiding) may pose the ultimate test for validating approaches to integrate humans with automated systems. These systems need to model students and users. The models they generate, as well as the interactions based on them, must adapt to the evolving knowledge and skills of individual students and users. Evaluation findings suggest that such adaptations are feasible, worthwhile, and cost effective. Data drawn from many evaluations of technology-based education and training indicate overall that these systems can reduce costs by one-third and that they can also either reduce the time to achieve instructional objectives by one-third or increase achievement (holding time constant) by one-third. The likely impact on military readiness and effectiveness suggested by these findings is significant. Evaluations of technology-based performance-aiding systems have suggested similar results of increased personnel effectiveness and cost-savings. They suggest a need to determine and readjust the balance between resources allocated to training and resources allocated to performance-aiding systems. Development of sharable, reusable objects and capabilities for assembling these objects on demand and in real time will substantially increase accessibility and will reduce costs of education, training, and performance-aiding while making them asynchronously and continuously available—regardless of distance and time. Specifications and capabilities for such objects are the goals of much current research and development (R&D).

15. SUBJECT TERMS

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