Assessment of Emerging Educational Technologies That Might Assist and Enhance School-to-Work Transitions

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EXECUTIVE SUMMARY

Today's Unique Challenge in Preparing for the Evolving American Workplace.

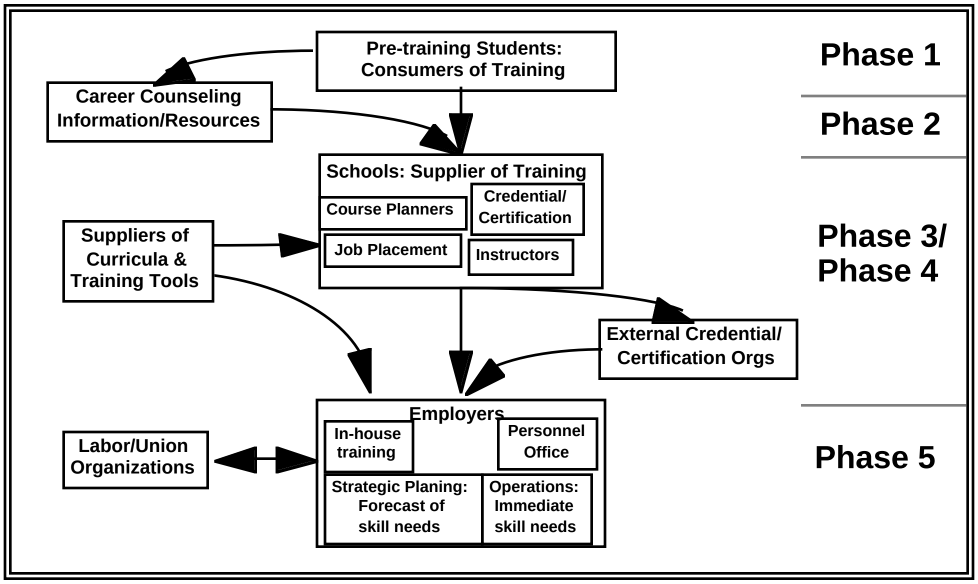
Section I of this study discusses how maintaining a "high skill/high wage" niche for America in the global marketplace requires a shift in work roles. Our economy is shifting away from smart machines automating human labor to manufacture standardized commodities. Instead, people increasingly are working in partnership with intelligent tools to create customized products and services. As this transformation to a post-industrial, "knowledge-based" economy occurs, an evolution of job requirements toward higher-order thinking skills is taking place in all types of occupations, blue- as well as white-collar. With advances in information technology during the next decade, people's creativity and flexibility will be vital as job skills, because the standardized aspects of problem solving will be increasingly absorbed by machines. Until the need for these new types of skills is routine in workplace settings, shifting the emphasis of occupational education is difficult for teachers and employers to initiate-- but by then a generation of our workers will be ill-prepared to compete in the global economic arena. The core challenge is to prepare today's students for a future workplace more disparate from present experience than at any time since the industrial revolution.

The Promise of Emerging Information Technologies to Aid School-to-Work (STW) Transitions

Changing workplace needs will reshape the goals, student population, and content of instruction. Shifts in pedagogical methods, the organizational structure of teaching/learning settings, and the locus of education will inevitably follow. Sophisticated information technologies can provide the leverage to make evolution to a new educational model possible; the same advances that are transforming the economy can empower new models of teaching/learning to facilitate the transition from school to work.

A STW "Process"-driven Framework for Technology Analyses

In Section II of this study, we propose a "process" view of the "school-to-work" (STW) transition and key stakeholders: people seeking a career, training, and employment ("Career Seekers"); providers of career counseling information; providers of training and accreditation; labor organizations; and employers. Providers of curricula and training technologies are also lesser stakeholders. This process view is pictured below.



Stakeholders and Career Seeker Movement though the STW Process

The STW process consists of five phases, as depicted in this diagram:

Phase 1. Search for, and selection of an appropriate career. This includes orientation about work, exploration of careers, self-assessment of skills and interests, and selection of a career.

Phase 2. Search for, and selection of an appropriate training institution/program for that career. This includes comparison of training opportunities, financial and personal/domestic preparation.

Phase 3. Acceptance into that training program and successful completion of the course of study and related accreditations.

Phase 4. General preparation in competing for a job, as well as skills and information on seeking and acquiring a job in that career area.

Phase 5. Good performance in new position, further development of work-related skills (work-based learning), attitudes, and habits while on the job, and preparation to adapt to future jobs.

This process view implies that two types of knowledge are needed by Career Seekers: factual knowledge of the employment domain (declarative knowledge, or "what" knowledge") and cognitive and motor skills (procedural or "how to" knowledge). Both must be acquired to progress through the STW process towards employment. Hand in hand with the types of knowledge to be acquired, we address the theoretical positions on how those different types of knowledge could be best communicated. Instead of making a commitment to a single learning and pedagogic theory, we present three currently prominent views and discuss their concomitant perspectives on how education and training should be carried out: an incremental or ruled-based approach, an analogical or a "case-based" learning approach, and a "situated cognition" approach. The analytic framework we apply to the various technologies reviewed highlights matches among the perspectives of these different learning theories and the capabilities of the various technologies we discuss.

Defining and Reviewing Categories of Educational Technologies

We divide information technologies that facilitate learning into six categories:

1. presentational computer-based training/computer-assisted instruction;
2. intelligent tutoring and coaching systems;
3. multimedia/hypermedia;
4. computer-supported collaborative learning (educational “groupware”);
5. experiential simulations (including virtual reality); and
6. computer-based tools as learning enablers (e.g., computer-aided design, intelligent agents for carrying out tasks, “webcrawlers” for searching the Internet, visualization tools).

Each of these categories is characterized by disparate assumptions about design and pedagogy, as well as different technological capabilities necessary for implementation. However, any specific educational technology application may incorporate more than one of these categories. In Section IV of the study, we illustrate this by presenting several future scenarios of STW applications in use.

In Section V, we describe a methodological framework for assessing the potential of each type of technology to aid the STW transition:

1. Goal and Use: What Actual/Potential Use of the Technology?
2. Track record: Evidence of Impact on Learners/Users?
3. Malleability: How “tunable” is the technology?
4. Integrative Potential: Will it help integrate the stakeholders?
5. Cost: What does/will this cost and when?
6. Commercialization: What will it take for the technology to bloom?
7. Implementation Barriers: What has to change?

Potential for Each Category of Technology to Aid STW Transitions

Section VI of this study discusses several exemplary illustrations for each category of technology, then assesses its potential by reviewing the seven key attributes above. The material below briefly summarizes both the description of each technology category and the results of that review. Table 3 on page 25 is also a useful overview reference.

Presentational computer-based training/computer-assisted instruction: Computer-based training (CBT), computer-assisted instruction (CAI), and a variety of similar terms all refer to educational applications that predominantly focus on tutorial or drill-and-practice pedagogy. An example would be a program that teaches how to repair a car by presenting information on how an engine works, using occasional quizzes to test understanding and to build associative recall. The instructional emphasis is on displaying material to the learner, checking for comprehension by monitoring student behavior on narrow tasks with readily observable outcomes, then branching to further presentation or practice as appropriate. The designer must anticipate every potential instructional sequence and must completely pre-define the screens of information to be shown; the computer controls the flow of material, programming the learner through a graduated sequence of skills and concepts. Because the underlying structure of most Career Information Delivery Systems (CIDS) and their roles as an instructor or decision aid in the area of career choice are similar to those of CBT, we group them into the CBT category.

Brief Review: The relatively low development cost and maturity of CBT makes it the most heavily commercialized and implemented of the technologies reviewed. Meta-analyses indicate that there are strong effects on learning in terms of shortening time to acquire moderately complex skills, as well as increasing interest in computers. Such systems will continue to be developed and fruitfully used in work-related educational settings, including eventual accessibility at a distance (for a fee) via the National Information Infrastructure (NII). As information about careers, training institutions, and job opportunities become increasingly available on the NII, the power of CIDS to aid Career Seekers' decisions will dramatically increase. Having this information available may also serve to better integrate the stakeholders in the STW process, as they become better aware of the markets from which they each draw and those markets to which they each serve as suppliers. For example, as employers have more awareness of the occupation-related educational experiences currently offered, they may see the value of better communicating their future training needs to the training institutions and directly to Career Seekers.

Intelligent Tutoring and Coaching Systems: Intelligent tutoring and coaching systems (ITS), also termed intelligent computer-aided instruction (ICAI), impart to educational technologies a semblance of teachers' cognitive abilities. The strategies underlying these types of educational applications are based on ideas from the field of artificial intelligence (which attempts to create software applications that can mimic the intelligent behaviors people exhibit). ITS/ICAI applications ideally contain dynamic models of the learner, the knowledge to be taught, and pedagogical discourse; the system "understands" who, what, and how it is teaching. In a full-fledged ITS, the material presented to the learner is interactively shaped by these dynamic models and generated by the system in real time (in contrast, CBT branches through a preprogrammed repertoire of screens).

Brief Review: Although a small number of ITSs have demonstrated very strong benefits on learning and show promise for instruction of complex, well-defined skills, ITS as a group are still immature and most remain largely in the laboratory. If their high development costs can be widely amortized, such systems promise strong improvements in our ability to educate effectively, with minimum human intervention, and across distance (via the NII). Their domains of applicability are still fairly narrow, but widening.

Multimedia/Hypermedia: Multimedia and hypermedia are different flavors of the same concept: structuring information based on studies of how the mind assimilates ideas. Multimedia software displays data in multiple formats simultaneously (text, still images, animations, video, voices, sounds, music). This enables people with various learning and working styles (visual, auditory, symbolic) to peruse material formatted in their preferred mode of communication. Also, multimedia is interactive; rather than passively viewing preprogrammed instruction, as in educational television, users can tailor presentations by selecting paths through the material customized to their interests. Hypermedia adds a further dimension to multimedia: associations among pieces of data. Often, the interconnections among pieces of information are more important than individual bits of material; the route to knowledge is via comprehending patterns of relationships, not through storing isolated facts. By displaying webs of interrelationships through concept maps or similar graphic devices, hypermedia systems enable learners to focus on the links among pieces of information as well as the data itself.

Brief Review: For students with appropriate study/learning skills (e.g., good self-guided or exploration-based learners) this highly malleable medium promises strong educational benefits, although the content of what is learned will, by design, vary across students. Less well-motivated and organized students tend to flounder. The high cost of very good "production value" material can potentially be recaptured in the current extensive, but increasingly competitive commercial markets for such materials.

Computer-supported Collaborative Learning: These technologies encompass a variety of ideas from the field of computer-supported cooperative work, including such capabilities as group decision support. Workplace environments increasingly emphasize teamwork and collaborative interaction. "Groupware" facilitates team performance; this requires building common conceptualizations by communicating each person's ideas, structuring group dialogue and decision making, recording the rationales for choices, and facilitating collective activities.

Brief Review: Although not as effective as face-to-face group learning, this malleable medium and supporting technologies provide a strong surrogate for actual cooperative learning. Benefits to geographically or economically isolated learners promise to be large. If participants in the collaborative learning come from different STW stakeholder groups, this technology has strong possibilities to better integrate the STW process. For example, if a team problem-solving group includes an aircraft mechanic from United Airlines, aircraft maintenance students from the local training institute, and curious observers (Career Seekers interested in what it is like to go through training), increased intercommunication may lead to better integration of the STW process. Implementation of this technology will be easiest where the educational process currently includes group-based work.

Modeling and Simulation: Instructional applications of simulation range from models that mirror the simplified essence of reality to elaborate synthetic environments with immersion interfaces that place students inside alternate virtual worlds. Fidelity-centered simulations enhance learning by creating a model of reality that retains only the basic situational characteristics students are to master. Single-user simulations allow an individual to interact with a model of reality (for example, flying a virtual airplane). An emerging technology--distributed simulation--enables many people at different locations to inhabit and shape a common synthetic environment; this empowers a broad range of educational uses (e.g., virtual factories, hospitals, cities). In contrast, artificial- reality simulations place learners in "microworld" environments that teach by controlled variation of how natural laws function. For example, by attempting to play baseball in a synthetic environment in which gravity can be turned off, a learner can comprehend through simulated experience the effects gravity has on many common phenomena.

Brief Review: This technology, still in its infancy, promises to provide strong educational benefits for certain skills and settings. These include domains that require the learner to acquire complex, three-dimensional pattern recognition and spatial manipulation skills that would be difficult, risky, or expensive to acquire in actual working environments. Shared virtual environments could provide a meeting point for members of different STW stakeholders, but this potential is not as great as for several of the other technologies. Costs for this technology currently vary widely, based on the simulated environment's degree of detail, verisimilitude, immersion, and amount of distributed interaction. Low end, single user versions of visualization tools are mature, but immersive, distributed environments are still high cost and often experimental. The barriers to wide implementation of this technology are high, both due to the cost of high-end technologies and to the need to develop alternative teaching and assessment methods. However, expenses and barriers may drop rapidly over time as the entertainment industry moves these technologies to "under the Christmas tree" status.

Computer-based Learning Enablers: Computer-based tools as learning enablers include a spectrum of capabilities such as computer-aided design (CAD) systems, intelligent agents for carrying out tasks, "webcrawlers" for searching the Internet, and data visualization tools. All these tools enable various types of "distributed intelligence," in which the learner is freed to focus on the concepts and skills to be acquired through the tool assuming part of the cognitive load. For example, machine-based "agents" with artificial intelligence can automate simple classification, reply, and retrieval tasks in accessing databases on a network, freeing learners to focus on creative interpretation of the information they are receiving.

Brief Review: These tools are still in their early stages of development for educational uses. They promise strong utility for scientific visualization and support of data collection, integration, and analysis, whether to carry out work tasks or to support career-related decision making. Simple webcrawlers and low-level visualization tools are already in use. Given the nature of their design as "tools" for learners, they will continue to be highly flexible and malleable. Their development costs are generally low, but intelligent "agents" are still in the prototype stage. If, for educational purposes, the rights can be worked out to allow limited access to versions of commercial software and proprietary databases, then some of the most severe implementation barriers will be lifted.

Overview of Policy Options for Enhancing the Development of Technologies that Enhance STW Transitions

In Section VII of this study, policy issues are discussed related to the use of technology in facilitating the STW process. Options are presented that may speed the development and incorporation of these technologies into work-related education. Overarching policy themes that affect all types of school-to-work transitions are the evolution of information infrastructures, incentives for information sharing, equity, and the implementation of new models of teaching/learning.

Hardware, software, and infrastructure evolution issues are concerned with how government sponsorship and regulation of high performance computing and communication technology development poses challenges and opportunities for participants in occupational training. Advocates of moderate government intervention to "prime the pump" for developing STW technologies might favor options such as:

---Government policies (e.g., investment and depreciation incentives, matching funds programs) could be used to encourage vendor development of software applications specialized for occupational instruction, job-finding, and other types of STW training. Similarly, matching funding could be provided to encourage the private sector in developing STW products that build on existing related military applications.

---Resources for the development of and studies on new types of pedagogical strategies (such as data visualization) could be provided, as could funding for research on the relative effectiveness of different kinds of STW education.

Information sharing and public/private partnership issues center on how various stakeholders in the STW process can be encouraged to function in an integrated manner for human capital development. Policy options that advocate moderate government intervention might include:

---Various levels of government could carry out general informational outreach to schools and employers through agents such as the National Occupational Information Coordinating Committee (NOICC), the State Occupational Information Coordinating Committees (SOICCs) or other pertinent existing federal or state organizations with access to STW stakeholders.

---Existing sources of federal and state moneys could be used as leveraging points to encourage schools and employers to make more information electronically available on the NII. An example would be tying work-related training institutions' acceptance of federal tuition training dollars to information communication requirements.

Equity concerns focus on ways that powerful learning technologies can narrow--not widen-- existing gaps in work-related educational opportunities and outcomes. A moderate-intervention-by-government stance on equity would support policies that stress open access regulation of the National Information Infrastructure, rather than simply scaling up traditional approaches to universal service. To limit the maximum gap between have and have-not students in access to powerful technology-based resources on STW, the minimum cluster of training services made available via the NII for all participants could steadily increase in its functionalities as hardware and software capabilities advance. Ensuring that telecommunications infrastructures are installed at equal rates in rich and poor neighborhoods would be a related policy intervention, as would funding programs that enhance the ability of institutions-in-need (both schools and businesses) to purchase STW-related training technologies.

The implementation of new models of teaching/learning involves policy issues such as financing educational technology infrastructure in schools and in the workplace, integrating technology usage into the training curriculum, and aiding instructor growth, not only in utilizing technology, but also in new models of pedagogy and learning. An advocate of moderate government intervention might argue for programs that disseminate to schools and businesses model approaches for training technology integration and budgeting. Government funding could be provided to ensure that STW technologies do not encounter the same barriers to success as prior types of instructional technology.

All of these types of policy initiatives are interconnected. As one example, regulatory, investment, and depreciation policies have a strong influence on the potential success of public/private partnerships. For this reason, regardless of one's stance on government intervention, coordination of federal, state, and local interagency policy initiatives is vital.

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GLOSSARY

Avatar	graphical figurines representing the personal presence of each participant in the synthetic environment
CAI	Computer-Assisted Instruction
CBT	Computer-Based Training
CIDS	Career Information Delivery System
CNC	Computer Numerically Controlled
CSCL	Computer-Supported Cooperative Learning
CSCW	Computer-Supported Cooperative Work
ESSCOTS	Educational Support System for Commercial-Off -The-Shelf software
GIS	Geographic Information System
HVAC	Heating, Ventilation, Air Conditioning
ICAI	Intelligent Computer-Assisted Instruction
ITS	Intelligent Tutoring System
Knowbot	a machine-based agent with very limited "intelligence" that can carry out simple tasks, such as collecting information in a distributed or shared environment
MUD	Multiple-User Dungeon or Dimension
NOICC	National Occupational Information Coordinating Committee
SOICC	State Occupational Information Coordinating Committee
STW	School-to-Work

SECTION I. OVERVIEW

TODAY'S UNIQUE CHALLENGE IN PREPARING FOR THE EVOLVING AMERICAN WORKPLACE.

Society mandates school attendance in part to prepare pupils for productive participation in the workplace; adults attend community colleges and universities or seek on-the-job training for new skills primarily to move up on their career ladder. In the past, preparing learners to compete effectively with other Americans in our domestic economy was sufficient to ensure their prosperity. However, the evolution of world-wide markets means that U.S. employers and employees must be more adept than their global competitors at meeting the needs of a very diverse range of customers.

In this new economic "ecology," each nation is seeking a range of specialized niches based on its financial, human, and natural resources. Developed countries, which no longer have easily available natural resources and cheap labor, have difficulty competing with rising-star developing nations in manufacturing standardized industrial commodities. However, America is utilizing her strengths (technological expertise, an advanced industrial base, an educated citizenry) to develop an economy that uses sophisticated people and information tools to produce customized, value-added products (1) .

Two opposite types of information technologies are now reshaping the workplace: smart machines and intelligent tools. Smart machines take control of the job, telling the worker what to do next; one example is the automated devices that guide medical technicians through analyzing blood samples. In contrast, intelligent tools provide workers with powerful capabilities to be utilized as they choose; an illustration is a graphic artist using a computerized animation program to create a cartoon. One way of understanding the impact of these two types of workplace devices on workers' occupational skills is to contrast how information technology has changed the job roles of the supermarket checker and the typist. Many supermarkets now have bar code readers; rather than finding the price on each item and punching it into the register, the checker needs only to pass the goods over the scanner. Efficiency and productivity have increased, but the food you buy tastes the same as before, and less skills are needed to do the job. Smart machines tend to increase efficiency, but also de-skill jobs, lower salaries, and make work more mechanical—the person becomes the eyes, arms, and personality for a device that does the recording, storing, "thinking," and decision making.

In contrast, substituting a office automation system for a typewriter requires a secretary to function in more sophisticated ways. To use the information tool for customizing a mass of data to the individual needs of recipients, the clerical role must shift from keyboarding to utilizing database, desktop publishing, and “groupware” applications. The job now demands higher-order cognitive skills to extract and tailor knowledge from the enormous information capacity of the tool, and the occupational role shifts to the new profession of information manager. Intelligent tools increase effectiveness rather than efficiency; new, more skilled roles are created that pay higher salaries.

America’s niche in the global economy—customized, value-added products—necessitates a shift in work roles away from smart machines manufacturing standardized commodities toward cognitive partnerships with intelligent tools (2). As this transformation to a post-industrial economy occurs, an evolution of job requirements toward some higher-order thinking skills is taking place in all types of occupations, blue-collar as well as white-collar (3). With advances in information technology during the next decade, people’s creativity and flexibility will be vital as job skills, because the standardized aspects of problem solving will be increasingly absorbed by machines (4). Because workers perform new tasks to increase effectiveness, as well as automating current processes to augment efficiency, measuring the contribution of information technologies to improving the productivity of work is difficult. The challenges of assessing information technology’s impact on work and managing the incorporation of new devices are discussed in Dunlop and Kling (5).

Imagining civilization a generation from now may be as difficult for us today as visualizing a commodities broker electronically monitoring soybean options would have been for eighteenth century farmers contemplating a steam tractor. America doesn’t have much time to understand and shape what is happening; the Industrial Revolution took more than a century to reach fruition, but global economic competition and the pace of technological advance will drive the next transformation much more quickly. Unprepared workers and nations will face difficult times. In all its various guises, vocational education must alter its focus to prepare learners for cognitive partnerships with intelligent tools. Until the need for these new types of skills is routine in workplace settings, shifting the emphasis of occupational education is difficult for teachers and employers to initiate—but by then a generation of our workers will be ill-prepared to compete in the global economic arena. The core challenge is to prepare today’s students for a future workplace more disparate from present experience than at any time since the Industrial Revolution.

THE PROMISE OF EMERGING INFORMATION TECHNOLOGIES TO AID SCHOOL-TO-WORK (STW) TRANSITIONS

Changing workplace needs will reshape the goals, student population, and content of instruction. Shifts in pedagogical methods, the organizational structure of teaching/learning settings, and the locus of education will inevitably follow. Sophisticated information technologies can provide the leverage to make evolution to a new educational model possible; the same advances that are transforming the economy can empower new models of teaching/learning to facilitate the transition from school to work.

This study is divided into four major parts. First, a conceptual framework for technology analysis is delineated that defines (a) a model of the skills and knowledge students need to make a successful transition from school to work, and (b) a model of how learning takes place (from a cognitive science and adolescent development perspective) based on emerging ideas about pedagogy and the nature of knowledge. Second, six categories of educational applications based on information technology are described, and visions of how these emerging applications might aid school-to-work transitions are depicted. Third, an evaluation methodology for assessing the potential contribution of each type of instructional technology is delineated, and the six categories of educational applications are reviewed using this methodology and the conceptual framework for analysis. Fourth and finally, the relative merits of each type of educational application are contrasted, and policy options and recommendations for facilitating the school-to-work transition via emerging information technologies are presented.

SECTION II. FRAMEWORK FOR TECHNOLOGY ANALYSES

In this section we lay out a framework for our analyses that includes two parts. First, we sketch a “process” view of the “ school-to-work” (STW) transition and identify the key stakeholders. This process view implies that two types of knowledge are needed by Career Seekers. Both must be acquired to progress through the STW process towards employment: factual knowledge of the employment domain (declarative knowledge, or “what” knowledge”) and cognitive and motor skills (procedural or “how to” knowledge). We briefly describe those two types of knowledge. We then briefly discuss a cognitive science-based approach to the different uses for such knowledge: navigating through the STW process as well as utilized in actual work in one’s chosen career.

Hand in hand with the types of knowledge to be acquired, we address the theoretical positions on how those different types of knowledge could be best communicated. Instead of making a commitment to a single learning and pedagogic theory, we present three currently prominent views and discuss their concomitant perspectives on how education and training should be carried out: an incremental or ruled-based approach, an analogical or a “case-based” learning approach, and a “situated cognition” approach. The analytic framework we apply to the various technologies reviewed highlights matches among the perspectives of these different learning theories and the capabilities of the various technologies we discuss.

PROCESS PERSPECTIVE ON THE " SCHOOL-TO-WORK TRANSITION"

Our analyses of technologies will be based on an abstract model of the process that a person might traverse on the way from uncertainty of career direction through success in their first employment. Our analysis describes students moving from school to work, but can be generalized to many aspects of retraining for movement between fields or human resource development of mature employees within a field.

The diagram pictured in Figure 1. portrays the major stakeholders in the STW transition and the transitions that people might make as they move from considering a career to employment. This is not meant to be a normative model, but instead acts as a guide for the different kinds of knowledge needed for success and, eventually, the technologies that might support the communication of that knowledge.

Figure 1. Stakeholders and Career Seeker Movement though the STW Process

The primary stakeholders are:

- people seeking a career, training, and employment (whom we will refer to as "Career Seekers")
- providers of career counseling information
- providers of training and accreditation
- labor organizations
- employers.

From the perspective of our focus on technologies to support this process of preparing for work, the providers of curricula and training technologies are also lesser stakeholders.[1]

Given these stakeholders, what is the STW process? We define that process as a number of phases:

Phase 1. Search for, and selection of an appropriate career. This includes orientation about work, exploration of careers, self-assessment of skills and interests, and selection of a career.

Phase 2. Search for, and selection of an appropriate training institution/program for that career. This includes comparison of training opportunities, financial and personal/domestic preparation.

Phase 3. Acceptance into that training program and successful completion of the course of study and related accreditations

Phase 4. General preparation in competing for a job, as well as skills and information on seeking and acquiring a job in that career area

Phase 5. Good performance in new position, further development of work-related skills (work-based learning), attitudes, and habits while on the job, and preparation to adapt to future jobs.[2]

Being explicit about definitions for these phases in the STW transition allows us to be specific about points of leverage for the different technologies we later review.

We also note that addressing these phases of the STW process separately does not imply that they are mutually exclusive activities. In fact, these are labels for sets of activities that may normally overlap greatly. We assume that the "better" or more

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[1]Note that this group currently supplies materials and technology to schools and employers for in-house training. Their future role in a richly distributed computing environment might involve providing training directly to the learner.

[2]We will discuss on-the-job training and retraining as they relate to this STW transition, without expanding into a broader discussion of continued occupational development and lifelong learning.

decision-relevant the knowledge acquired by stakeholders in this process (given their capacities and strategies), the better decisions that each will make (6). In the context of appropriate incentives to each, these “better decisions” by the stakeholders mean that process performs as a more integrated whole and the country moves towards a "high-skill equilibrium" (7).

Given this process view and set of stakeholders, the next question to be addressed is “what kinds of knowledge and skills do Career Seekers need to progress through this process both efficiently and effectively. We define “efficient and effective” in this context as moving through the STW process in the minimum amount of time, with the fewest changes in path, and emerging with the most skills and highest probability of acquiring and maintaining work that is both meaningful and fulfilling to the employee and employer.

DIFFERENT TYPES OF KNOWLEDGE ARE RELEVANT TO PREPARATION OF PEOPLE FOR WORK

First, we group “declarative” (factual, or “what” knowledge), and “procedural” (cognitive and/or motor skills, or “how to” knowledge) under the general category of “knowledge.” We also describe two basic kinds of knowledge that people must acquire in order to optimally move through the STW process depicted above.

1. Knowledge that will inform choosing/navigation through the decision points in the STW process. Examples: What is it like to be an aircraft mechanic? Who teaches such skills in my area? What specific jobs will be available in this area when I’m finished with my training?

2. Knowledge that person will need to in order to make the transitions through the process. This can be conceptualized in an economist’s terms as knowledge that directly increases one’s “human capital”. Examples: The necessary domain-specific skills to diagnose and repair a faulty hydraulic system for a aircraft landing gear. The knowledge needed to pass necessary accreditations. The interpersonal and cooperation skills needed to be a good member of a repair team for an aircraft engine overhaul. The interview and general presentation skills required to be initially hired.

Crossing the two general kinds of knowledge described as procedural (”how to” knowledge) and declarative (factual knowledge underlying expertise in an area) with the uses of that knowledge (navigation through the process vs. directly applicable or “domain-relevant” knowledge) yields a 2x2 matrix presented as Table 1. Examples are included of the kinds of knowledge in each of the cells.

	Examples of Factual Knowledge	***Examples of Procedural Knowledge (Skills)***
Transition Relevant Knowledge: Facts and Skills Needed to Successfully Proceed through the School-To-Work Process	**Phase 1:** data on hours and conditions of work in potential careers, knowledge of personal strengths & abilities. **Phase 2:** "consumer guide" information re: training institutions, application information **Phase 3:** information on how to be a successful student, including requirements and status **Phase 4:** Knowledge regarding specifics of different types of positions **Phase 5:** Information on performance review process, additional training possibilities to extend career ladder	**Phase 1:** skills in how to access information regarding different careers, how to compare and contrast personal and professional information **Phase 2:** skills in how to gather and integrate information on various training opportunities and domestic concerns **Phase 3:** skills in how to effectively apply for programs, study skills, test-taking skills **Phase 4:** Resume preparation, effective interview skills **Phase 5:** Effective communication skills, cooperation skills, continued motivation to learn and advance
Domain Relevant Knowledge: Facts and Skills Needed to Acquire Best Employment and Perform Well on the Job	**Phase 1:** knowledge about the specific, target career **Phase 2:** knowledge of which courses at specific institution potential employers will most value **Phase 3:** Mastery of specific technical and organizational content and details to complete coursework and pass accreditation. **Phase 4:** Information on the target employers' technical needs and requirements **Phase 5:** Mastery of the employer's business practices, organization, and products.	**Phase 1**: Simulated practice of the domain skills in the target environment **Phase 2:** Ability to evaluate quality of various training institutions **Phase 3:** Mastery of required manual, cognitive, and social skills to both graduate and pass accreditations **Phase 4:** Ability to discuss technical details, evaluate quality of various work environments **Phase 5:** Mastery of the employer's specific procedures, communication and cooperation with fellow employees

Table 1. Examples of both factual (declarative) and procedural (skills) knowledge crossed with the goal of use of the knowledge and examples at each phase of the STW process

These different kinds of knowledge can be couched in terms of different learning theories and are differentially supported by diverse technologies. In the next section, we discuss a learning theory framework to support our analysis.

LEARNING THEORIES THAT ADDRESS HOW DECISION-MAKING/NAVIGATION KNOWLEDGE AND SKILLS ARE ACQUIRED

We have proposed that a person must acquire or possess very different types of knowledge to effectively move through the proposed process of STW transition. Various underlying epistemologies and learning theories view these kinds of knowledge quite disparately, as well as making divergent recommendations about how skills should be instructed and assessed. We have chosen to break these learning/pedagogical theories into three classes that are currently prominent in the area of education and training:

1. An incremental or ruled-based approach. The advocates commonly associated with this approach are Herbert A. Simon (8, 9), John R. Anderson (10, 11), and Alan Lesgold (12, 13). Inherent in this view of knowledge and skill acquisition are assumptions about the roles of explanation and automaticity in learning: Explanation helps to guide attribution of failure and aid repair of problem-solving rules while practice helps to speed up problem-solving ability. Relatively little emphasis is put on the social and environmental contexts of instruction. Learning goes on "in the head of the learner".

2. An analogical or a "case-based" learning approach. The advocates most commonly associated with this approach are Roger C. Shank (14-16)and his various collaborators (17-20). This view of learning is failure-driven; learning occurs by analogical processes--lack of success in problem solving leads to changes in action plans based on analogies to other experiences. Social and environmental contexts take on a greater role.

3. A "situated cognition" approach. Proponents of this approach include William J. Clancy (21), James G. Greeno (22) and Jean Lave (23-25). Prominent in this view of knowledge and learning is the role of social and environmental context to support actions. To varying degrees, learning takes place through actions carried out in the environment or actual practice, strongly supported by other people around the learner and shaped by the local environmental resources and cues. The learning takes place as students integrate themselves into the social and physical environment.

We will not argue in this report that one pedagogical approach is absolutely superior to another. Those discussions are on-going in the field of cognitive science (26) and education generally, and specifically in the area of technology to support learning. Instead, in this paper we will use these three different approaches to reflect on possible differences in effectiveness of applications of our technology typology. For example, most intelligent tutoring systems are based on having well-defined simulations of skill in a domain. Such tools might be fairly effective in teaching diagnosis of problems in electronic circuits (a reasonably well-defined set of skills and context), but not effective at directly supporting growth of cooperative skills. Conversely, group use of exploration-based microworlds might be quite effective at supporting the growth of cooperation and higher-order thinking skills among learners, but less effective at teaching specific sets of cognitive skills.

Table 2. is an attempt to very briefly summarize the three views of knowledge above (epistemology), related inferences regarding how each view of knowledge argues for how mental models are most naturally learned by humans (acquisition), and the

concomitant view of how that knowledge should hence be taught (pedagogy) and assessed.

General Epistemology	***How Knowledge is Acquired***	***How Pedagogy Should Occur***
Knowledge is productions: Knowledge is made of discrete units that are acquired independently and assembled consciously or unconsciously by the learner	Acquired in an incremental process through practice. More practice leads to new and more accurate productions. Social, metacognitive aspects of learning are less important	Explicitly communicate facts and rules, provide practice with that knowledge to promote automaticity. Provide immediate feedback to signal errors. **Assessment:** Should be incremental, hierarchical
Knowledge is stored cases: Knowledge is a rich collection of well organized, scripted stories *or cases that* can be tuned and used as analogies	Acquired through analogy and adaptation. Access an appropriate, similar case, vary necessary features, create and apply new story. Learning is strongly failure driven and metacognitive. Less emphasis on social aspects.	Provide examples of problem situation with appropriate content presented. Immediate feedback on suboptimal action in the form of a story or analogy. **Assessment:** Applicability of case repertoires and adaptability in interactive environments
Knowledge is distributed experiences: Knowledge is a rich collection of distributed experiences, highly interconnected with the context in which the experiences occurred, highly distributed in environment, highly dependent on the individual learner	Acquired through watching mentors and participating in activities of the target culture. Learning is largely shaped by environmental cues and social interactions. Richer experience further integrates learner into knowledge environment.	Provide situated practice on whole tasks in a apprenticeship setting. Model all aspects of task, including social. Support learner's skills when necessary to complete task. **Assessment:** Joining/passing in a human community of practice

Table 1. Brief Overview of Three Popular Theoretical Views of Knowledge and Implications for Pedagogy

In sum, we built our broader analytic framework by first laying out a process view of the STW transition and primary stakeholders.[3] From a cognitive science perspective, we then discussed the different kinds of knowledge needed for efficient and effective progress through this process. We closed this section with a review of three of the most prominent current theories of "knowledge" and how that knowledge is acquired and taught. These different views shape our specific categories for evaluation, as described in Section V.

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[3]Including a lesser stakeholder, the provider of curricula and educational technology.

SECTION III. DEFINING CATEGORIES OF EDUCATIONAL TECHNOLOGIES

For the purposes of this study, we are dividing information technologies that facilitate learning into six categories:

1. presentational computer-based training/computer-assisted instruction;
2. intelligent tutoring and coaching systems;
3. multimedia/hypermedia;
4. computer-supported collaborative learning (educational “groupware”);
5. experiential simulations (including virtual reality); and
6. computer-based tools as learning enablers (e.g., computer-aided design, intelligent agents for carrying out tasks, “webcrawlers” for searching the Internet, visualization tools).

Each of these categories is characterized by disparate assumptions about design and pedagogy, as well as different technological capabilities necessary for implementation. However, any specific educational technology application may incorporate more than one of these categories. Brief definitions and illustrations for each category are given below. A detailed discussion of how these various types of educational technology may aid school-to-work transitions is presented later in this study.

PRESENTATIONAL COMPUTER-BASED TRAINING/COMPUTER-ASSISTED INSTRUCTION

Presentational computer-based training (CBT), computer-assisted instruction (CAI), and a variety of similar terms all refer to educational applications that predominantly focus on tutorial or drill-and-practice pedagogy. An example would be a program that teaches how to repair a car by presenting information on how an engine works and using occasional quizzes to test understanding and to build associative recall. The instructional emphasis is on displaying material to the learner, checking for comprehension by monitoring student behavior on narrow tasks with readily observable outcomes, then branching to further presentation or practice as appropriate. The designer must anticipate every potential instructional sequence and must completely predefine the screens of information to be shown; the computer controls the flow of material, programming the learner through a graduated sequence of skills and concepts. The underlying structure of most Career Information Delivery Systems (CIDS) and their role as an instructor or decision aid in the area of career choice group them into the CBT category.

INTELLIGENT TUTORING AND COACHING SYSTEMS

Intelligent tutoring and coaching systems (ITS), also termed intelligent computer-aided instruction (ICAI), impart to educational technologies a semblance of teachers' cognitive abilities. The strategies underlying these types of educational applications are based on ideas from the field of artificial intelligence (which attempts to create software applications that can mimic the intelligent behaviors people exhibit). ITS/ICAI applications ideally contain dynamic models of the learner, the knowledge to be taught, and pedagogical discourse; the system "understands" who, what, and how it is teaching. In a full-fledged ITS, the material presented to the learner is interactively shaped by these dynamic models and generated by the system in real time (in contrast, CBT branches through a preprogrammed repertoire of screens). For example, in teaching how to diagnose the cause of an automobile engine misfiring, an ideal ICAI application would internally simulate both the operation of the car's engine and the learner's current mental model of cause-and-effect within the motor. The pedagogical module would then utilize both these models to determine what experience next to give the student—perhaps a troubleshooting opportunity with a computer-based coach ready to provide guidance if suboptimal diagnostic strategies are used. The designer must create these models and determine their interaction; the system then generates instructional material to help the student evolve from a naive to an expert model of performance.

MULTIMEDIA/HYPERMEDIA

Multimedia and hypermedia are different flavors of the same concept: structuring information based on studies of how the mind assimilates ideas. Multimedia software displays data in multiple formats simultaneously (text, still images, animations, video, voices, sounds, music). This enables people with various learning and working styles (visual, auditory, symbolic) to peruse material formatted in their preferred mode of communication. Also, multimedia is interactive; rather than passively viewing preprogrammed instruction, as in educational television, users can tailor presentations by selecting paths through the material customized to their interests.

Hypermedia adds a further dimension to multimedia: associations among pieces of data. People can interrelate a wide range of ideas in part because human memory is associative; for example, the word "apple" conjures memories about the computer corporation, Snow White, Isaac Newton, the Beatles' record company, the Garden of Eden, orchards, and pies. Often, the interconnections among pieces of information are more important than individual bits of material; the route to knowledge is via comprehending patterns of relationships, not through storing isolated facts. By displaying webs of interrelationships through concept maps or similar graphic devices, hypermedia systems enable learners to focus on the links among pieces of information as well as the data itself. In both multimedia and hypermedia, the designer develops the material to be presented and the routes through it, but the learner selects what to view and which path to follow. This provides a powerful method of revealing and concealing complexity as dictated by the needs and learning style of the student.

COMPUTER-SUPPORTED COLLABORATIVE LEARNING

Computer-supported collaborative learning encompasses a variety of ideas from the field of computer-supported cooperative work, including such capabilities as group decision support. Artificial intelligence and multimedia/hypermedia are technologies primarily targeted to enhancing an individual's effectiveness, but workplace environments increasingly emphasize teamwork and collaborative interaction. "Groupware" facilitates team performance; this requires building common conceptualizations by communicating each person's ideas, structuring group dialogue and decision making, recording the rationales for choices, and facilitating collective activities. The designer creates a suite of interrelated tools (e.g., a window on the screen that presents the same information to all team members, the capability to automatically archive the material displayed on each participant's monitor). With the teacher's guidance, learners then utilize these groupware tools to develop a shared mental model enriched by multiple perspectives or to perform work-related tasks best accomplished by a team with complementary skills and knowledge rather than an individual.

MODELING AND SIMULATION

Instructional applications of simulation range from models that mirror the simplified essence of reality to elaborate synthetic environments with immersion interfaces that place students inside alternate virtual worlds. Fidelity-centered simulations enhance learning by creating a model of reality that retains only the basic situational characteristics students are to master. Single-user simulations allow an individual to interact with a model of reality (for example, flying a virtual airplane). An emerging technology—distributed simulation—enables many people at different locations to inhabit and shape a common synthetic environment; this empowers a broad range of educational uses (e.g., virtual factories, hospitals, cities).

In contrast, artificial-reality simulations place learners in "microworld" environments that teach by controlled variation of how natural laws function. For example, by attempting to play baseball in a synthetic environment in which gravity can be turned off, a learner can comprehend through simulated experience the effects gravity has on many common phenomena. For any type of simulation, the designer creates a learning situation in which much of the knowledge to be gained is implicit and contextual, mastered by the student through reflection on the results of interactions with the synthetic environment.

COMPUTER-BASED LEARNING ENABLERS

Computer-based tools as learning enablers include a spectrum of capabilities such as computer-aided design (CAD) systems, intelligent agents for carrying out tasks, “webcrawlers” for searching the Internet, and data visualization tools. All these tools enable various types of “distributed intelligence,” in which the learner is freed to focus on the concepts and skills to be acquired through the tool assuming part of the cognitive load. For example, machine-based “agents” with artificial intelligence can automate simple classification, reply, and retrieval tasks in accessing databases on a network, freeing learners to focus on creative interpretation of the information they are receiving. As another illustration, visualization enhances learning by using human perceptual systems (vision, hearing, touch) to find patterns in large amounts of information. Graphical data visualizations that model thunderstorm-related phenomena (e.g., downbursts, air flows, cloud movements) are valuable in helping meteorologists and students understand the dynamics of these weather systems. In all computer-based learning enablers, the designer creates a tool that complements some aspect of human cognition and is optimized to aid mastery in some conceptually challenging situation.

SECTION IV. SCENARIOS OF TECHNOLOGIES IMPROVING STW TRANSITIONS

An inspirational scenario is valuable less as a recipe for innovation than as a creative violation of our default assumptions about the status quo. These vignettes do not show a perfect approach to how technology might facilitate school-to-work transitions, nor do they present a complete vision of a future educational system. Rather, they illustrate how applying advanced information technologies--either in school or at work--could help students and newly hired workers transpose skills and knowledge learned in school into the workplace. To illustrate the importance of combining complementary capabilities when creating real-world applications, these scenarios blend together technologies from the different categories we have defined. In a later section discussing how each type of technology aids learning, we will discuss in more detail examples excerpted from these vignettes.

LEARNING JOB FINDING THROUGH A WEB OF STORIES

This vignette shows an apprentice physical therapist learning how to find a job once he graduates from his preparatory program. As the scenario suggests, this type of educational application would also be effective in earlier stages of the STW process (for example, in deciding among potential careers or in selecting a training institution). Hypermedia, geographic information systems, and artificial intelligence among the emerging technologies underlying this vignette.

An apprentice physical therapist is learning how to identify prospective employers, then market himself effectively to them. He hums quietly to himself as he and his computer skim through a sea of stories, harvesting metaphors and analogies. By sifting through the stored experiences of students similar to him, he can identify new ideas to try, building on what others in comparable situations have already learned about finding a job.

On the computer monitor, a map of various hospitals and nursing homes in the city is shown, with some highlighted in different colors. Several paragraphs of text describing the current story are displayed at the bottom of the screen, ignored by the apprentice. Since his learning style is predominantly visual and auditory rather than symbolic, STORYWEB is vocalizing this textual material while he watches a graphical pointer maneuver about the diagram. At any point, he can interrupt the flow of this story to activate one of the hypermedia links at the left of the screen; these lead to related reference materials such as job application forms, material about unions, people to call for additional information, etc. Three figurines are gesturing near the top of the display, indicating that they know related stories. The learner can leave this story at any time to shift into one of these related cases; if he does so, other figurines will appear, denoting the availability of additional stories related to this new case. In this manner, the user can traverse a web of interrelated cases to find those that are the best match for his interests and needs.

In addition, the person who told each story can be accessed through the system via automated electronic mail, surface mail, or telephone messaging. STORYWEB is a case-based reasoning shell that acts as a guide, conversing with a person engaged in problem solving and responding to problem descriptions with recollections about similar situations encountered by other practitioners. These concrete examples are pedagogically valuable in suggesting possible approaches, warning of potential pitfalls, and fleshing out abstract rules-of-thumb. Beyond a repertoire of cases, STORYWEB also provides access to other knowledge sources, including the people who told these stories.

Many of the technological capabilities in this vignette are based on extensions of current work. For example, Kolodner's research on pedagogical applications of case-based reasoning inspired the pedagogical strategy, and STORYWEB is loosely based on a prototype application she and her colleagues developed for learning about architecture (27). The web of stories depicted in the scenario has similarities to the TRANSASK story web developed at Northwestern University's Institute for the Learning Sciences (28). Apple Computer's work on "guides" embedded in multimedia applications to provide alternative perspectives stimulated the figurines at the top of the display (29).

KNOWLEDGE WEBS TO GUIDE APPRENTICESHIPS

This vignette portrays a teacher's aide-in-training learning via a mixture of technology resources distributed among a classroom setting, her home, and her future workplace. Both job-specific and occupationally generic knowledge are being acquired, and this cluster of technologies could be used for a broad spectrum of content. Also, this model of training could be adapted to other stages of the STW process, such as searching for potential careers and educational institutions or preparing to shift to a new type of job. The technologies underlying this vignette include computer-based training via videodiscs and CD-ROMs, electronic mail and computer conferencing, and navigating tools for the World-Wide Web.

Gwen is a elementary school aide-in-training. She longs to be a teacher's aide, but had been reluctant to get her credentials until she heard about an innovative program at New Community College that integrates content, methods, and technology. She is now taking the elementary science methods workshop that has recently been reformulated to integrate materials from "The Idea of Science " project. She will use a core text; video programs that help illustrate important concepts; a workbook that helps her apply the concepts to different grade levels; a CD-ROM curriculum matrix that lists elementary school materials that relate to specific concepts; and on-line networks that allow her to contact peers, veteran science teachers, and research scientists.

Gwen is just completing a lesson that she will teach tomorrow in Ms. Dean's third grade class. Ms. Dean has been teaching at a local elementary school for more than 12 years and is one of the many resource teachers who helps regularly with students in Dr. Farah's elementary science methods workshop at New Community College.

For two weeks, Gwen and her peers have been planning a unit on ecosystems to enrich this third grade class's science instruction.

Gwen signed off the Science Methods Computer Conference Center (SMCCC), a local computer bulletin board and conferencing system operated by New Community College. She sighed: sixteen messages were a lot to wade through. Still, compared to the complexities of arranging face-to-face meetings or playing telephone tag, this method of interaction was a lot more effective. Developing shared goals and integrating their individual lessons had been relatively easy for her group. Communicating electronically was convenient; and their face-to-face planning meetings with Dr. Farah, guided by her text's workbook activity sheets, had soothed over a few potentially divisive conflicts.

The World-Wide Web had also proven a valuable resource for locating databases on ecology, as well as archives of third grade lesson plans and ongoing electronic forums on teaching science. "Surfing the net" had proven to be less difficult that Gwen had expected, in part because the concept map organizers on each resource's Home Page had provided a constant visual referent for aiding her navigation. The multimedia "pages" that displayed information in graphics, text, and images were particularly useful in suggesting ways to package content for the diverse learning styles of her students.

The video on ecosystems on the videodisc packaged with her textbook was certainly a rich resource. Even two weeks after viewing and discussing the video, she and her collaborators were still generating insights from it on how to teach the lesson tomorrow. Tonight, to evolve these ideas farther, Gwen planned to skim one more time through the ecosystems chapter in her text. Since her learning style was symbolic, she liked having textual material that complemented the video. Her insights on the readings had won respect from the visual learners in her group, improving Gwen's self-image. She no longer felt like a "drop- out."

Gwen finished printing her latest Internet message from Dr. Xao, a noted biochemist doing ground-breaking work on urban ecosystems. He had been delighted to help her group formulate the lesson and had suggested some engaging activities with ants to try with the third graders. Gwen had generally negative feelings about ants, but the lesson planning process had made her a little more appreciative of their role in the general scheme of things. She had to laugh at the "Good luck; break a leg!" salutation on his message. Scientists seemed much more approachable and human in this virtual community of electronic mail.

However, Gwen was glad that their workbook activities from the text had aided them in planning appropriate activities. The CD-ROM Curriculum Finder included with the textbook had been a big help as well in identifying materials both related to ecosystems and appropriate for grade three. If her group hadn't prepared a good plan for the lesson before contacting Dr. Xao, he might not have been so willing to assist.

Gwen also appreciated the encouraging Internet message she just received from Ms. Dean. She had remembered her own first night jitters and gave Gwen some suggestions on how to relax. Ms. Dean had participated in the group's planning and helped them to develop "practice lessons" blending into the total curriculum for her third grade class. Without computer conferencing and email, Gwen thought, Ms. Dean, Dr. Farah, and Dr. Xao would all have played a much smaller role as resources. For that matter, Ms. Dean would not have been able to consult other third grade teachers around the country who had used the curriculum materials that Gwen's group was considering. The several critiques Ms. Dean had received on the materials the group was considering had been invaluable for Gwen's planning.

The best message, though, had been from Dr. Farah, complimenting the group on its choice of evaluation strategies. Gwen felt proud, as she knew her own ideas were the core of that part of the unit. “Now I’m an expert on ants,” she thought, “if I ever get bored with teaching, I can become an exterminator!” Relaxed and happy, Gwen shut off her personal computer and headed for the dining room; her husband had just finished cooking dinner.

The “Idea of Science” project, with its associated technological aids, is an actual curriculum currently being designed at George Mason University. This project is based on the work of Drs. Robert Hazen and James Trefil, who are noted scientists concerned with enhancing learners’ capabilities for interdisciplinary scientific literacy (30). All the types of educational technologies portrayed in this vignette (CD-ROMs, the World-Wide Web, computer conferencing, etc.) are in current usage by various groups of science educators across the country; the futuristic part of this scenario is simply the integration of already existing, disparate instructional applications.

COLLABORATIVE TRAINING IN A SHARED SYNTHETIC ENVIRONMENT

This vignette is set in the workplace, although it could take place inside school as well. Here, the training for new employees centers on performing tasks related to electronics diagnosis and repair. The learning outcomes include both psychomotor and intellectual skills, as well as abilities to collaborate across distance for shared problem solving. In addition to generic occupational capabilities such as distributed teamwork via groupware, the educational applications portrayed in this scenario could prepare new workers or students for a wide range of domain-specific job skills. Technologies underlying this educational application include intelligent tutoring systems, hypermedia, groupware tools, visualization, and an immersion interface to a virtual world.

Karen is a new employee at a telecommunications company. As part of her initial workplace training, she sits at her educational workstation, currently configured as an electronics diagnosis/repair training device. When sign-in is complete, the workstation acknowledges her readiness to begin Lesson Twelve: Teamed Correction of Malfunctioning Communications Sensor. Her “knowbot” (machine-based agent) establishes a telecommunications link to Phil, her partner in the exercise, who is sitting at a similar device in his cubicle two floors down.

“Why did I have the bad luck to get paired with this clown?” she thought, noting a hung-over expression on his face in the video window. “He probably spent last night partying instead of preparing for the lesson.” A favorite saying of the corporate problem solving expert to whom she was apprenticed flitted through her mind, “The effectiveness of computer-supported cooperative work can be severely limited by the team’s weakest member.

“Let’s begin,” Karen said decisively. “I’ll put on the DataArm to find and remove the faulty component. You use the CT (cognitive transducer) to locate the appropriate repair procedure.” Without giving him time to reply, she put on her head-mounted display, brought up an AR (artificial reality) depicting the interior of a TransStar communications groundstation receiver, and began strapping on the DataArm. The reality-engine's meshing of computer graphics and video images presented a near-perfect simulation, although too rapid movements could cause objects to blur slightly. Slowly, she "grasped" a microwrench with her "hand" on the screen and began to loosen the first fastener on the amplifier's cover. Haptic feedback from the DataArm to her hand completed the illusion, and she winced as she realized the bolt was rusty and would require care to remove without breaking.

Meanwhile, Phil called up the CT for Electronics Repair; on the screen, a multicolored, three-dimensional network of interconnections appeared and began slowly rotating. He groaned; just looking at the knowledge web made his eyes hurt. Since the screen resolution was excellent, he suspected that last night's fourth margarita was the culprit.

Phil said slowly and distinctly, "Lesson Twelve," and a trail was highlighted in the network. He began "teleporting" among the nodes of information, simultaneously watching a small window in the upper left-hand corner of the screen that was beginning to fill with data from the diagnostic sensors on Karen's DataArm. Traversing the network at the speed with which Karen was working was difficult, given his hangover, and he made several missteps.

"Knowledge Base," Phil said slowly, "infer what the optical memory chip does to the three-dimensional quantum well superlattice." The voice of his knowbot suddenly responded, "You seem to be assuming a sensor flaw when the amplifier may be the problem." "Shut up!" Phil thought savagely, hitting the cut-off switch. He groaned when he visualized his knowbot feeding the cognitive audit trail of his actions into the workstations of his industry trainer and the corporation's communications repair expert; he could not terminate those incriminating records. Phil cringed when he imagined his trainer giving him another lecture on his shortcomings.

Mentally, he began phrasing an excuse to send his instructors via email at the end of the lesson. Meanwhile, Karen was exasperatedly watching the window on her AR display in which Phil's diagnostic responses should have been appearing. "He's hopeless," she thought. Her knowbot's "consciousness sensor" (a biofeedback link that monitors user attention and mood) interrupted with a warning: "Your blood pressure is rising rapidly; this could trigger a migraine headache." "Why," Karen said sadly, "couldn't I have lived in the age when trainees learned from textbooks..."

As with the earlier vignettes, many capabilities in this depiction were drawn from existing technological prototypes. Robertson, Card, & Mackinlay's work (31) on information visualization inspired the "Cognitive Transducer." Maple's "µuSE" project at Sandia National Laboratories (discussed later in the modeling and simulation examples) prefigures the artificial reality envisioned here (32). As discussed later in the section on "intelligent tutoring systems," the "knowbots" in this vignette are extended versions of the smart agents and intelligent coaches being created by researchers in educational applications of artificial intelligence.

SECTION V. ANALYTIC FRAMEWORK FOR ASSESSING EACH TECHNOLOGY

Below we offer seven key attributes of a technology itself, its previous application to support the school-to-work transition, and its potential for--and barriers to--such support. Each attribute will be evaluated for the specific technology examples in each category.

1. Goal and Use: What Actual/Potential Use of the Technology?

To what extent has the technology actually been used for education, training, or transition-support purposes? If it has not been yet applied, what is the potential application of the technology? This category attempts to pull apart the application of the technology from the evidence of its success, reviewed in the next section.

2. Track record: Evidence of Impact on Learners/Users?

What evidence is there in the literature that the technology has been successful in its goal of supporting the transition to work? For example, have students moved through a curriculum more quickly with the same level of comprehension? Have they learned more or different material than in the traditional curriculum? Have they found careers, training opportunities, or employment more effectively with the support of the technology? And, how generalizable are such findings?

3. Malleability: How "tunable" is the technology?

This judgment about a technology has two aspects. The first is to what extent the technology be adapted by developers for different applications outside of its original application. For example, if the developers take on the task, how adaptable is an ITS for geometry to another mathematics domain? How difficult would it be for them to adapt it to a more disparate curriculum area, such as formal logic or musical composition? The second aspect of malleability is the extent to which the instructor or student/learner can customize the application to conform to her curriculum, language, or teaching style. How easily can a classroom instructor change the technology to "wrap" it around their classroom, as opposed to "bending" their classroom to use the technology.

4. Integrative Potential: Will it help integrate the stakeholders?

What is the potential for the technology to coordinate or fragment the various stakeholders an institutions in the STW transition? Clearly some of the network-based technologies have the potential for sharing work-related information and training between and among stakeholders. Each technology will be judged on its potential to interconnect entities that have historically been relatively un-integrated.

5. Cost: What does/will this cost and when?

Costing current and future applications of technologies to education is a complicated endeavor. A number of systemic costs are not obvious, such as infrastructure investments for LANs or WANs, education of instructors, or the costs to develop the curriculum and materials that accompany an educational technology. Where possible we will define of the scope of an hypothetical unit of implementation (e.g., a single workstation to provide access to a microworld, a server for career information, etc.) and provide a provide rough estimates of the costs of the hardware and software required for that unit. We will not address the larger systemic costs mentioned earlier.

6. Commercialization: What will it take for the technology to bloom?

This category is intended to address what it will take for a technology to find a viable role in support the STW transition. In particular, this category identifies what roles various stakeholders might play to support a promising technology to the point where it becomes commercially viable. Special attention will be paid to applications that are DoD-developed technologies that have not yet found commercial uses or advocates.

7. Implementation Barriers: What has to change?

This category is perhaps least defined, yet the most important if a technology is to be incorporated into an education or training environment. Interesting evidence from previous looks at how technology has been used to support education (33) suggests that some of the most important aspects of use for a technology are how well it fits into the larger structure of an educational institution. For example, certain types of exploration-based curricula may be more effective if there are longer periods of use than possible in a traditional high school schedule of 50 minute class periods. Another example is that the technology may teach knowledge/skills that are not normally or easily assessed. How could such a technology be deemed “useful” or productive unless other attributes of the institutional structure are changed, such as the assessments? For each category we will point out aspects of the traditional “institutional culture” or environments that might have to be transformed in order for a technology to succeed in classrooms or work-based learning environments.

Table 3., below, is a summary of the technologies we review, crossed with the seven assessment attributes we have just outlined. Included in the cells of this table are very short, telegraphic summaries of our conclusions from the following sections. We

present this summary of our results at this point to serve as a organizer for the individual technology reviews, which follow immediately.

Table 3 (a separate .pdf file on the www.virtual.gmu.edu website) goes here

SECTION VI A. EVALUATING THE POTENTIAL OF PRESENTATIONAL COMPUTER-BASED TRAINING/COMPUTER-ASSISTED INSTRUCTION TO SUPPORT THE STW TRANSITION

As defined in Section III of this study, presentational computer-based training (CBT), computer-assisted instruction (CAI) and a variety of similar terms all refer to educational applications that predominantly focus on simple tutorial or drill-and-practice pedagogy. Some of these capabilities were illustrated by the vignette earlier that depicted a teacher's aide-in-training learning from videodisc and CD-ROM based multimedia materials that complemented a conventional textbook. We will refer to these systems generically as CBT.

We will also focus some of our attention on educational tools in the CBT tradition, the goals of which are to educate the user and provide support to career decisions. These are sometimes referred to as Career Information Delivery Systems (CIDS). As in CBT, the designers of CIDS must lay out and support a diagnostic/instructional sequence and must completely predefine the screens of information to be shown at each point, based on the results of previous student assessments and choices; the computer controls the flow of material, programming the learner through a graduated sequence of concepts about careers, their skills, and decision-making.

We will begin by focusing on the following three areas:

• General cases of CBT use for commercial and military training and evaluation

• RIDES CBT authoring environment

• Career Information Delivery Systems

Each will be briefly summarized before providing a general review of the overall CBT area.

APPLICATIONS OF CBT IN COMMERCIAL AND MILITARY TRAINING

Frame-based CAI and CBT has existed since the 1960s (commercially available since the mid-1960s) and has been used in a large number of settings and with a large variety of learners.[4] As such, it has had the opportunity to be implemented and tested in a variety of ways and hence has gone through a long maturation process. Evidence of

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[4]See Saettler (1990) for succinct histories of CAI/CBT and ITS development.

this maturation can be found in numerous publications on fielding and testing[5]. Interest in educational applications of computers appears to be steadily growing. Open any training magazine or journal, and there are many advertisers, large and small, with promises of the effectiveness of their CBT for training needs. Companies cited as leaders include Motorola, which uses a variety of advanced technologies in its workforce training (35).

Innovative CBT uses include training for nuclear power plant operators, aircraft maintenance, office automation CBT and skill on-line assessments developed in-house by a large temporary employment agency, and assembly/maintenance training for complex

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[5] Fletcher (34) contains a general summary.

communications technology (36). Adding audio and optical disc technologies to CBT to incorporate photographic images and videotaped footage is now common. As Lewis (37) in his review of emerging educational technologies for vocational education:

> Commercial educational applications of CAI and optical disc technology have appeared for teaching a variety of skills, from sales techniques to automobile engine repair. As an example of a current commercially available application of optical disc technology, imagine a student learning to correct the timing on an ignition system. As the student makes decisions on how to correct the problem, the system can display a video image of the engine in the engine compartment of the specific car the student is working on, show video clips of the car driving uphill pulling a trailer with the engine making noises, and then play the pre-stored sound of the engine as attempts are made to tune the car. Note that in this case of a CAI system, all the instruction is pre-planned and all the images are pre-stored. None of the feedback or decisions of the CAI system are generated on line.

A plethora of CBT and assessment applications are currently in use round the world. Traditional CBT that is custom built for an training area is a fairly mature, commercially available technology. A mark of this maturity are books that prescribe in detail how to implement CBT in organizations, e.g. the text by Grey (38).

A leader in STW-related CBT training is Honeywell, whose Industrial Automation and Controls Division operates an Automation College that trains both internal and customers' personnel on how use Honeywell technology for greater workplace effectiveness (39). The College uses "flextraining" approaches that stress individualization via CBT techniques. About 10,000 students are trained per year, with demand for these services steadily rising.

RIDES, an Authoring and Delivery System for Simulation-Based Training: Generative Instruction on Mechanical Device Operation and Maintenance Tasks

Bringing down the costs of developing CAI has been a long pursued goal. Although the technology and curricula are reasonably well understood, the costs of building new systems are still high. Movement towards authoring environments that are more than just better frame-based editors continues. Of particular interest are tool kits that incorporate simulation to speed the building of CBT for complex devices (40). Adding such simulations pushes authoring environments away from traditional CAI and towards true simulation-based trainers.

A very strong example of such a authoring environment is the Rapid ITS Development System (RIDES) system (40, 41) funded by the Air Force and developed by Behavioral Technology Laboratory of the University of Southern California. Currently RIDES provides both authoring and delivery capability for CBT, but its goal is to eventually do the same for intelligent simulation-based training. Once a device is simulated in RIDES, it is can to automatically generate component identification and recognition tasks. It also enables curriculum designers to demonstrate (by example) action sequences on the simulated device which RIDES can then use to tutor and assess performance. Introducing faults that must be identified by the learner is also easy, and the RIDES system can provide limited, scripted feedback about learners' errors. Areas of application for RIDES CBT currently include systems to teach orbital dynamics, operation of a tactical radar set (41) and repair of the B2 bomber's main landing gear. Simulation-based authoring environments like RIDES point the way towards a new family of CBT that continues to narrow the gap between CBT and ITSs. The addition of sophisticated models of pedagogy and student knowledge will further close that gap.

CAREER INFORMATION DELIVERY SYSTEMS: TOOLS TO EDUCATE AND GUIDE CAREER AND JOB SEEKERS

A recent review of commercially marketed career information delivery systems (CIDS) (42) in California (43) reported the results of a questionnaire survey on 25 CIDS products. These CIDS run on a variety of hardware, are based on a variety of underlying theories, and assess a variety of job-seeker attributes, including evaluations of values, interests, temperament, aptitudes, transferable skills, and metrics related to standardized tests. These STW applications include information on careers and jobs from a variety of public and private sources. The "ERIS/TCA" system, among the most comprehensive of those reviewed, applies and scores assessments then uses those assessments to suggest possibly suitable occupations for potential workers. It also then ties those occupations into the local labor markets and training providers. Systems like ERIS/TCA and SIGI Plus (System of Interactive Guidance and Information), the most recent in a line of CIDS developed by the Educational Testing Service (44, 45)provide a good deal of potentially useful information to job seekers. However, users must be self-motivated, reasonably computer fluent, and supplemented by a well-trained human guidance counselor (46).

In general, CIDS applications operate by first assessing a Career Seeker's interests, skills, and abilities. Then, by having the Career Seeker rank order alternatives, they can come up with a range of career possibilities that match the profile automatically generated of the user. Just as with traditional CBT, this technology has a prescribed method of assessing and gathering information, so CIDS are fairly rigid. However, others allow users to choose the path they wish to take through the decision aid.

Generic Underlying Learning Model and Pedagogic Supports in CBT

Underlying most CBT is an “incremental or rule-based” model of learning. This is consistent with the seminal influence that drove the early CBT development: Operant conditioning (47). Learners are acquiring individual skills by engaging in activities and getting feedback. These skills can be assembled into hierarchies of increasingly complex skills. Some of the CBT systems use video feedback of potential social responses to decisions (such as sales tactics), but in general the systems are devoid of the broader contexts of job environments or social/group work. Learners are assumed to work independently and at their own pace; they are provided with immediate feedback about errors. Immediacy of response combined with pre-developed feedback is at the core of the pedagogic supports offered by CBT.

Types of skills and concepts in each knowledge framework (rule-based, analogical, situated) that CBT supports

The traditional CBT format of an “action-response” cycle, combined with the pedagogical strength of immediate feedback, make this type of technological application best suited to learning facts and action sequences or supporting real-time decision-making. By presenting feedback in the form of alternative cases to the action or decision of the user (as is done in the case of many intelligent tutoring systems--discussed later), CBT systems could potentially also embrace an analogical learning framework: The response to an incorrect decision could be a story or analogy relevant to the error and correct action. Due to the complexity of the hand-crafted situations and responses, skills that involve responses to many variants of a dynamic situation would be less well-suited to CBT. And, since interacting with CBT is unlike most actual "tasks" in the world, its “ecological” artificiality suggests little reason to support an advantage of CBT for teaching situated skills or knowledge.

ANALYTIC FRAMEWORK

1. Goal and Use: What Actual/Potential Use of the Technology?

Based on our process model of the STW transition, CBT has roles in several of the phases we defined. First, there are clear current uses of CBT-like CIDS for helping job-seekers in the first phase of “search for, and selection of an appropriate career”. There are many CIDS competing in the commercial market now, with changes and improved features added regularly. Providing access to distributed information about training opportunities, including geographically distant job opportunities (even international opportunities) and consumer-type decision support (e.g. ability to make integrative spreadsheets of collected information for use comparing opportunities) might greatly enhance the overall effectiveness of such tools.

For example, information on occupations and labor markets that State Occupational Information Coordinating Committees (SOICCs) and National Occupational Information Coordinating Committee (NOICC) assemble and distribute (42, 48-50) could also be made more available for use by CIDS through distributed access. Demonstration prototypes of such a system are under development (51). Adding intelligence to such tools would allow more adaptivity to a job-seeker's level of motivation and need for free versus guided access to career-related information. This added intelligence would also move the tools into the intelligent tutoring system category reviewed following this section.

The most frequent uses of traditional CBT have been in the third phase of the STW process in which job seekers are in pre-employment or on-the-job training, both in civilian and military settings. Some CIDS also offer help in preparing for job seeking and interviewing, which occur in Phase 4 of the STW process.

2. Track record: Evidence of Impact on Learners/Users?

Evidence from meta-analyses of the effectiveness of CBT with secondary school students (52, 53) and with adult learners (54, 55) show significant educational benefits over more traditional classroom instruction. The average effect of computer-based instruction is to raise scores by .35 standard deviations (53). Adult learners using computer-based instruction average 24% reduction in instructional time as well liking their classes significantly more and developing more positive attitudes about computers (53). Similar results appear to be true under certain conditions with military training and CBT-based uses of optical disc technologies (34, 36). Evidence of motivational effects of well-designed CBT on both students and teachers also exists: Students are generally free to progress at their own pace and teachers often are able to work with smaller groups or individual students.

3. Malleability: How "tunable" is the technology?

CBT traditionally has been very un-malleable: Systems come fairly "canned". Presentations and feedback generally cannot be easily changed, nor can the curriculum usually be reorganized beyond the level of re-ordering large pieces of the material (akin to skipping chapters in a text). For example, an instructor could not edit out specific problems. The growth of simulation-based authoring systems (40) presents interesting possibilities for teacher intervention, but this remains generally untested.

4. Integrative Potential: Will it help integrate the stakeholders?

Traditional CBT aimed at training skills has no particular leverage in better integrating stakeholders' activities in the STW transition. However, distributed access to information about training institutions, employers, and job-seekers, as in CIDS, has strong potential for integrating these stakeholders. This point is addressed in more detail in the policy section of this paper.

5. Cost: What does/will this cost and when?

The development costs of CBT are not low, but many firms and the military have found it still cost-effective for many training tasks. CBT is generally focused on individual instruction, so the unit of analysis is the individual workstation. Most CBT will run on mid-size personal computers, but the addition of optical discs or videotapes substantially increase cost. Developing the rest of the curriculum to surround the CBT (e.g., the problem sets, the course materials, and assessment) is commensurate with related development costs for other educational materials.

6. Commercialization: What will it take for the technology to bloom?

CBT technology is currently commercially viable, and costs for development should continue to decrease slowly as more powerful tools for developing and reusing pieces of applications emerge. Distributed access to CBT or CIDS is generally not commercially available. Most software is licensed to run on individual machines and contains all the data needed.

Governments could encourage improved access to distributed information regarding career, training, and job opportunities. Such incentives, if properly designed could potentially yield strong benefits to users of CIDS, training institutions (who might better tune their curricula to student and labor market needs), and employers. This is discussed in more detail later in this study, in the section on possible policy options.

7. Implementation Barriers: What has to change?

Incorporating CBT into training is taking place throughout various industries. Programmed instruction using paper and pencil methods with programmed texts has been an integrated part of training since the 60's. Aside from the financial investments in hardware and software, ongoing maintenance, and additional instructor education to take advantage of the technology, no large organizational or structural changes are needed to incorporate CBT. The structure of classrooms and teachers' roles must change to allow learners to proceed at their own pace and move the teacher into more of a tutoring role than a sole provider of knowledge.

Barriers to incorporating CIDS more widely currently appear to be cost of access to the services or copies of the software. The software also appears to be more effectively used under the guidance of a knowledgeable counselor to help interpret the results.

SECTION VI. B. EVALUATING THE POTENTIAL OF INTELLIGENT TUTORING AND COACHING SYSTEMS TO SUPPORT THE STW TRANSITION

As defined in Section III of this study, intelligent tutoring and coaching systems (ITS) use artificial intelligence techniques to simulate parts of the cognitive abilities of a human tutor. The goal is to achieve some of the documented pedagogical effectiveness of one-on-one tutoring (56). Examples of applying artificial intelligence capabilities to an STW training application were presented earlier in the vignette on learning electronics repair with help from "knowbots."

There are a number of examples of ITSs for work-related education (37, 57) and the work-related education community is becoming aware of emerging technologies relevant to their needs (58-61). This review will focus on work coming from four projects that are strong exemplars of current research into applying ITSs to work-related and academic education We review the details of each project before providing a general review of the area.

Air Force's Armstrong Laboratory: ITSs for Maintenance Training and Academic Topics

Work applying artificial intelligence to training is being done and sponsored by the Air Force out of their Armstrong Laboratory in San Antonio, Texas. Their ITS work originally focused on building prototype intelligent tutors to teach diagnosis and repair skill for complex electro-hydraulic-mechanical systems such as the blade-fold mechanism on a large Navy helicopter (62). This system applied and taught problem isolation skills through modeling, providing explanations, and providing model-based, error-specific feedback. More recently their work has focused on the foundations of an authoring tool to decrease the cost of fielding intelligent tutoring systems (40) and on teaching basic economics and statistics (Shute, (63). See Youngblut, (41) for a broad review of their ITS work and material at

http://xexon.brooks.af.mil/HSC/AL/HR/hr-home.html

for a good overview of their structure and efforts.

The SHERLOCK/BELVEDERE project at University of Pittsburgh: Unifying Tutors for Electronic Debugging Skills and Argument

The continuing SHERLOCK work, which supports student debugging of complex electronic systems, has achieved strong results (64, 65) and a well-deserved recognition. More recently a work on BELVEDERE, a coaching environment for teaching effective argumentation skills, has been developed initially in earth science domains. Recent proposals to unify these two types of environments will take advantage of the coached learning-by-doing in SHERLOCK as well as the opportunities and visualization tools for reflection on argument building. Youngblut (41) offers a nice review of the SHERLOCK work and more information on the Learning Research and Development Center can be had at

http://www.lrdc.pitt.edu/leartec.html

including information on SHERLOCK.

Case-Based Teaching Environments at Northwestern University: Learning Sales, Customer Service, and other Work-Related Skills Through Experience with Simulated Social Interactions

Work at Northwestern's Institute for the Learning Sciences has focused on how case-based teaching architectures can be applied to training a variety of work-related skills (16). These tutors rely on stories, sometimes in video form, to provide instruction to trainees. To provide the maximum educational leverage, the goals and contexts of the presented stories are tuned to be directly relevant to specific points in a social interaction the learner is trying to master. An example is the delicate process of a telephone interaction in which a water company representative is diagnosing problems with tap water quality (66). A review of the underlying motivations and theories supporting this work (67) and an article by Kass, Burke, and Fitzgerald (68) provides a nice description of some applications of case-based tutoring. A current publication on aspects of case-based reasoning applied to teaching work-related skills is by Kass (66). Information at

http://www.ils.nwu.edu

provides a broader context for work at the Institute for learning sciences.

The ACT tutoring project at Carnegie Mellon University: Intelligent Tutors for Well-defined Mathematics and Computer Programming Skills

Driven by an evolving theory of cognition, now called ACT-R (Anderson, 1993), Anderson's research group had been simulating the cognitions and tutorial actions of expert human tutors for over 10 years. In a recent review article published by the Advanced Computer Tutoring Group at Carnegie Mellon (69), discusses the last ten years of their work developing intelligent tutoring systems in the areas of high school mathematics and computer programming languages (LISP, Pascal, and Prolog). Their views of the task of building ITSs has changed from trying to emulate expert humans to instead trying to build environments (with an emphasis on cognitively appropriate interface design) in which helpful information can be provided based on a diagnosis of where the user is within a problem-solving task. See Anderson, Corbett, Koedinger, and Pelletier (69), Anderson, Boyle, Corbett, & Lewis (70) and

http://sands.psy.cmu.edu/

for more detailed recent overviews and reviews of this work.

Generic Underlying Learning Model and Pedagogic Supports

Blends of all three learning models underlie the systems being developed by the projects described above. The systems created by the Air Force, at LRDC, and by the ACT Research group lay closest to the “incremental" or "rule-based” model of learning. Information is presented in the context of solving a problem that is largely isolated from the broader job context and social constraints. Learners are assumed to work independently, at their own pace, and are provided access to tutorial information. However, although these are the assumptions at the heart of the efforts, each project will also voice their support of the importance of broader context and human interaction aspects of learning. The case-based work from Institute for Learning Sciences at Northwestern is strongly based upon the assumptions that learning is done analogically through comparison to existing or tutor-presented scripts or experiences. However, the “situated cognition” learning model (strong role for environment and social factors) is also partially embraced by the ILS work. The actions the learner is undertaking are seen as intrinsically embedded in the context of social situations (e.g., sales situations), as opposed to in decontextualized settings (e.g. when the domain content is an abstract or solo mental task such as solving a geometry proof or finding a short in a circuit).

The general pedagogic supports provided to the learner are similar, but the details vary greatly based on the underlying learning model. In the case of the Air Force, LRDC, and ACT tutors, the feedback is generally immediate and involves specific information relevant to the goal and action in which the student is engaged. In the case of the ILS tutors, the feedback consists of the presentation of rich cases or alternative examples that are tuned to the goals underlying recent student actions.

Types of skills and concepts in each knowledge framework (rule-based, analogical, situated) that ICAI supports

An interesting interaction seems to occur between what is being tutored and what model of learning is being applied. Skills that involve social interaction (and include complicated motivational and informational aspects, as well as dynamic goals due to the possibility of the other actor changing goals during the interaction) are being tutored in the context of a case-based learning model with a strand of situated learning embedded. Skills that are more cognitively abstract and applied in more stable goal environments (e.g., writing a computer program or finding a hydraulic fault) are being tutored in more of a rule-based approach.

ANALYTIC FRAMEWORK

1. Goal and Use: What Actual/Potential Use of the Technology?

Based on our process model of the STW transition, ITSs appear to have roles in several of the phases we define. Like CBT, the most frequent use has been in the third STW phase where job seekers are in pre-employment training or on-the-job training. We are beginning to see the advent of similar technologies in the evaluation/accreditation process (71, 72). ITSs have been used in school and training settings (both civilian and military) for learning generally well-defined sets of skills. However, such technologies also have roles in other phases of the STW transition. An ITS in the style of those under development at the ILS could be applied to teach skills for selecting and competing for employment (Phase 4 of the STW process). Intelligent tools could clearly have a role in supporting the STW transition if they were to assist in the process of helping job-seekers to effectively explore and select a career.

2. Track record: Evidence of Impact on Learners/Users?

There is ample experimental evidence in the literature that well designed, well developed ITSs can train very effectively (with examples referenced above) as well as the general results of the positive effects of computer-based instruction presented by Kulik (53) and his colleagues over the years. For interesting reasons, Lesgold's SHERLOCK I taught more about how to troubleshoot the electronics of a complex device in 20–25 hours than much more senior colleagues had learned in many years of experience (13). The reason for this huge effect was that SHERLOCK provided simulated fault situations that only occurred rarely, and--when they did--no expert help was available for the diagnosis and repair. Results from Anderson's LISP tutor showed students using the tutor completed the curriculum substantially more quickly (between 30–60% faster) and performed better on posttests (30–40% higher) (69). In a geometry classroom, students essentially performed at one higher level grade (i.e., a "C" student became an "B" student via experiences with the tutor). Many reports also exist of the motivational effects of ITS on both students and teachers. However, we found no evidence in the literature of the use of ITSs to improve movement through the STW transition, at least in part because ITS work has not focused on this area.

Questioning the generalizability of these findings is important. The caveats in the initial sentence of this evaluation are that the ITS is both well designed and developed.

In Anderson, et al (69), tutors are reported that, for reasons of poor design, did not support the transfer of skills from the ITS's domain to the practice of skill in the real world. As Anderson, et al (69) point out, students must learn both the rules that make up the skill as well as the mapping of the rules from the training domain to the actual domain. If the skills are substantially different between the two, and no mapping is provided,students will not transfer their knowledge. The closer the actions and interface are to the actual skill, the more transfer will take place.

3. Malleability: How "tunable" is the technology?

ITSs have proved to be quite static in terms of their ability to be generalized to new domains. The availability of "authoring systems" for ITS building is still an unrealized dream. There are shared underlying architectures for building ITSs, and many researchers include plans for modularity and reusability of code for tutor building, but very limited evidence exists to date of such generalization for existing systems. Building new tutors in related domains is still a time-consuming process, even for domains that are well-defined. Different domains appears to require very disparate interfaces and sometimes major or minor changes in architecture.

In terms of malleability by instructors, the current ITSs appear to be largely tuned by the developers. ITS developers realize the importance of having a tunable environment, and future generations of ITSs will likely provide teachers with such abilities.

4. Integrative Potential: Will it help integrate the stakeholders?

There is no clear promise that any of these applications of ITSs will end up directly improving the level of integration of the various STW stakeholders.

5. Cost: What does/will this cost and when?

Current development costs for ITSs are the highest of any of the technologies we review. This is driven by the desire/need to build detailed simulations of the task performance, the learner's knowledge, and the teacher's pedagogy. The development tools and architectures are still evolving, so there has historically been little cost savings across even large jumps in generations of an ITS. The Air Force work has specifically been aimed at reducing costs and has experienced the most success with their tools. Their goals are to reduce development costs by 95% (from $1M to $50k) and reduce development time by "up to 80%" (41).

Given the general focus of ITSs on individual instruction, the unit of analysis is the individual workstation. Although hardware costs have come down substantially in the past 10 years, current systems still require top-end personal computer hardware and large amounts of memory to perform well in real time. Developing the curriculum to support the ITS (e.g., the problem sets, the course materials, and assessment) is commensurate with related development costs for other educational materials.

6. Commercialization: What will it take for the technology to bloom?

This technology is still generally considered to be not yet commercially viable. Companies develop and sell CBT, but education or training applications that incorporate “intelligence” are not yet near the commercial market. We estimate that it will take a number of years (5–10) in which broader successes are attained, development tools are built, and design methods are improved before ITSs are robust enough to be used widely in commercial and public environments.

Possible federal roles to attempt to speed the maturation of ITSs are unclear. Current funding is aimed at experimental development and practical application (as in the military)

7. Implementation Barriers: What has to change?

The roles of many of today’s experimental ITSs fall generally within traditional frameworks of education/training in a similar manner to CBT’s ready adoption into largely presentational courses. ITSs provide coached practice in a number of tasks that exist in current courses. One barrier to implementation is the need for research and development costs for each new domain, as well as the limits on what domains can be gainfully taught. Certainly there is the barrier of the initial financial investment for infrastructure such as hardware, the software, and maintenance. However, the need for new types of assessment does not appear to be a significant constraint on upcoming ITSs because the tasks being taught are largely part of current curricula. However, the instructors’ roles must change from teaching whole classes to instead being more of a tutor for individual or small groups of students.

SECTION VI. C. EVALUATING THE POTENTIAL OF MULTIMEDIA/HYPERMEDIA TO SUPPORT THE TRANSITION FROM SCHOOL TO WORK

As defined in Section III of this study, multimedia and hypermedia are learner-controlled interactive technologies; in contrast to CAI/CBT and ICAI, users can tailor presentations by selecting paths through the material customized to their interests. Also, this type of educational application displays data in multiple formats simultaneously (text, still images, animations, video, voices, sounds, music); this enables people with various learning styles (visual, auditory, symbolic) to peruse material presented in their preferred mode of communication. In addition, by displaying webs of interrelationships through concept maps or similar graphic devices, hypermedia systems enable learners to focus on the links among pieces of information, as well as the data itself.

Multimedia systems are now used for workforce training, including the education of new employees, by a variety of companies. For example, Apple Computer has developed a multimedia database, ARPL, that provides indexed, multi-format information to allow marketing and sales people unfamiliar with a product to rapidly develop an understanding of that device. The company estimates that this training approach has saved forty percent in education costs over alternative instructional approaches to the same problem. As another illustration, the MITRE Corporation built an interactive multimedia tutor for software system maintenance, now used by the DoD for rapidly transferring system-specific knowledge to new personnel (73).

Many companies are interested in expanding their present programs in multimedia-based workforce training. Some of these corporations recently submitted proposals to the National Institute for Standards and Technology, U.S. Department of Commerce, urging the initiation of an Advanced Technologies Program to fund Learning Technologies for industry-based training. Companies currently active in workplace training with many school-to-work implications include Chrysler, which spends $300M per year on employee education, much of this on remedial basics and people skills for foremen and floor workers. Chrysler is part of a coalition that includes Ford and GM to develop a “virtual university” of electronic knowledge modules to train its engineers based on real-world manufacturing cases (74). Other companies with substantial current investments in STW-related multimedia training include Hewlett-Packard, Apple, Shell, Xerox, and Lockheed-Martin (75).

In the vignettes presented earlier on how emerging technologies could aid school-to-work transitions, one student worked with a hypermedia "knowledge web" that used data visualization to display the interconnections among pieces of information related to electronics. A second traversed the World-Wide Web to find information on ecosystems and science teaching, displayed in multimedia format to suggest ways of communicating content appropriate for various learning styles. A third student skimmed through a web of stories, using case-based reasoning to find job-finding strategies customized to his particular situation.

Jasper videodisc series for mathematics learning : Cognition and Technology Group, Vanderbilt University

An exemplary illustration of multimedia/hypermedia applied to learning work-related skills is the Jasper videodisc series for mathematics learning developed by the Cognition and Technology Group at Vanderbilt University (76). The Adventures of Jasper Woodbury is a video-based series designed to promote problem solving, reasoning, and effective communication. After viewing each quarter-hour adventure, a complex challenge integral to resolving the adventure's narrative is presented to upper-level elementary students; these authentic problems are based on real world issues such as trip planning or generating a business plan using statistics. Over the course of a week, students must work together to solve these problems before they view how the movie characters resolve the same challenges. Using a videodisc with associated textual and graphic materials, learners first navigate through a complicated multimedia database to find the information they need to formulate the problem, then apply mathematical reasoning to solve the challenge and to generalize their solution to related problems presented in ancillary materials.

For example, in the adventure "Rescue at Boone's Meadow," the protagonists must convey a wounded bald eagle to medical attention as quickly as possible. Alternative trip plans are possible through various combinations of people, vehicles, and routes. The ultralight airplane available as one of the vehicles introduces additional complexities of payload, range, and landing requirements. The mathematical, problem solving, and reasoning skills needed to find the optimal outcome generalize to a wide class of workplace related challenges, as do the teamwork and communication skills students must use in small groups competing to find the best solution.

Sophisticated, large-scale evaluations of the Jasper series show statistically significant results in the following areas (77):

1. Students working with Jasper understand basic math concepts as well as control group students exclusively studying these concepts during an same equivalent time period, even though Jasper does not directly teach basic math.

2. Students in Jasper-based classrooms perform better on word problems and planning problems than learners in equivalent control groups.

3. Students learning via the Jasper series had more positive attitudes toward mathematics and problem solving than control group students; in addition, Jasper students had a better self-image of their abilities to master this material.

On a qualitative level, teachers and parents were generally very positive about how well children responded to Jasper, in contrast to the conventional mathematics curriculum. Multimedia-based experiences such as Jasper seem to build knowledge and skills that bridge abstract mathematical formalisms to practical methods for applying these concepts in problem-solving contexts similar to real-world occupational situations.

Broadcast News Project: Institute for Learning Sciences, Northwestern University

A second example of leading-edge work with multimedia to develop work-related skills is the Broadcast News project at Northwestern University’s Institute for Learning Sciences (78). Broadcast News is a research prototype that teaches social studies and journalism skills to high school students by allowing them to edit and anchor a TV News Show. An embedded hypermedia system presents a rough draft of a news story; the learner’s job as an assistant producer is to edit the text and video associated with that draft, eliminate bias, correct factual errors, and fill in missing details. To accomplish these tasks, the student must navigate through a complex web of multimedia source materials (including film segments, text files, and reference works).

Lists of frequently-asked-questions relevant to the story and the task are provided; if the learner asks one of these questions as a plea for help, this triggers textual responses and video clips of advice from experts in history, the social sciences, and journalism. An artificial intelligence-based program evaluates the student’s edited version and provides detailed feedback on whether the story is now “ready for prime-time.” If so, the system enables the learner to act as a news anchor by provided a computer-controlled teleprompter; segueing to video feeds at predetermined times; and creating a videotape of the student’s broadcast to compare to other learners’ broadcasts, as well as to professional news presentations of the same event.

The goal-based scenario of working as an assistant producer supplies an organizing framework for students’ exploration of this hypermedia database, and the opportunity to serve as news anchor provides motivation for creating a quality product. This prototype is still in its development stages and has not been formally evaluated, but the content and format both provide training for journalistic roles in the workplace. Comparable multimedia databases and goal-based scenarios could be created for a range of occupational roles that involve information filtering and formatting.

Generic Underlying Learning Model and Pedagogic Supports

The generic model of learning underlying these types of multimedia/hypermedia systems is analogical, case-based learning-by-doing. Students navigate through a complex database, trying various strategies to reach an assigned goal. When their approaches fail because the mental model they have constructed of the task is inadequate, trainees can request help through following links or triggering answers to prestructured questions. Both the materials students access and the processes they utilize to acquire information reflect concepts and skills valuable in workplace settings. All the types of knowledge described in Section III (declarative and procedural, STW-process-based and occupational-role-specific) can readily be incorporated into hypermedia and multimedia, which are very flexible representational containers.

However, the instructional system is passive compared to CBT or ITS; the learner selects what to view and whether to seek help. While this type of student control may be motivating for many trainees, naive learners can waste substantial time browsing, utilizing relatively unproductive strategies to attain the desired goal, or ignoring help from the system that could aid their progress. Designing implicit structure into the task, the web of links, and the opportunities for help is crucial in guiding effective learning with multimedia/hypermedia applications.

Types of skills and concepts in each knowledge framework (rule-based, analogical, situated) that multimedia/hypermedia supports

Presentational multimedia/hypermedia applications support rule-based and analogical pedagogical models. Goal-based scenarios and similar "learning-by-doing" applications potentially support all three types of instructional strategies, but are strongest for analogical learning.

ANALYTIC FRAMEWORK

1. Goal and Use: What Actual/Potential Use of the Technology?

In terms of the analytic framework in Section V, multimedia and hypermedia are widely used on a presentational level in today's education and training settings; goal-based learning applications are beginning to emerge as research prototypes. These types of applications could be used to enhance every phase of the STW process, since learners can skim through rich, complex materials to find the specific knowledge they need or can practice skills via a goal-based scenario.

2. Track record: Evidence of Impact on Learners/Users?

Evaluation studies highlight student control, motivation, and fit with various learning styles as strengths of this type of technology (79, 80)]. Navigating educational webs also builds valuable information-finding and -filtering skills for the emerging high-tech workplace. However, as with other types of constructivist learning-by-doing, trainees floundering in a sea of complex information is a concern. In particular, learners with "field-dependent" traits (who need substantial structure and guidance) do less well with multimedia and hypermedia applications than "field-independent" learners (81-83).

3. Malleability: How "tunable" is the technology?

Multimedia and hypermedia are relatively malleable by both developers and instructors. With access to its underlying authoring tools, adding material to an existing application—or modifying its web structure—is relatively easy.

4. Integrative Potential: Will it help integrate the stakeholders?

Through weaving a network of pedagogical communications, this type of technology has some potential to integrate the activities of various stakeholders in STW processes. For example, links in a school-based web could lead to workplace experts and archives. However, such coordination will only occur as the result of deliberate, front-end design. The installed base requisite for this type of intercommunication is likely to develop, since equipment manufacturers are increasingly building hypermedia and multimedia capabilities into the core utilities of their machines. However, significant numbers of educational devices inadequately configured for the full capabilities of multimedia/hypermedia will persist into the early years of next century.

5. Cost: What does/will this cost and when?

Dropping costs for video-production technology enable the generation of add-on video clips with relative ease. However, because television and videogames are generating rising expectations of quality, learners expect high-production-value materials; these require substantial financial resources and design sophistication to create. In addition, since multimedia and hypermedia networks typically have no obvious boundary that constrains the knowledge they should contain to be "complete," developers can be trapped in a "black hole" situation of adding more and more information to an instructional web.

6. Commercialization: What will it take for the technology to bloom?

This type of technology is relatively mature; multiple authoring systems are available for presentational hypermedia and multimedia, and tools for constructing the types of goal-based activities described above are beginning to emerge. Various levels of capability, including sophisticated high-production-value authoring systems, can be purchased “off the shelf”; and coming generations of desktop machines will have the processing power needed for actualizing top quality computer animation, digital video and sound, and visualization tools for web navigation. The growing popularity of the World-Wide Web on the Internet is driving the rapid evolution of standards for distributed multimedia/hypermedia, as well as pushing down costs through generating a large installed base of users.

7. Implementation Barriers: What has to change?

Implementation barriers to the usage of multimedia and hypermedia STW applications are unlikely, since these technologies can be used either to automate traditional presentational instruction or to enhance constructivist pedagogy. However, any type of learning-by-doing curriculum will require greater flexibility in classroom time schedules, since this type of instruction does not uniformly fit into pre-specified, relatively short time periods. Also, student assessment strategies must shift because many useful outcomes of such instruction are better measured by portfolio-like evaluations or totally new types of assessments than by standardized tests.

SECTION VI. D. EVALUATING THE POTENTIAL OF COMPUTER-SUPPORTED COLLABORATIVE LEARNING TO SUPPORT THE TRANSITION FROM SCHOOL TO WORK

As defined in Section III of this study, computer-supported collaborative learning (CSCL) facilitates team performance through tools for communicating each person's ideas, structuring group dialogue and decision making, recording the rationales for choices, and facilitating collective activities. With the teacher's guidance, learners utilize these groupware tools to develop a shared mental model or to perform work-related tasks. In one scenario depicted earlier on how emerging technologies could aid school-to-work transitions, two trainees used collaboration tools to interact across distance as they repaired a communications groundstation. In a second scenario, through computer conferencing and electronic mail, a teacher's aide-to-be created a virtual community to provide intellectual and emotional support.

Collaborative Visualization project (CoVis): Institute for Learning Sciences, Northwestern University

An exemplary illustration of computer-supported collaborative learning applied to mastering work-related skills is the Collaborative Visualization project (CoVis) at Northwestern University's Institute for Learning Sciences (84) which is supporting study of the weather and its effects. High school students become "weather specialists" by using groupware tools to communicate across distance with other students, university researchers, and field-based scientific experts. The emphasis of this project is on atmospheric and environmental sciences—including meteorology and climatology—learned through shared scientific exploration and the use of visualization techniques similar to those employed by professionals.

The "collaboratory" workbench students utilize includes desktop video teleconferencing; joint software environments for remote, real-time collaboration; access to the Internet; a multimedia notebook with embedded templates for sharing ideas; and scientific visualization software. Through these media, learners determine authentic problems they would like to study (e.g., why is sand different in various locations?), identify people who can help them across distance, then use joint inquiry and shared design techniques to evolve answers to these problems. This provides both content knowledge potentially valuable in a range of occupations and generic process skills in inquiry and collaboration useful in any geographically distributed organizational setting.

Distant Mentor project: SRI International

A second leading-edge example of computer-supported collaborative learning targeted to enhancing the school-to-work transition is the Distant Mentor project at SRI International (85). Based on both a literature review and classroom field studies of the challenges in transposing skills from school to work, these researchers developed a conceptual framework, “cognitive mentoring,” for enabling workplace experts to mentor students in an apprenticeship-across-distance mode. In this “telementoring” strategy, mentors and learners pass through six stages: initiative, negotiation, diagnosis, execution, evaluation, and reflection. This model was validated through field studies of on-the-job learning, and prototype CSCL tools were developed to support student and mentor in each stage of their interaction across distance.

“Distant mentoring” prototype software has been constructed for training students in skills associated with the operation of a circuit board manufacturing line. This application allows people in two different locations on a UNIX network to interact with a manufacturing simulation (and, potentially, many other types of work-related models), while maintaining a conversation over a network-based audio channel. Small-scale laboratory experiments have validated that the graphical user interface and natural language input associated with this collaboration shell are easy to master. Further evaluation of this system’s effectiveness is in progress.

Teaching Teleapprenticeships: University of Illinois, Champaign-Urbana

Another project that enhances trainees’ skills through computer-supported collaborative learning links with distant workplace experts is the “Teaching Teleapprenticeships” work at the University of Illinois, Champaign-Urbana (86). This group is exploring several different types of teleapprenticeships for bachelor’s level teacher education students; these involve interactions with Internet-based resources, apprenticeships with practicing teachers, and mentoring K-12 apprentices from participating classrooms. A Learning Research Server with a suite of specialized CSCL tools has been developed to facilitate these diverse kinds of teleapprenticeships. These CSCL tools include email and computer conferencing facilities, as well as a shared, structured knowledge space for collaborative access to educational materials (e.g., documents, images, software, sounds, databases). These capabilities and pedagogical strategies that this project is evolving potentially generalize to a wide range of occupational preparation programs, through providing virtual collaboration facilities that allow workplace practitioners to aid in the preparation of students planning to assume similar jobs.

The researchers are conducting teleapprenticeship field studies using this computer-supported collaborative learning environment to ascertain which tools are most useful and how they could be improved. These studies include teleapprenticeships for elementary education students in an introductory biology class, in a science methods course, and in a pre-service student teaching program; secondary teachers-in-training participated in teleapprenticeships in an English student teaching situation. Preliminary results indicate that the students found the collaboration tools valuable in overcoming barriers of time and distance that impede learning outside the classroom setting. Increased access to workplace experts (practicing teachers) was also cited as a major advantage.

Classrooms with Electronic Walls: Apple Computer, Inc.

Research on “classrooms with electronic walls” that can be superimposed on real-world settings is another example of leading-edge work-related CSCL. By using notebook-sized computers, pen-based interfaces, wireless networking, and customized software, teachers can conduct field-based experiences in which students are physically distributed across an environment, yet linked together by shared data, collaborative discussion, and pedagogical guidance. In classrooms with electronic walls, the notebook computer carried by each student group accepts pen-based data input and continuously updates the information collected by all groups. Results are displayed on multimedia databases, spreadsheets, and geographic information systems customized to that lesson’s structure and are simultaneously available to all participants. Walkie-talkies allow communication among groups separated by distance. Camcorders and digital cameras enable collecting visual data for documentation and analysis. A cellular phone and fax link the field-based team to both instructional resources and learners at a variety of sites. All this empowers collaborative groups of learners to collect data about authentic phenomena with guidance from a virtual community of peers, teachers, and subject experts. In the last several years, Apple Computer has conducted small-scale field trials that demonstrate the technical feasibility of this distributed learning approach (87).

The capability to create these superimposable “classrooms with electronic walls” could be very useful in certain types of workplace training. As illustrations:

• Students in an economics class could gather consumer behavior data in different sections of a shopping mall.

• Newly hired employees evaluating health care delivery could disperse throughout a hospital to monitor simultaneously the progression of a patient and his paperwork, while tracking doctors, nurses, and others involved in treatment.

• Trainees studying technology could master descriptive modeling techniques while studying the interacting engineering infrastructure subsystems of a typical community (e.g. power plants, highways).

• Geography students could extend systematically in different directions to produce computer maps documenting zoning, traffic flows, concentrations of various types of businesses, pollution levels, soil types, cultural patterns within neighborhoods.

• Trainees studying ecology could spread through a canyon, simultaneously relaying data to each other on changes in different habitats with the passage of time.

In addition, through this pedagogical approach, students learning any field can acquire overarching skills in inquiry, research methodology, statistics, and mathematical analysis. Further, they can engage experts in real-time discussions of authentic phenomena.

Generic Underlying Learning Model and Pedagogic Supports

Any of the three models of pedagogy presented in Section III can underlie computer-supported cooperative learning systems. Peer tutoring via CSCL can be either instructionist/presentational or analogical/constructive. If expert advice is available, that can be delivered in either of the two forms just mentioned, or in a more situated-cognition format through mentor/apprentice relationships. The knowledge presented can be declarative or procedural, STW-process-based or occupational-role-specific. Typically, the CSCL tools embedded in an application will predispose interactions toward a predetermined type of learning model. For example, the Distant Mentor project is structured to suggest apprentice/mentor interactions.

Computer-supported collaborative learning tends to be motivating for many students who would otherwise be uninterested in educational technology. A wide range of participants are attracted to cooperative virtual environments because they gain something valuable by collaborating together. Social network capital (an instant web of contacts with useful skills), knowledge capital (a personal, distributed brain trust with just-in-time answers to immediate questions), and communion (psychological/spiritual support from people who share common joys and trials) are three types of “collective goods” that bind together virtual communities enabled by computer-mediated communication (88).

Types of skills and concepts in each knowledge framework (rule-based, analogical, situated) that CSCL supports

In terms of the analytic framework in Section V, CSCL systems are evolving from the “talking heads” format characteristic of unsophisticated distance education to suites of media and tools customized to different types of learning tasks. CSCL is a very flexible representational container that can enhance all three types of pedagogy, especially situated learning. Also, through watching virtual communities in action, CSCL researchers are beginning to identify new dimensions of learning styles orthogonal to the visual/auditory/kinesthetic/symbolic categories now underlying pedagogical approaches to individualization. For example, some types of trainees who don't do well in spontaneous spoken interaction (e.g., students who are shy, reflective, more comfortable with emotional distance) find that asynchronous, text-based communication better fits their learning style. For this kind of person, informal written communication via computer conferencing is often more "authentic" than face-to-face verbal exchange; lower bandwidth, cheaper groupware tools may work better for such students than high-end videoconferencing applications.

ANALYTIC FRAMEWORK

1. Goal and Use: What Actual/Potential Use of the Technology?

CSCL provides a powerful means of enabling/enhancing communication among learners, teachers, and workplace experts, as well as other stakeholders in the STW process. Through type of application, multiple perspectives are brought to bear in understanding situations, and learners can receive individualized intellectual and emotional feedback.

2. Track record: Evidence of Impact on Learners/Users?

Evaluation studies highlight many strengths characteristic of all collaborative learning: seeing issues from multiple perspectives, building skills in interpersonal communication, receiving emotional as well as intellectual support (89, 90). CSCL applications have more flexibility than face-to-face collaboration, however, as students and people serving as learning resources do not have to juggle schedules to be in the same place at the same time. On the other hand, "telepresence" does not fully convey the power of direct human contact, although it provides a means of educational communication when face-to-face interaction is not possible (91, 92).

3. Malleability: How "tunable" is the technology?

Computer-supported collaborative learning is a malleable medium, as flexible as the teams of people who participate in the virtual communities it enables. As the illustrative applications above indicate, the range of pedagogical strategies that can be implemented via CSCL systems is very broad.

4. Integrative Potential: Will it help integrate the stakeholders?

By facilitating intercommunication and shared activities, this type of technology has great potential to integrate the activities of various stakeholders in the STW process. As the installed base of computer-supported cooperative work tools grows, corporate and government sites will increasingly have information infrastructures into which CSCL capabilities can easily be incorporated.

5. Cost: What does/will this cost and when?

The standard telecommunications capabilities beginning to be utilized in many workplace and university settings will support CSCL applications, so infrastructure costs will be moderate (higher for schools and other institutions slow to implement videoconferencing-level bandwidth in their cabling). Ongoing support costs for metered interactions across distance could be significant.

6. Commercialization: What will it take for the technology to bloom?

“Groupware” technology for decision support, collaborative design, and telecommuting is rapidly evolving in workplace settings. As these applications mature, computer-supported cooperative work (CSCW) tools will become routine parts of most organization’s information infrastructures, especially businesses that conduct distributed operations in the global marketplace. Such an assimilation process will enhance capabilities, promote standards, and drive down costs through a large user population. Ubiquitous, inexpensive CSCW environments are a natural platform for overlaying STW computer-supported cooperative learning applications, such as those described above.

7. Implementation Barriers: What has to change?

Various implementation barriers to the usage of computer-supported collaborative learning STW applications may arise. Some people strongly resist being forced to modify their interpersonal style to work (or learn) with a group using technology-mediated communication. Ultimately, part of why CSCW approaches increase team productivity and effectiveness is that they constrain the range and style of interaction, thereby minimizing miscommunications. However, people limited to a small set of responses may view such systems as too constraining and strongly oppose their usage (5). To facilitate implementation, CSCL developers must find an appropriate balance between restricting individual flexibility and providing a common framework to encourage teamwork and knowledge sharing.

SECTION VI. E. EVALUATING THE POTENTIAL OF EXPERIENTIAL SIMULATIONS TO SUPPORT THE TRANSITION FROM SCHOOL TO WORK

As defined in Section III of this study, experiential simulations range from models that mirror the simplified essence of reality to elaborate synthetic environments with immersion interfaces that place students inside alternate virtual worlds. Simulations can provide a learning experience for a single student or can involve multiple students interacting in a distributed virtual environment. Their content can reflect real phenomena made less complex to enhance understanding or can embody virtual universes that operate on different physical and social principles than our world. In the vignettes presented earlier on how emerging technologies could aid school-to-work transitions, through full sensory immersion in a synthetic environment, a learner used a diagnostic device to repair a malfunctioning communications groundstation.

Virtual Corporate Setting: Advanced Learning Technologies Project, Carnegie Mellon University

One exemplary illustration of experiential simulation applied to learning work-related skills involves software engineering education; students are trained in a technical process, code inspection, that is one stage of a formal methodology for software development (93). Using hypermedia, Digital Video Interactive (DVI), and rule-based expert systems, the Advanced Learning Technologies Project at Carnegie Mellon University created a virtual environment similar to a typical corporate setting. The trainee interacts with this artificial reality in the role of a just-hired software engineer still learning the profession. Through direct instruction and simulated experience, the student practices the process of formal code inspection.

The learner can access various rooms in the virtual software company, including an auditorium, library, office, training center, and conference facility. Machine-based agents (knowbots) that simulate people, such as a trainer and a librarian, facilitate the use of resources to learn about the code inspection process. Via specialized tools in the office, the student can prepare for a simulated code inspection, in which he or she can choose to play any of three roles out of the four roles possible in this formal software review process. For each inspection, a rule-based expert system utilizes DVI technology to construct knowbots that simulate the three roles not chosen by the learner. This knowledge-based system controls the topic of conversation; determines who should speak next; and models the personalities of the knowbots in the inspection meeting, altering their cognitive and affective perspective depending on what is happening.

The learner uses a menu-based natural language interface to interact with these simulated beings, who model behaviors typical in code inspection situations. The student not only can choose from a wide range of options of what to say, but can determine when to make remarks and can select the emotional inflection of his or her utterances, from a calm passive tone to an aggressive snarl. By mimicking the reactions likely from human participants in a real simulation, the knowbots provide the learner with a sense of the strengths and weaknesses of different intellectual/psychosocial strategies for that role in a code inspection.

While the application built by this project focused on code inspection as the skill to be trained, through similar means preparation could be provided for a wide variety of work-related situations that involve social interaction within a limited range of formalized behaviors (e.g., learning to be a customs agent, developing skills in job interviewing). The educational effectiveness of this application was assessed both by the Southwest Research Institute and via a doctoral thesis at Carnegie Mellon University (94). The results of these evaluations document that this simulation is both instructionally effective and highly motivating for participants.

Multidimensional User-oriented Synthetic Environment (μuSE) project: Sandia National Laboratories

A second example of leading-edge work with experiential simulation to develop work-related skills is the Multidimensional User-oriented Synthetic Environment (μuSE) project at Sandia National Laboratories (32). As a means to depict complex relationships and enhance learning, a software shell has been developed that maps information into visual, auditory, and kinematic representations in an immersive interface. For example, a specialized microchip has been modeled through data fusion that conveys sixty simultaneous dimensions of information about the chip's dynamic operation. A virtual craft—much like a private office complete with a wide array of display, motion, and interactive capabilities—travels with learners as they explore and interact with this information. This interface modality allows students to teleport to, fly through, and dynamically attach the craft to the chip, the electrons flowing through it, the information traversing its circuits, etc.

Through learner-controlled representations ranging from computer-aided design (CAD) models and finite element meshes to signal variations in circuit simulations, students can learn sophisticated diagnostic techniques made more comprehensible by converting abstract symbols into sensory form. The Advanced Manufacturing Initiatives Department at Sandia is using the μuSE shell to develop a range of approaches to collaborative design and training in a computer-integrated manufacturing environment.

Other experiments with implications for work-related education include medical training via modeling CT scan data of the human brain, design education through allowing high school students to explore self-generated CAD models through the visualization capabilities of the µuSE shell, and the analysis of satellite digital terrain elevation data for insights about geology. Work on the µuSE interface is still in its prototype stages, so assessments of training effectiveness have not yet been conducted.

Remote Exploratoriums: Center for Lifelong Learning and Design, University of Colorado, Boulder

A third group using experiential simulation to enhance work-related skills is Fischer's Center for Lifelong Learning and Design at the University of Colorado, Boulder. Their "Remote Exploratoriums" project is designed to move students navigating the World-Wide Web beyond the passive role of viewing archives to the active role of manipulating simulations and models (95). The network-accessible exploratory design environments being constructed enable students to build artifacts; work-related learning environments already developed include a simulation world for electric circuits, a model of melting ice, and a virtual ocean ecology.

The underlying authoring application for these remote exploratoria is Agentsheets, a visual programming environment based on a grid system roughly parallel to spreadsheets and cellular automata. Agentsheets has been integrated into the World-Wide Web and "webcrawler" applications such as Mosaic to enable remote access and interaction. This work on distributed simulation environments is in an early prototyping stage, but research conducted on non-remote simulations constructed with Agentsheets indicates that students are motivated and engage in virtual design activities similar to those used by professionals in workplace settings. The optimization of remote, collaborative design tools to optimize workplace skills is also being studied by Gay's group at Cornell University (96).

Generic Underlying Learning Model and Pedagogic Supports

The generic model of learning underlying most types of experiential simulation systems is analogical, case-based construction of knowledge. Students try an approach; if it fails, they reflect on why, then "replay" using another strategy. In theory, situated-cognition pedagogical strategies could also be implemented in virtual worlds; this would enable the addition of powerful pedagogical strategies such as mentoring and apprenticeship. In practice, most synthetic environments have such low fidelity that achieving the psychosocial subtleties necessary to enable mentoring would be challenging. [One of the authors (Dede) is about to initiate exploratory research in using caricature to express subtleties of mood and sociocultural meaning (as cartoonists do).

Types of skills and concepts in each knowledge framework (rule-based, analogical, situated) that experiential simulation supports

All the types of knowledge described in Section III (declarative and procedural, STW-process-based and occupational-role-specific) can be incorporated into experiential simulation. However, this type of instruction works best for students who already have some background knowledge and wish to practice their skills. Naive learners just beginning to understand a subject often flounder in virtual learning-by-doing environments, leading to frustration. Students who need a lot of structure and guidance also tend to find experiential simulation confusing. On balance, this type of application is best for analogical and situated cognition styles of pedagogy and is not well suited to rule-based instruction.

In virtual worlds, interpersonal dynamics provide leverage for learning activities in a manner rather different than typical face-to-face encounters. For example, participants in synthetic environments often feel as if the machine-based agents they encounter are real human beings, an illustration of the general principle that users tend to anthropomorphize information technologies (97). As a complement to responding to knowbots as if they were human, participants in a virtual world interacting via avatars tend to treat each other as imaginary beings. As a complement to responding to knowbots as if they were human, participants in a virtual world interacting via avatars (graphical figurines representing the personal presence of each partaker in the synthetic environment) tend to treat each other as imaginary beings.

Perhaps because a synthetic social context is less mutually apparent than cohabiting a physical environment—and therefore less subject to consensual agreement—users experience both positive and negative disinhibition. Normally shy people speak out more, but usually polite people also “flame” more at others, hurling insults that they would never use face-to-face (98). While negative behavior must be channeled into isolated contexts that minimize damage to others, disinhibition is a potential lever for learning in constructivist environments, since this creates cognitive and emotional dissonance that can undercut suboptimal mental models. In the early stages of workplace training, disinhibition is also valuable in encouraging learners to ask “dumb questions” of workplace experts without feeling shy about showing ignorance.

Another psychosocial dynamic of virtual environments that opens opportunities to encourage learning is the fluidity of users’ identity. Prior communications media (the printed word, the telephone, the television) dissolved social boundaries related to time and space. Synthetic environments based on text and computer graphics dissolve boundaries of identity as well, enabling communication about very personal things through a depersonalized medium (99). Many aspects of this openness are quite positive from a constructivist perspective, as people often reject new ideas because they feel that their own identities are contained in their existing mental models.

However, the challenging side of personal revelation is that an avatar’s authenticity is always questionable due to the masking and distancing properties of the medium. The psychosocial fascination that experiential simulation induces is not always positive for participants. Some users find virtual worlds so compelling a medium that they fall into addictive behaviors (100). Being able to have interesting conversations with people on demand—any time of the day or night, with your own identify fluid—can induce communications addiction in some participants. Turkle (101) has studied which types of personalities may be most vulnerable to this form of addiction. This issues is important in the design of simulated environments for workplace training to ensure that learners stay on-task without being unduly distracted by social aspects of the virtual world.

ANALYTIC FRAMEWORK

1. Goal and Use: What Actual/Potential Use of the Technology?

Various forms of experiential simulation enable practicing already acquired knowledge and skills in simulated settings, collaborative learning and mentoring among “avatars” in a virtual environment, and sensory immersion into imaginary worlds that facilitate understanding reality through illusion. These capabilities could enhance many phases of the STW process by allowing the simulated performance of skills and the contextualized acquisition of knowledge.

2. Track record: Evidence of Impact on Learners/Users?

Evaluation studies highlight learner motivation and the enhancing psychosocial effects discussed above. However, concerns about addiction and about the floundering that naive learners experience are frequently expressed. Research studies that compare simulator training to learning the same skills in real world situations are beginning to appear. For example, a comparison of truck driving instruction in two types of simulators versus traditional driving instruction in real vehicles showed that the students trained via simulation often did better than the group trained in actual trucks (102). The primary reason advanced for the superiority of simulator training is that these virtual environments provide an intensive learning experience in which specific situations or problems can be rapidly reproduced as often as necessary to attain mastery. Simulators also allow the isolation of various forms of input (e.g., the traffic observable through the windshield and through the truck’s rearview mirror, the data from the instrument panel) to avoid initial overloading of naive trainees and to enable step-by-step mastery of complex skills. Such advantages of simulation generalize to a wide spectrum of training work-related skills.

Also, Loftin (103) used immersive virtual environment technology to construct a model of the Hubble Space Telescope and to train astronauts, flight controllers, and mission specialists in the cognitive elements of the repair procedure. Approximately one hundred members of the repair mission teach received over two hundred hours of training using this virtual environment. After-mission studies showed that the trainees found this virtual reality learning experience to be valuable in enhancing their performance in the actual mission. Evaluation studies of collaborative (rather than individual) training in experiential environments are just beginning; Fletcher (104) presents an overview of assessment models for networked simulation.

3. Malleability: How "tunable" is the technology?

This technology is fairly malleable in content for the teacher. An increasing number of educational simulation environments contain embedded authoring tools that allow an instructor to add examples and even to modify the underlying model. As an illustration, the pedagogically popular SimCity application published by Maxis allows users to create and save their own cities, each with distinctive assumptions about urban dynamics. However, seldom do teachers have complete access to the full range of authoring tools used by designers of simulations, so their ability to alter content and rules is somewhat constrained.

4. Integrative Potential: Will it help integrate the stakeholders?

Through constructing virtual environments that encompass disparate stakeholders in the STW process, this technology has some potential to integrate their activities.

5. Cost: What does/will this cost and when?

In contrast to high-production-value multimedia/hypermedia, the costs of building educational applications using experiential simulation can be relatively low. Systems for authoring single-user simulations have become quite powerful, enabling rapid construction of models that can involve learners for many hours of interaction. Most of the underlying telecommunications tools and standards for enabling distributed simulation have already been developed by the U.S. military, and databases of various virtual objects that can be used to create synthetic environments are constantly growing. Under these conditions, the resources needed to author new learning experiences are modest, since the interactions among learners themselves creates much of the instructional content. This stands in sharp contrast to the expensive teams of domain experts, instructional designers, programmers, and interface developers needed for building high-end multimedia applications. Moreover, user expectations for fidelity in artificial realities tend to be modest, as opposed to the elegant video and animation demanded in multimedia by learners accustomed to high- production-value commercial television and movies.

6. Commercialization: What will it take for the technology to bloom?

Experiential simulation is in its early stages as an instructional medium, especially in distributed or immersive form: This technology is still relatively immature. The military has substantial experience with a limited type of distributed simulation related to virtual battlefields, but outside of that area few standards have emerged for designing and developing synthetic learning environments. Defense conversion funding is one possible vehicle to shift over protocols and ideas from military uses to STW applications; commercialization by military contractors is another possible model for transfer, but will be much slower without government leveraging. Moreover, expertise in instructional design appropriate for immersive learning-by-doing situations will take time to evolve, as conventional instructional design theories are based on a completely different set of pedagogical assumptions and technological capabilities.

Unlike multimedia/hypermedia or groupware, little workplace leverage exists for creating a large user population involved with experiential simulation, since distributed simulation is not routinely used in work today to the degree that are multimedia/hypermedia and groupware. Further, vendors are not routinely building distributed simulation capabilities into their operating systems, network protocols, and information infrastructures, as they are with multimedia/hypermedia and groupware. As a result, the major installed base for STW applications of this technology will likely come from videogames, which widely accepted market estimates indicate will have a strong installed base in homes. In the near term, the costs of implementing distributed simulation systems are likely to remain relatively high, especially for environments with full sensory immersion.

However, text-based virtual environments (e.g., MUDs) are gaining in popularity on the Internet; as these develop graphical capabilities, a large, experienced, and committed population of advocates may emerge. Researchers are beginning to explore whether even these low-end environments can enhance generalizable occupational skills (e.g., effective written communication), social capabilities and attitudes valuable in workplace settings (for example, teamwork, motivation to contribute to an organizational environment larger than one’s immediate context), and a qualitative sense of what working in a particular type of institution might be like (e.g., modeling working in a hospital modeled via a simulated hospital).

7. Implementation Barriers: What has to change?

The continued evolution of powerful and easy-to-use modeling tools will aid widespread creation and utilization of experiential simulation environments. However, the most severe implementation barriers to this type of educational technology occur after the development phase, as such learning-by-doing activities require different pedagogical skills than standard instructional practice, need greater flexibility in classroom time schedules, and necessitate shifts in student assessment toward sophisticated, outcome-based measures. For example, guiding students in how to succeed in a virtual factory setting is better done by modeling and coaching than by lecture (c.f. the Jasper multimedia evaluations described earlier in this study). Further, transactional learning experiences in such a setting do not necessarily fit neatly into forty-five to fifty minute class periods, nor are the knowledge and skills students master completely assessable through multiple-choice standardized tests.

SECTION VI. F. EVALUATING THE POTENTIAL OF COMPUTER-BASED LEARNING ENABLERS TO SUPPORT THE STW TRANSITION

As defined in Section III of this study, computer-based tools as learning enablers include a spectrum of capabilities that enable various types of "distributed intelligence", which allows the learner to more effectively acquire concepts and skills via the tool assuming some of the cognitive load. The designer creates a tool that complements some aspect of human cognition and is optimized to aid mastery in some conceptually challenging situation. In the vignettes earlier, a teacher's aide-to-be used a "webcrawling" tool to access distributed materials for science education, and a trainee learning electronics repair used an information visualization aid to image a complex network of diagnostic resources.

A few current examples of such tools are specific to work-related education or supporting the STW transition. For example, Mei Technology developed an Integrated Maintenance Information System (IMIS) as a job aid for aircraft maintenance technicians; this system is now being extended to become a computer-aided-training system (105). Below we discuss many possible future applications and evaluate them via our analytic framework.

Professional Design and Visualization Tools for Use in Training: Developing Educational Support Systems for Commercial-Off-The-Shelf Software (ESSCOTS)

Professional design, simulation, and visualization tools enhance learning by both providing the human perceptual systems (vision, hearing, touch) with more integrated information and also providing other cognitive analytic support to ease the process of finding meaningful patterns in large amounts of information. Work on turning visualization software, or other software tools used by professionals, into educational supports involves wrapping easy-to-use interfaces and exploration support tools around the existing software tools. This ideas has been called Educational Support Systems for Commercial Off-The-Shelf software (106). .An example is building a learning environment around a commercial Geographic Information System (GIS) that allows 14 year-olds to look for patterns in real social, demographic, and public health data from counties in the United States. Tools to aid that visualization were built, including automatic "hot spot" color-coded maps of the variable values in each county, with hotter colors representing higher values and cooler colors representing lower values. A second example is using an existing, government-funded simulation of a developing country (originally built for policy analytic purposes) as the core of a simulation-based environment to teach why people might rebel against their governments, such as occurred in 1776. In this case, a theory for how complex social, political, and economic factors interplay can be explored through multiple experiments.

Now imagine that tool in the hand of an employee in on-the job-training at a highly automated, employee-owned specialty steel mill in Ohio. To gain a better sense of the need to maintain high quality standards, understand her company's international competitiveness and inform her vote on management issues that worker might use such a tool to explore data regarding changes in international steel prices, displayed geographically, to understand the effects of foreign “dumping” of steel into US markets. Another ESSCOTS for CAD software might allow workers to understand or improve the layouts of their shop floors or production processes. An ESSCOTS for graphical data might allow a machinist in training to examine her data for possible three-way interactions in the quality control data her class had collected over the last 2 weeks of training on a CNC lathe. She can explore her intuitions that something was occurring with one of the machine’s tolerances when working with certain kinds of metals while being cut by certain types of tools.

Extending Learning Through Intelligent Agents: Knowbots and "Webcrawlers" for Searching the Internet

Learners preparing for work could use help finding appropriate opportunities for both training and employment. Imagine that you are an job-seeker who is nearing completion of your training as a health technician, specializing in a certain type of equipment and application area. As you get within months of graduation, instead of sending out resumes, you instead send out a custom tailored, autonomous data-gathering-and-depositing agent that will continuously wander through machines on the Internet with job postings, searching for a position exactly fits your interests and strengths, anywhere in the country. The agent reports back via email on near misses to see if you are interested in applying and--if the job meets the requirements--drops off multi-media resume information and pointers to examples of project work at the training institute’s site. Such thoughts, though seemingly far-fetched, are not far from commercial realization. For example, a web site now exists that collects information on current “world wide web robots, wanderers and spiders” This site at:

http://web.nexor.co.uk/mak/doc/robots/robots.html

catalogs some primitive agents, but the list is apparently growing. There are also recent books by Kennedy and Morrow titled: “Electronic Resume Revolution: Create a Winning Resume for the New World of Job Seeking” (107) and "Electronic Job Searches

Revolution: Win with the New Technology that's reshaping today's job market"(108). Electronic job posting and even electronic "headhunter" or job posting firms currently exist on the Internet, aimed primarily at college graduates (see

http://www.careermosaic.com/cm/

for a well-designed commercial advertising firm's homepage). This is not new; jobs have been posted on the Internet since it was the ARPAnet.

Again, all these tools decrease a learner's cognitive load and allow him/her to focus their mental resources on the underlying material to be learned. For example, machine-based "agents" with artificial intelligence can automate simple classification, reply, and retrieval tasks in accessing databases on a network, freeing learners to focus on creative interpretation of the information they are receiving.

Generic Underlying Learning Model and Pedagogic Supports

Interestingly, the ESSCOTS work views the role of supporting learning as providing students with powerful tools that enable more productive and better supported explorations. The underlying learning model is a blend of rule-based and situated cognition, for the tools are meant to allow students to practice the skills of problem finding, question definition, and scientific discovery. However, the tools are also designed with pairs of students in mind to capitalize on the social aspects of exploratory learning. The data for the GIS ESSCOTS pilot was also specifically developed to be meaningful to students of this age. Based on a choice of variables, young teenagers from a local ethnically diverse middle school chose to explore patterns of data in income, gender, high school graduation rate, teen pregnancy, crime, and ethnicity. The fact that this is actual data on our country appeared to add to the motivation to explore.

Given the social setting and the data driven nature of the learning, such tools could also be argued to support a situated approach to learning. The pedagogic supports for ESSCOTS and autonomous agents are minimal. In the case of ESSCOTS, the pedagogic supports were planned to be self-documenting traces of exploration to support reflective learning after an exploration.

Types of skills and concepts in each knowledge framework (rule-based, analogical, situated) that ICAI supports

Again, a mix of rule-based and situated learning is taking place with ESSCOTS. Not only are students learning to use the tool itself, but they are learning a number of higher order thinking skills, or what have been termed "generic" skills for the workplace (109). These include social cooperation skills, task management, and help seeking.

ANALYTIC FRAMEWORK

1. Goal and Use: What Actual/Potential Use of the Technology?

Based on our process model of the STW transition, these learning enablers appear to have roles in several of the phases we define. The ESSCOTS clearly seem to support training goals found in pre-employment education institutions as well as in on-the-job training. The autonomous agents have clear applications in seeking specific job opportunities as well as seeking appropriate training opportunities. If appropriate career or occupation-related information existed on the Internet, autonomous agents might eventually replace CIDS as a source of career data. Instead, autonomous agents would wander the net with a profile of the owner searching for interesting careers and returning with that information, future job predictions in the domain, as well as predictions about where such jobs will be geographically located. As all information becomes distributed, applications will evolve that effectively search this sea of information and retrieve that which is relevant.

2. Track record: Evidence of Impact on Learners/Users?

To date, we could find no data on the impact of such tools on learners.

3. Malleability: How "tunable" is the technology?

If designed properly, an ESSCOTS should have the interface code accessible to the moderately trained programmer. With progress on direct manipulation programming interfaces, little future need may exist for detailed programming expertise to change the environment in which a learner is exploring.

Future autonomous agents will be highly tunable by the individual owner, much in the way that current word-processing software will allow you to tune your writing environment to match a writer's preferences.

4. Integrative Potential: Will it help integrate the stakeholders?

There is no clear promise that any of these applications of enabling tools will help to integrate of the STW transition stakeholders.

5. Cost: What does/will this cost and when?

The high cost of developing exploratory learning environments from scratch was one of the original motivators for the ESSCOTS work. Given the rise in good macro packages that accompany COTS, the growing ability to communicate between software packages, and the growth in commercial front-end development tools, the costs of ESSCOTS development will continue to decline. Their costs should be below both those of CBT and ITS development.

The costs of autonomous agents on the Internet will eventually be small fees for access to some generic, tunable agent software, as well as some fees for the time the agent spends on the network. Both costs will be relatively low.

6. Commercialization: What will it take for the technology to bloom?

ESSCOTS technology is still largely undemonstrated. Although commercially viable in terms of lower development costs, more research work is needed to better define what tools would best support different types of learning. A federal role may be needed to heighten incentives for commercial firms to make educational versions of their software available.

Webcrawlers appear to be evolving in the academic world. Increasing demand for such data retrieval and integration tools is leveraged by the growing resources available around the Internet. Commercial firms are developing increasingly semi-intelligent search tools at this time, so no public support is needed to develop autonomous agents. As data access and filtering challenges expand, the market for commercially available agents will grow.

7. Implementation Barriers: What has to change?

The strongest barriers to ESSCOTS development appear to be in the area of getting rights to use the commercial software, at a reduced price and capability, for educational applications. At RAND, the pilot work with a GIS worked on a small, experimental scale with a very agreeable software firm, but other ventures to secure permission to develop even an experimental version of proprietary software have been extremely slow and cautious on the part of companies: They lack incentives to make educational use of their software.

The largest barrier to autonomous agents to support the STW transition is currently the lack of available information on the Net. As the amount of distributed, training and job-related information increases, we foresee commercial firms arising to sell agent software. Such software will probably come with a limited or renewable life.

SECTION VII. POLICY OPTIONS FOR ENHANCING THE DEVELOPMENT OF TECHNOLOGIES THAT ENHANCE STW TRANSITIONS

Overarching policy themes that affect all types of school-to-work transitions are the evolution of information infrastructures, incentives for information sharing, equity, and the implementation of new models of teaching/learning. Since this study centers on technology drivers for STW processes, this discussion will focus on those policy issues most closely related to that topic.

Hardware, software, and infrastructure evolution issues are concerned with how government sponsorship and regulation of high performance computing and communication technology development poses challenges and opportunities for participants in occupational training. **Information sharing and public/private partnership issues** center on how various stakeholders in the STW process can be encouraged to function in an integrated manner for human capital development. **Equity concerns** focus on ways that powerful learning technologies can narrow-- not widen-- existing gaps in work-related educational opportunities and outcomes. **The implementation of new models of teaching/learning** involves policy issues such as financing educational technology infrastructure in schools and in the workplace, integrating technology usage into the training curriculum, and aiding instructor growth not only in utilizing technology, but also in new models of pedagogy and learning.

Policy Options: Hardware, Software, and Infrastructure Evolution Issues

The major infrastructure-related policy issues for school-to-work education center on how government sponsorship and regulation of the emerging National Information Infrastructure influence the technology options of STW educators. Educational perspectives are often underrepresented on the various bodies designing, funding, and regulating the National Information Infrastructure; for example, only two of the thirty-seven members on the U.S. Advisory Council on the NII are educators. This can create problems because sometimes the impact of a proposed policy on education is understood only by those familiar with that field. For example, the Federal Communication Commission’s May, 1995 decision to allow unrestricted voice messaging in the 920-978 Mhz range of the electromagnetic spectrum will adversely affect potential educational uses of the emerging “classrooms with electronic walls” wireless devices discussed earlier.

Potential policy initiatives an advocate of moderate government intervention might consider include:

- As with other types of computing and networking technologies, government policies (e.g., investment and depreciation incentives, matching funds programs) could be used to encourage vendor development of software applications specialized for occupational instruction, job-finding, and other types of STW training. Similarly, some software originally developed for military purposes (e.g., multimedia authoring systems, distributed simulation architectures) has potential for redesign to advance STW applications. Matching funding could be provided to encourage the private sector in developing STW products that build on existing related military applications.
- Resources for the development of and studies on new types of pedagogical strategies (such as data visualization) could be provided, as could funding for research on the relative effectiveness of different kinds of STW education.
- Sophisticated software requires a computational and telecommunications infrastructure much more powerful the existing installed base in schools and in the training sectors of many businesses. Particularly for rural and old urban schools, as well as small businesses, the financial challenges involved in retrofitting individual classrooms could threaten educational equity. Targeted financial aid and specialized information resources could be provided to organizations-in-need to address this concern.

A low-intervention-by-government approach would argue that, when sufficient need arises, the free market will generate profits sufficient to encourage development of all these capabilities, with no need for governmental intervention. In contrast, a moderate-intervention strategy would posit that “priming the pump” is important to encourage the initiation of these various forms of infrastructure and instructional STW applications, since no single organization may have a critical mass of internal resources to develop initial, generic capabilities foundational for development in this area. Such a moderate-intervention position might also argue that populations historically under-served by free market processes will continue to struggle with STW processes unless some form of government intervention were to build their capacity as a self-sustaining market.

To accomplish the three types of STW technology initiatives just described, government policies could also be initiated to encourage STW-related partnerships between public education and the private sector. The policy instruments that could be used are illustrated by the dual-use grants and contracts the U.S. Department of Defense has provided over the past few years; these encourage government-business alliances by funding the development of products that can serve similar purposes in military and civilian sectors (e.g., a portable device that might aid communications both on a battlefield and for police activities). As another illustration of government policies that aid public/private partnerships, the National Institute of Standards and Technology, U.S. (NIST-ATP) initiative in Learning Technologies. The NIST-ATP efforts provide federal support for private industry to develop emerging technologies not quite yet robust enough for marketplace consumption. The Department of Commerce matches industry expenditures on commercial development, thus leveraging private funding; in the case of learning technologies, such an initiative could enable government support for educator/industry coalitions to create new approaches to STW education. The federal programs just described are primarily oriented to developing hardware and software capabilities for enhancing physical infrastructures; comparable programs could be initiated by other agencies to build social infrastructures. For example, the National Science Foundation's program on Networking Infrastructure for Education funds alliances among businesses, vendors, and schools to create educational uses of information infrastructures. This NSF effort centers on developing human resources and conducting research and evaluation studies on promising educational applications of high performance computing and communications. As another illustration, the National School Network Testbed (funded by the National Science Foundation) is creating a web of schools with advanced telecommunications capabilities and skilled teachers. Such a network of sophisticated educators could attract partnerships and investment in STW activities by industry, as well as local, state, and federal agencies. Without any public funding, regulatory, tax, and depreciation incentives could also be provided by government to encourage partnerships among educators, businesses, and vendors for the types of STW infrastructure activities described above. The Rural Electrification program provides good examples of the types of public policies proven effective in encouraging infrastructure development. However, for low-government-intervention advocates, all these types of alliance-related policy initiatives raise issues of public intervention in free market mechanisms and incite concerns about commercial interests biasing the training curriculum (e.g., Whittle’s Channel One project). On balance, despite these concerns, the authors favor a moderate-intervention strategy.

Policy Options: Incentives for Enhanced Sharing of STW-relevant Information

If STW stakeholders were to have ready access to better decision-relevant information and the skills to take advantage of that information, the overall STW process (as outlined in Section III and pictured in Figure 1) would function more effectively. Below we address how each stakeholder might benefit from such STW-relevant information and present possible policy options that create incentives for improved sharing of this data.

- For Career Seekers moving through the STW process, access to better STW-relevant information enables them to minimize the amount of time they spend searching for a career, searching for appropriate training, restarting training or changing training institutions, searching for a job, and shifting from one employer to another. Such information may also possibly promote greater longevity in a job.
- If schools have better access to information about the training needs of employers, they could more effectively meet those needs through curriculum design and teaching emphasis. This tailoring could place them at a competitive advantage in the training provider market: they would have a better job placement rate.
- If employers better communicate their training needs and job openings, as well as having strong internal educational facilities that improve the skill base of entering workers, they stand to both attract and retain more appropriately skilled workers.

In sum, improving access to decision-relevant information could reduce the STW process time and produce more appropriately trained job candidates. The various markets would be able to function more efficiently and could result in financial saving to the economy. From a policy perspective, the question is whether and how to provide government incentives for the various stakeholders to make relevant information more widely and readily available. Several policy options to accomplish this goal are outlined below.

The first option is for various levels of government to carry out general informational outreach to schools and employers through agents such as the National Occupational Information Coordinating Committee (NOICC), the State Occupational Information Coordinating Committees (SOICCs) or other pertinent existing federal or state organizations with access to STW stakeholders. Such outreach could highlight the potential benefits of taking advantage of various information resources to communicate STW-relevant information. The public good in making such information available is the relatively low cost relative to potential future savings in time and training/retraining efforts. A moderate-intervention-by-government stance would posit that a private service providing this type of informational integration is unlikely to emerge without initial government support. In contrast, those who favor low governmental intervention would argue that a market will spontaneously emerge for these information integration services when their utilization is sufficiently worthwhile for stakeholders to invest in such activities.

A second, non-exclusive option is to use existing sources of federal and state moneys as leveraging points to encourage schools and employers to make more information available. An example is tying work-related training institutions' acceptance of federal tuition training dollars to information communication requirements. Occupationally-focused schools might be required to make publicly available (even electronically available) information about student placement and starting salary records, instructor credentials, and course syllabi. If a company were a government contractor, that organization could be required to make job slot and hiring information available, as well as forecasts of future needs for skills.

Both these types of policies might be advocated by those who favor moderate governmental intervention. However, a low-intervention strategy would argue that such regulation would be an unfunded mandate unlikely to generate benefits commensurate with its costs. On weighing existing evidence, the authors feel that moderate government intervention is warranted in this situation.

Policy Options: Enhancing Equity and Access

In terms of equity, all new media initially reduce equal opportunity; those who first have access to innovative, powerful capabilities gain an advantage over members of society who do not. In time, as the technology matures and is universally available, that inequity erodes and the gap between haves and have-nots narrows. The dissemination of the telephone is a good example of this evolution.

Unfortunately, enhancing equity via educational technologies is not so simple. Computers are more expensive than telephones: Households with incomes of $50,000 or more are five times more likely to own a personal computer and ten times more likely to have access to on-line services. In a survey of college graduates with children, 49% had personal computers, compared to 17% of homes in which the parents had only high school diplomas (110). Telecommunications services have higher penetration into homes: 92% of American homes do have a telephone, and 98% have a television (with a growing proportion linked to cable services). However, computer-based gaming systems (e.g., Nintendo, Sega) may alter this balance, as quite powerful computational platforms are becoming commonplace in homes via the entertainment industry.

In schools, students and teachers have more access to computers than telecommunications. Almost all U.S. students now spend at least a few minutes per week interacting with a computer, but less than ten percent of classrooms have telephones. 75 percent of schools have computers with some type of telecommunications capabilities, 74 percent have cable TV, 70 percent have broadcast TV, but only 35 percent of schools currently have any Internet access (111).

Small and even moderate sized businesses also typically have few technology resources to invest in training facilities, reducing potential access to the STW applications depicted in this study. Providing all learners with access to equipment that enables equal usage to high-end STW applications is very challenging, yet students who participate in these services may gain a lifelong advantage over those who do not.

A moderate-intervention-by-government stance on equity would support policies that stress open access regulation of the National Information Infrastructure, rather than simply scaling up traditional approaches to universal service (112). To limit the maximum gap between have and have-not students in access to powerful technology-based resources on STW, the minimum cluster of training services made available via the NII for all participants could steadily increase in its functionalities as hardware and software capabilities advance. Ensuring that telecommunications infrastructures are installed at equal rates in rich and poor neighborhoods would be a related policy intervention, as would funding programs that enhance the ability of institutions-in-need (both schools and businesses) to purchase STW-related training technologies. However, an advocate of low intervention by government might argue that equity is a local responsibility and should not be accomplished through national-level regulation or support of telecommunications infrastructure implementation. The authors believe that a moderate intervention approach is needed to minimize the widening of already troubling gaps between haves and have-nots.

Policy Options: Facilitating the Effective Implementation of STW Technologies

Programs that disseminate to schools and businesses model approaches for training technology integration and budgeting could reduce common mistakes in implementing STW initiatives. For lack of access to “lessons learned” from prior educational technology implementations, typical problems are reiterated at numerous organizations. In schools, these mistakes include isolating networking and computer technologies into special labs and rooms rather than integrating these into classrooms throughout the building, as well as not making on-going technology costs--including equipment depreciation--part of the regular budgeting process (113). Businesses too often rely solely on “talking heads” approaches that simply automate conventional classroom instruction, not realizing the many suboptimal characteristics of this pedagogical strategy (114).

The U.S. Advisory Council on the NII is considering a recommendation that a National Clearinghouse on Educational Usage of the NII be established. Government funding could be provided to ensure that STW technologies do not encounter the same barriers to success as prior types of instructional technology. However, a low-intervention-by-government advocate would likely see these implementation issues as a local concern to be solved by individual and private initiatives rather than a government-sponsored project. Again, the authors believe that a moderate intervention strategy is warranted.

Coordinating Policy Initiatives at Various Levels of Government

All of these types of policy initiatives are interconnected. As one example, regulatory, investment, and depreciation policies have a strong influence on the potential success of public/private partnerships. For this reason, regardless of one’s stance on government intervention, coordination of federal, state, and local interagency policy initiatives is vital.

SECTION VIII. SHORT SUMMARY

The core challenge of school-to-work education today is to prepare today's students for a future workplace more disparate from present experience than at any time since the Industrial Revolution. Our economy is shifting away from smart machines automating human labor to manufacture standardized commodities. Instead, people increasingly are working in partnership with intelligent tools to create customized products and services. As this transformation to a post-industrial, "knowledge-based" economy occurs, an evolution of job requirements toward higher-order thinking skills is taking place in all types of occupations, blue- as well as white-collar. Sophisticated information technologies can provide the leverage to make evolution to a new educational model possible; the same advances that are transforming the economy can empower new models of teaching/learning to facilitate the transition from school to work.

This study describes a "process" view of the "school-to-work" (STW) transition and key stakeholders:

- people seeking a career, training, and employment ("Career Seekers")
- providers of career counseling information
- providers of training and accreditation
- labor organizations
- employers

Providers of curricula and training technologies are also lesser stakeholders.

The STW process consists of five phases: Search for and selection of an appropriate career; Search for and selection of an appropriate training institution/program for that career; Acceptance into that training program and successful completion of the course of study and related accreditations; General preparation in competing for a job, as well as skills and information on seeking and acquiring a job in that career area; and Good performance in new position, further development of work-related skills (work-based learning), attitudes, and habits while on the job, and preparation to adapt to future jobs.

We divide information technologies that could facilitate STW-related learning into six categories: Presentational computer-based training/computer-assisted instruction; Intelligent tutoring and coaching systems; Multimedia/hypermedia; Computer-supported collaborative learning; Experiential simulations; and Computer-based tools as learning enablers. Our findings about the potential utility of these technologies are briefly summarized in Table 3 of the study.

Overarching policy themes that affect all types of school-to-work transitions are the evolution of information infrastructures, incentives for information sharing, equity, and the implementation of new models of teaching/learning. Policy options that may speed the development and incorporation of these technologies into work-related education include:

- **Matching funds programs and investment and depreciation incentives** to encourage vendor development of software applications specialized for occupational instruction, job-finding, and other types of STW training
- **Resources for the development of and studies on new types of pedagogical strategies** (such as data visualization) could be provided, as could funding for research on the relative effectiveness of different kinds of STW education
- **General informational outreach to schools and employers** through agents such as the National Occupational Information Coordinating Committee (NOICC), the State Occupational Information Coordinating Committees (SOICCs) or other pertinent existing federal or state organizations with access to STW stakeholders
- **Using existing sources of federal and state moneys to encourage schools and employers to make more information available** by tying funding to such actions
- **Stress open access regulation of the National Information Infrastructure**, making a minimum cluster of training services available via the National Information Infrastructure, ensuring that telecommunications infrastructures are installed at equal rates in rich and poor neighborhoods, and funding programs that enhance the ability of institutions-in-need (both schools and businesses) to purchase STW-related training technologies
- **Disseminating to schools and businesses model approaches for training, technology integration, and budgeting**

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