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ABSTRACT

A literature search that included project reports, overviews, software reviews, and other sources from a variety of settings and a focus group meeting of vocational educators were conducted to determine developments in computer-based education, their applications to vocational education, and barriers to the use of computer-based technology in the field. Following a section discussing the scope of the review and the issues identified in educational uses of computers (teacher's role, motivation, and gender issues), this report presents the outcomes of the study in four additional sections. Section 2 describes the strengths and weaknesses of existing computer-assisted instruction as a point of comparison for the emerging classes of tools. This discussion is followed by an overview of new optical disc technologies for delivering multimedia instruction. Section 3 classifies emerging computer technologies, using examples from the literature, and summarizes the strengths and weaknesses of each. Also included is a subsection that reviews the vocational education literature on the same technologies. Section 4 discusses the results of the focus group interviews to assess the feasibility of adopting the new technologies. Section 5 summarizes the findings and includes recommendations for how vocational educators can prepare for the emergence of these educational tools and participate in their development. A table provides an evaluation of emerging computer-based tools. Appendices include a tabular summary of selected literature, its focus group questionnaire and 242 references. (KC)

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Matthew W. Lewis

RAND
Santa Monica, CA

National Center for Research in Vocational Education
University of California at Berkeley
1995 University Avenue, Suite 375
Berkeley, CA 94704

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PREFACE

This Note is part of the National Center for Research in Vocational Education's ongoing effort to track advances and innovations in educational methods and tools. It is intended to serve as a resource for interested members of the vocational-education community, from classroom instructors through administrators. It provides an overview and discussion of emerging trends in computer-based educational tools and their current and potential uses in a broad range of vocational education settings. This Note also addresses potential barriers to development and implementation of new educational technologies for vocational settings and suggests some ways to overcome those barriers.

SUMMARY

The training needs of America are growing and changing. Changes in the workplace have increased or will increase the necessary levels of skill ("upskill") for many job categories. Responsibility, quality control, and corporate decisionmaking are becoming more distributed. Employees are being required to adapt to organizational and technological changes as American industry adapts to a more variable and competitive world market. Acquiring the skills to adapt demands retraining: The American Society for Training and Development predicts that, by the year 2000, 75 percent of workers currently employed will need retraining. Many corporations and the military are increasingly moving toward a reliance on advanced technologies to meet this challenge. One of the principal educational technologies in this movement is the computer.

FINDINGS

Based on a limited review of the literature in the field and a focus group with vocational educators, the following issues and findings are relevant to future applications of the emerging computer-based tools to a broad range of vocational education settings.

Four classes of tools are emerging from research settings with potential benefits for use in vocational education. Each class is appropriate for different goals, subject areas, and learners and promises to support the higher-order thinking skills demanded by the changing workplace.

1. *Intelligent tutoring systems* support the acquisition of well-specified skills by providing strong guidance and requiring little prior knowledge from the learner. These systems, which use artificial intelligence programming techniques to simulate some aspects of good human tutors, have appeared primarily in experimental uses to date, but promise to play a role in technical training in the future.
2. *"Microworlds,"* a type of simulation, support exploratory learning of well-understood content areas while supplying limited, implicit guidance to the learner. They make moderate demands on students to structure their own learning experiences. Their primary purpose is to help the student develop a

deep understanding of the underlying relationships in the microworld and to provide practice with discovery learning skills. Microworlds have to date only been used in a limited, experimental way in work-related education. Although their potential for training use appears high, their final impact on vocational education remains an open question.

3. *Hypermedia environments* support the exploration, construction, understanding, and communication of complex webs of related information. However, they require a good deal of student initiative and provide little guidance to the learner. Hypermedia environments to link information (prose, images, audio, and audiovisual) in ways that are unlike traditional, linear formats are being experimented with widely in academic education, but vocational applications currently appear to be rare. Because of low start-up costs, the development and use of hypermedia for vocational education will likely increase greatly, including use as access to multimedia reference materials.
4. *Collaborative learning environments* strongly support cooperative learning, communication, and group problem solving. Any guidance is provided by the other collaborators, whether they are other learners or teachers, instead of from the system itself. These environments can be used as a tools to support the learning of any domain with moderate demands on the learner. Few examples exist in vocational education, and their future role is generally unclear, with the exception of applications to geographically isolated populations.

The emerging tools show promise for educational effectiveness. There is strong evidence of the educational effectiveness of earlier, less-sophisticated computer-assisted instruction. This evidence, combined with preliminary positive experimental results from applications of the emerging classes of tools, suggests their strong future educational potential.

The new educational technologies may support the acquisition of the "higher-order thinking" or "generic skills" increasingly demanded by changing workplaces. The Conclusions section explicitly links changes in the work environment to the skills those changes require and the tools that appear to support learning those skills. However, the ability to support acquisition of these skills remains to be convincingly demonstrated.

Collaborative learning environments have the potential to benefit geographically isolated vocational student populations. By providing the possibility for educational interactions that bridge distance and time barriers, such environments potentially provide inexpensive "teleapprenticeships" for inner-city or rural students with limited opportunities for actual apprenticeships in fields of their choice.

Developing mastery of classroom use of any computer has two components and takes significant amounts of time. Teachers that effectively use classroom computers have (a) mastered the computer hardware and software and (b) mastered integration of computers into a teaching style and curriculum. Results suggest that developing the mastery required for effective classroom use takes five to six years.

Although there are many uses for computers in vocational education, vocational educators currently make only very limited use of new tools. Military and corporate research and development appear to be leading innovation in the use of these new tools, as reflected in the literature review summarized in Appendix A. There is limited use of, or experimentation with, these tools in the domain of public vocational education. This appears to be due, in part, to limited funding and a lack of appropriate expertise in the vocational education community to support relevant research and development.

A small sample of vocational educators perceived the new tools as potentially appropriate and beneficial. Given an introductory description, discussion, and videotaped examples of the four types of systems, a focus group of vocational educators representing a wide range of areas envisioned a variety of potential educational uses for these tools. Many of the ideas they generated are viable hypothetical applications of the tools. Their ability to envision creative and viable applications of the tools argues that they had a realistic understanding of the technologies and lends credence to their assessments of the potential barriers to implementation of these tools. In addition, the barriers cited are the same as the the barriers to earlier classroom applications of computers, both in vocational and academic settings. Hence, addressing these barriers would provide general benefit to the vocational education community and beyond.

RECOMMENDATIONS

Based on these findings, the following four recommendations suggest methods to broadly prepare for evaluating and incorporating commercial educational software, once proven effective.

Prepare now to exploit new technologies as they emerge through teacher and general education. To avoid future barriers, the vocational education community needs to make a strong commitment now to build further the foundations for expertise in using computer-based tools in classrooms. As cited earlier, such expertise appears to have two components (Sheingold and Hadley, 1990): mastering the technology itself (one of the barriers identified) and mastering the integration of the technology into the classroom (another of the barriers identified). These mastery processes take time and resources, with five to six years reported in the literature. While waiting for more quality software to be developed for vocational areas, members of the community should acquire experience with computers and their integration into instruction. This would position vocational educators to take advantage of emerging software and, at the same time, builds a school environment that supports computer use and hence reflects trends in the work world.

Address the "infrastructure" issues surrounding implementing and supporting computers in classrooms. Related to the first recommendation for providing education is preparation for other aspects of implementing computers into classrooms and then providing ongoing support for their use. How can the vocational community most broadly, efficiently, and cost-effectively install and maintain the computers and related hardware (e.g., optical discs and local area networks)?

Many of the problems related to implementation, support, and the start-up costs of the emerging technologies are not specific to vocational educational community or settings. Indeed, the findings and recommendations for how to carry out implementation and support are of interest to a wider audience than vocational education and for a wider variety of tools than just the emerging classes: Earlier computer-based educational tools, such as computer-assisted instruction, and uses of computer-based multimedia in academic education face the same issues. One way to directly address these issues is through funding research into successful models of implementation that are appropriate to vocational settings. Such development work done by the vocational education community will have a higher chance both of promoting smooth integration and of having a wider impact.

Encourage funding of research and demonstration projects of applications in vocational education domains. Since the tools appear to be appropriate to vocational education and are potentially beneficial, that potential should be explored, preferably by members of the vocational education community itself. Members of the community should urge policymakers to support the funding of more developmental or "high risk" projects in specific vocational areas (Dede, 1989).

Such funding can support some examples of projects from within the vocational education community as well as support partnerships or collaboration with ongoing projects developing academic or military educational or training applications. Vocational educators should be included in all phases of this research through requirements that grants be awarded to teams explicitly comprised of vocational education researchers and practitioners paired with educational technology researchers. This would engender more research targeted at building systems directly focused on the needs and goals of vocational educators. Such activities begin to establish a community of developers who can also help with the evaluation of future commercial applications.

Encourage members of the vocational educational community to play a personal role in software development via points of direct participation. Direct participation in software design and development can take two forms: establishing direct ties to university-based research projects with large teams and high levels of financial support, such as those recommended above, and funding small grants for software experimentation and development by motivated individuals or small groups of innovators or "entrepreneurs" in the vocational education community.

Clearly, such grants need to be large enough to cover the costs of hardware, software, and generous amounts of developer time to learn about the technology, experiment with it, produce some educational product, and then reach out to the community. Also recommended are electronic mail links between innovators and gatherings of the grantees. Both forms of communication would provide social and technical sharing and support. The two classes of tools with the lowest startup costs for individual innovators are hypermedia environments and collaborative learning environments.

In sum, the four classes of tools are emerging from research laboratories and moving into academic classrooms and training centers, both in America and around the world. They promise to support the learning of a variety of important general, work-related skills, including critical thinking, cooperative problem solving, communication, and information seeking. Such skills are being increasingly demanded of workers who must adapt to meet the challenges of an increasingly dynamic, competitive world market.

One of the results of this review is that the question is not "if" these tools will affect work-related education: Their influence has already begun and continues. These tools are being developed and refined, and they appear in corporate and military training. The vocational education community must take action to position itself most effectively to use the tools as they mature and to help shape those tools to make them feasible for vocational classrooms.

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FIGURE

TABLES

1. INTRODUCTION

The training needs of America are growing and changing. Changes in the workplace have increased or will increase the necessary levels of skill for many job categories ("upskill"), while responsibility, quality control, and corporate decisionmaking are becoming more widely distributed (Bailey, 1990; Carnevale, Gainer, and Meltzer, 1988; National Center on Education and the Economy, 1990). Employees must adapt to organizational and technological changes as American industry responds to a more variable and competitive world market (Burke and Rumberger, 1987; NCEE, 1990). Acquiring the skills to adapt demands retraining: The American Society for Training and Development predicts that, by the year 2000, 75 percent of workers currently employed will need retraining (Carnevale, Gainer, and Meltzer, 1988).

Corporate technical trainers maintain that it is not a matter of choice for American industry to move toward more efficient methods of vocational instruction: It is a matter of survival (Graham, 1990). Limited budgets and new training requirements demand better instructional methods. Many corporations and the military are increasingly moving toward a reliance on advanced technologies to meet this challenge. One of the principal educational technologies in this movement is the computer.

BACKGROUND

Changes are occurring in work and the workplace that demand new skills from workers, and hence new kinds of vocational education. These changes are occurring in the social organization of work and as a result of the impacts of new technologies on the workplace.

The Changing Social Organization of Work

As American corporations incorporate new models of management, employees are increasingly being asked to participate in quality control and in management of their plants (NCEE, 1990; Wiggins, 1990). This requires knowledge about how corporations function, as well as new evaluation and decisionmaking skills. At the same time, the spread of electronic mail in the workplace is increasingly distributing work over distance and time (Licklider and Vezza, 1988) and changing the way that employees interact (Sproul and Kiesler, 1988).

Technology in the Workplace

Computers and microelectronics are changing the tasks in which workers engage. Two work environments that have undergone significant changes because of the introduction of this technology, for example, are the banking and textile industries (Bailey, 1988; Bailey and Noyelle, 1988). The general result appears to be upskill: Technology is requiring new and more diverse skills to accommodate changes. The changes in these two industries model the changes that will occur throughout large sectors of the workplace.

New and diverse skill demands are partially caused by two aspects of technology itself:

- **Technological change is accelerating.** The fast pace of innovation is pushing more generations of new technologies—especially computer technologies—through the workplace. Employees will be increasingly asked to retrain to use these new technologies (Carnevale, Gainer, and Meltzer, 1988).
- **Workings of machines are becoming less observable.** As more parts of devices become controlled by digital, as opposed to mechanical components (e.g., thermostats, ignition systems, timers), there is less possibility to understand the operation of a new device by taking it apart or observing it (Zuboff, 1988). For example, it is a very different task to diagnose and repair a computerized automotive ignition system than it is a mechanical one. Workers cannot view the components that are moving or being adjusted. They need to have a "mental model" (Genter and Stevens, 1983) of the electronic interconnections to be able to reason about the system being repaired and to carry out all but rudimentary diagnostics.

The changes in the social organization of work, the changing technologies used in the workplace, and the increased need for retraining argue for increasingly stronger general or "generic" skills (Bailey, 1990; Stasz et al., 1990) than have traditionally been the targets of instruction in vocational education. The generic skills referred to here are complex reasoning skills, such as the abilities to define and solve problems, think critically, acquire new knowledge, and evaluate problem solutions. These are different from "well-defined" skills, such as memorizing the specific facts or algorithms surrounding a job.

IMPLICATIONS FOR VOCATIONAL INSTRUCTION

To stay competitive, workers will be increasingly required to adapt to new working conditions. Employees will need to cooperate, communicate, formulate problems, and think critically about decisions that will affect the operations of their organizations (NCEE, 1990).[1]

New employees are increasingly expected to arrive with more than a set of narrow, well-defined skills or facts about a type of work or use of some existing piece of technology (such as a specific lathe or text editor) (Michigan Employability Skills Task Force, 1988). Instead, forward-looking employers are increasingly seeking workers with higher levels and more "generic" skills, as well as those who show an aptitude for acquiring new skills (NCEE, 1990; Wiggins, 1990).

These changes promise to affect vocational education directly. A basic implication of the electronic workplace is that students need familiarity with emerging computer technologies. Furthermore, although computer-based instruction has been part of vocational education for many years, a new generation of educational technologies is appearing. These have in common powerful capabilities for simulating work environments and guiding students through them interactively. For the first time, vocational classrooms will have available resources for modeling and exploring complex work situations previously accessible only to on-the-job apprentices. These computer capabilities permit increased restructuring of the vocational classroom and curriculum to mirror workplaces more closely. In addition, the new technologies possess other educational possibilities:

- Their interactive capabilities allow individualized, self-paced instruction for all students.
- Electronic links enable student-teacher interaction across vast distances.
- Inspectable and manipulable abstract models of complex devices can be developed.
- Experience can be provided with interactive simulations of costly equipment or possibly hazardous working environments.
- Approximations of human one-to-one tutoring can be offered.

[1]Note that these skills might be thought of as traditional white-collar skills, leading to interesting questions about the integration of vocational and academic education.

- Students can access and manipulate a rich variety of multimedia reference materials.

PURPOSE OF THE STUDY

The goal of this study is to describe emerging computer-based educational technologies and discuss their potential relevance to vocational education. The research addresses four questions:

1. What are the emerging technologies in computer-based education, and what are their strengths and weaknesses?
2. To what extent is the vocational education community making use of these new computer-based educational tools?
3. How desirable and feasible is it to adopt computer tools in vocational instruction?
4. How might vocational educators, both as individuals and as a community, influence the development and adaptation of appropriate educational technologies for vocational education?

This study was carried out to inform vocational educators (classroom practitioners, curriculum planners, and administrators) about the trends in computer-based education appearing in other educational settings, as well as about applications that are also appearing in vocational education. Critical awareness of emerging educational technologies will help vocational educators participate in shaping those technologies and prepare for their appropriate use.

APPROACH

The research was conducted in two phases. Phase one was a literature review. The first part of the literature review identified developments in computer-based education. The second part of the review focused more narrowly on computer-based educational tools in areas of relevance to vocational educators. The review included project reports, overviews, software reviews, and other sources from a variety of settings, including industry, the military, and secondary and postsecondary schools.

Phase two was a meeting with a small group of vocational educators to assess the possible applications and barriers to using computer-based technologies in their fields. This focus group consisted of classroom instructors (eight people), curriculum planners (three people), and supervisors (four people). The focus group was conducted in a workshop setting. Participants were first briefed on the emerging technologies, then asked a set of questions. These questions included brainstorming opportunities regarding the possible uses of such technologies in their fields of expertise, as well as questions to determine what they perceived to be the barriers to development and implementation of such tools. A fuller description of these questions appears in Section 4.

RATIONALE FOR THE CLASSES OF EMERGING TOOLS

An analysis of the technology and education literature suggests that four classes of computer-based instruction are emerging from laboratories and beginning to appear in classrooms: intelligent tutoring systems (ITSs), microworlds, hypermedia environments, and collaborative learning environments. A central, unique educational feature provides a theoretical core for each class:

- ITSs contain some artificially intelligent, human-teacher-like component that attempts to tune instruction to individual learners and individual problems in complex ways.
- Microworlds are a subset of some reality that affords the learner interactive participation, but are broader than simulations or simulators in that microworlds allow the learner to change or adjust fundamental aspects of the simulated reality.
- Hypermedia environments provide a nonlinear, multiply linked representation of multimedia information that allows learners to extend or restructure the information by adding new information and creating new linkages.
- Cooperative learning environments explicitly provide social support for learning and, in different forms, can provide instructional interactions among students and teachers that can also bridge distance and time.

As the review points out, each class also addresses a different set of educational variables, including setting, outcome, prior knowledge, and pedagogical style. In addition, these classes are similar to those put forward by other reviewers (Dede, 1987b; Hannum, 1990), but are specifically chosen to describe applications that are not yet appearing widely in classrooms and that are specifically educational in nature. As the technologies mature, increasingly hybrid systems will be developed to capitalize on the separate educational benefits of each class.

SCOPE OF THE LITERATURE REVIEW

The literature search covered a range of vocational education and training journals, as well as technology-related educational journals. Since many of the corporate or industry-developed programs or tools appear to be rarely reported in academic or public databases, such commercial applications are probably underreported in this review.

The literature review excluded four types of publications, based on the focus of this report. The first type of literature excluded is publications that pertain to teaching the use of computers as a tool (e.g., teaching programming, word processing, use of spread sheets), as opposed to using computers as teaching tools. Reports in which computers had both uses, such as using an intelligent tutoring system to teach computer programming to Air Force recruits (Shute, Woltz, and Regian, 1989), are included.

The second type of excluded literature, articles that addressed ways in which traditional software (e.g., spreadsheets, computer programming) has been used to support vocational education, was generally not reviewed. Such work has been going on for some time, has penetrated into many vocational classrooms, and has been generally reviewed for vocational educators elsewhere (Herschbach, 1984; Matthews and Winsauer, 1984; Nasman, 1982, 1987; Rodenstein, 1983; Simpson, 1984; Zahniser, Long, and Nasman, 1983). However, for comparison, a review of the literature on computer-assisted instruction in vocational education was included. Appendix A includes a number of articles on applications of traditional software to vocational domains as a reference for interested readers.

A related third type of excluded literature is the application to education of novel computer-based technologies that were not specifically originally designed to have educational applications. Included in this group are educational applications of group decision-support software: Software that is designed and prestructured to aid groups of decisionmakers to check and trace the logic and arguments in their process of reaching a decision (see Kraemer and King, 1988, for a general review of such software). Such software could be systematically adapted for educational uses by increasing the social support provided, but evidence of such work has not yet appeared.

Fourth, references dealing exclusively with technologies that enable long-distance learning, such as broadcast radio, TV, and satellite, were also excluded. Although important, these do not necessarily include computer mediation and hence were beyond the scope of the current study.

ISSUES AND RESEARCH RELATED TO EDUCATIONAL USES OF COMPUTERS

Several important topics surrounding the use of computers for education were also beyond the scope of this review. The following list is meant to provide a starting point for interested readers:

- The teacher's critical role as an implementor and his or her relationship to the technologies. See Amarel (1983) and Schofield and Verban (1988a, 1988b) for overviews of the issues.
- Motivational effects of computer-based tools. See Malone (1981a, 1981b) for an overview of the issues.
- Growing literature on gender effects and equity issues in use and outcomes from computer-based educational technology. See Sutton (1991), Siann et al. (1990), Arenz and Lee (1990), and Collis, Kieren, and Kass (1988) for recent findings and overviews of the issues.

POPULATION OF VOCATIONAL LEARNERS AND SETTINGS ADDRESSED BY THIS NOTE

This Note describes studies and implementations of computer-based education tools designed for and used with a wide range of students: high school vocational students, college students, on-the-job trainees, and military personnel. In addition, such tools are being developed and tested with elementary-age students. Although no cross-age studies of educational effectiveness have been done on these new tools to date, they appear to be usable by a wide breadth of ages and learning styles and to cover a wide variety of topics.

ORGANIZATION OF THE NOTE

Section 2 begins by describing and discussing the strengths and weaknesses of existing computer-assisted instruction as a point of comparison for the emerging classes of tools. This discussion is followed by a brief overview of new optical disc technologies for delivering multimedia instruction. This discussion is deliberately in a separate section from the emerging classes of tools to underline the distinction between a delivery technology, such as dense storage and rapid display of digital video images via optical discs, and the underlying pedagogy or educational tool that is employing the delivery technology. Section 3 classifies emerging computer technologies, using examples from the literature, and summarizes the strengths and weaknesses of each. Also included is a subsection that reviews the vocational education literature on the same technologies. Section 4 discusses the results of the focus group to assess the feasibility of adopting the new technologies. Section 5 summarizes the findings of this work and includes recommendations for how vocational educators might prepare for the emergence of these educational tools and participate in their development.

2. EXISTING COMPUTER-ASSISTED INSTRUCTION AND DELIVERY TECHNOLOGIES

Before addressing the emerging tools, we provide a description of computer-assisted instruction (CAI) as a comparison point for discussion of later tools. We also briefly discuss another emerging technology for storing and selectively presenting large quantities of information for educational purposes called optical disc technology: a technology that can present multimedia instruction that can be used in a variety of ways by the emerging tools. One goal of this section is to underline the distinction between a type of software tool (like CAI) and a type of delivery mechanism (like optical disc technologies).

TRADITIONAL COMPUTER-ASSISTED INSTRUCTION IN VOCATIONAL EDUCATION

Computer-based vocational instruction has been in use for some time. CAI, which is also called computer-based training (CBT) and computer-based instruction (CBI), is probably the most familiar kind of computer instruction to most educators. We discuss it briefly here because it provides a useful reference point for understanding the newer technologies.

CAI has existed since the 1960s and has its roots in programmed instruction, which was based largely on behaviorist psychology. Programmed instruction can be carried out by pencil and paper using workbooks that branch a student's instruction to different "frames" of information (or pages) based on student responses to carefully designed questions. The questions and all acceptable responses must be designed into the workbook. The student basically makes decisions and moves through a predetermined branching instructional curriculum.

The prototypical interaction with a CAI program involves offering the student a screen full of text or graphics and requesting a response by the student. Based on their response, another attempt, remediation, the next screen full of material, or other information is presented. Such instruction has been shown to be effective in training and education (Kearsley, 1983; Kulik, Kulik, and Cohen, 1980). Several large CAI systems with programming languages for developing curricula were built and fielded in the 1960s and 1970s and met with some success. The best known of these are PLATO (CERL, 1977) and TICCIT (Bunderson, 1974). Both eventually became commercial products and are still used in some educational and training settings.[1] CAI has been used widely in vocational education, as reported in the summary review in Appendix A.

[1]See Park, Perez, and Seidel (1987) for a summary of the development of CAI and the differences between CAI and ITSs. See Fletcher (1990) for a recent summary of the

The strength of well-designed, effective CAI lies in teaching individual students a well-defined set of facts or procedures by providing immediate feedback on common errors. Students are allowed to progress at their own pace, and the simplicity of the underlying method of instruction allows CAI to be implemented on very inexpensive computer hardware.

However, CAI has distinct limitations (Park, Perez, and Seidel, 1987). CAI programs

- Provide limited pedagogical guidance to students
- Are extremely limited in adapting to student incentive or exploration
- Are not "generative"; i.e., they are unable to solve novel problems presented by the student or to generate instruction about those problems
- Focus on teaching facts or procedures and are not generally designed to support cooperative learning or teamwork
- Are limited in their ability to adapt to the needs of individual students
- Are expensive and tedious for producing curricula, largely because complex topics require extensive amounts of design work.

Each of the emerging computer technologies described in later sections excels in bridging one of these limitations.

RECENT INSTRUCTIONAL DELIVERY TOOLS: OPTICAL DISC TECHNOLOGIES

A variety of optical disc technologies have arisen in recent years and have begun to penetrate significantly into education and training. Again, we discuss this delivery technology separately from the emerging classes of tools to emphasize the distinction between a delivery technology and the underlying pedagogy or educational tool that is employing the delivery technology. These optical disc technologies include digital video-interactive (DVI); interactive videodisc (IVD); compact disc, read-only memory (CD-ROM); and compact disc-interactive (CD-I).[2] These different systems all share the common functionality that they store and rapidly retrieve massive amounts of information,

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application of CAI to training. For an interesting view of the promise of CAI for vocational education in 1984 and a thoughtful discussion of the policy issues surrounding decisions about technology education, see Herschbach (1984).

[2]See Hannum (1990) for a recent, vocationally oriented overview of the different optical disc technologies.

including video images, sound, and text. The medium stores the materials not magnetically (like the magnetic marks on recording tape or floppy disks), but optically. This storage medium is much more dense and capacious. One type of optical disc can store the images of 54,000 color slides, volumes of printed pages, or the equivalent of 30 minutes of videotape on each side of a single videodisc. This includes tracks for stereo sound. Each video frame can be accessed quickly (in less than two seconds) and can be "frozen" on the screen for study (Nasman, 1987). Early applications of optical disc technologies were used as passive means to store and display visual images, such as museum art collections.

Although the technologies differ in a number of capabilities, they all essentially provide ways in which you can present multimedia information to a learner. In each case, a computer controls access to the stored information; to date, most educational applications of optical disc technologies in vocational education have been in the context of frame-based CAI (Oliver, 1985).

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 prestored 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 preplanned and all the images are prestored. None of the feedback or decisions of the CAI system are generated on line.

Optical video disc technologies provide a powerful device for a variety of computer-based educational technologies outside of vocational settings and, to date, have been most commonly combined with CAI, with positive outcomes. A metanalysis of research on interactive videodisc instruction for military education and training by Fletcher (1990) concludes that interactive videodisc instruction is more effective than conventional instruction in a number of contexts. It is also more cost-effective than conventional instruction, when that instruction involves use of more expensive training resources, such as expensive equipment or simulators. However, he also notes that it may increase the time required to perform the task. Similar results from Army communications training research are reported by Winkler and Polich (1990).

Since the material on the videodiscs must be prestored, optical disc technologies naturally lend themselves to the preprogrammed structure of CAI or to the use of on-line data sources, such as maps and encyclopedias. As the emerging classes of technologies (described in the next sections) continue to mature, they will increasingly take advantage of optical disc technology as one of their output devices.

3. EMERGING COMPUTER-BASED EDUCATIONAL TOOLS

In this section, we classify computer-based educational tools that are emerging from research laboratories and beginning to appear in experimental use in classrooms. We describe and compare them in terms of various features they contain and learning they support. Each subsection begins with a real or hypothetical example of how the tool could be, or is, used. We also summarize existing vocational education projects making use of these tools, followed by a summary evaluation of important features, strengths, and potential drawbacks of the tool. Note that these technologies are described as if a prototype exists for each and the boundaries between them are clear. In reality, these boundaries are fuzzy, and many systems are hybrids.

It should also be restated that these classes of tools are relatively new and do not yet have a body of literature that convincingly demonstrates educational effectiveness. Although there have been demonstrated benefits from CAI and although there are sound theoretical reasons for each of the classes discussed below to fulfill a promise of educational effectiveness, a cautious, critical attitude towards future research results remains prudent. The immaturity of these technologies demands more well-executed applications and careful evaluation studies in the coming years.

INTELLIGENT TUTORING SYSTEMS

> The student computer repair person is stumped. He is staring at a video image of the main circuit board of a disk drive trying to decide which part of the circuit board contains the faulty component. Using an image of a voltmeter, he checks the voltage in the circuit at various points with no luck. This student is stuck. After a pause, the computer that is displaying the images and monitoring his search for the bad part of the circuit asks: "It looks like you have made some good attempts to find and debug this problem. That last check was quite important to finding the bad component. If you'd like a suggestion on how you might plan the next check, hit the help button."

Several systems exist that can debug circuits, monitor a student's circuit-debugging behavior, and offer strategic suggestions (Brown, Burton, and de Kleer, 1982; Lesgold et al., 1989; Towne and Munro, 1988). In general, systems that contain problem-solving knowledge and can offer such help are called ITSs and are an outgrowth of CAI that improves on it in fundamental ways. CAI systems encode information only about the target domain (the content of the instruction); they leave implicit the instructional or pedagogical decisions of the designers. The teaching expertise is embedded in how the questions are written and connected to one another by the designers. This instruction is static: The information must follow a preprogrammed sequence. In contrast, ITSs explicitly encode both domain knowledge and decisions about how best to convey that knowledge. For example, imagine an ITS for teaching someone to design the layout of a kitchen. The ITS has the skill to perform the task and (separate from that skill) different methods for teaching that skill, whereas a CAI system would have both kinds of knowledge embedded in the sequence of frames. This separation allows for a great deal of flexibility, including different approaches to teaching the underlying skill, such as modeling, didactic instruction, or passive coaching, depending on the situation and the student's performance.

The use of the term "intelligent" to describe ITSs comes from a field of computer science called artificial intelligence (AI). The study of AI has been incorporated into computer-based educational systems to make them behave in ways that are arguably "intelligent." For example, ITSs that teach problem solving in a domain (such as algebra, physics, or computer programming) have an explicit simulation of problem-solving skill encoded into them that will solve problems in human-like steps: planning, setting goals, and taking actions. If presented a novel problem (within a fairly narrow class of problems that the system has the intelligence to handle), the system can solve the problem and then guide a student through the problem.[1] Because ITSs can generate solutions to novel problems, they are often labeled "generative" systems.

Figure 1 depicts the components of a prototypical ITS. The domain knowledge (separate from the pedagogical or teaching knowledge) is a simulation of human problem-solving expertise in the domain. This component can solve novel problems in the domain. The student model is a dynamic representation of an individual student's knowledge. The pedagogical component is intended to combine the information from the student model and the domain model to make teaching decisions about how to interact with the human learner, via the interface.

But how do these components interact to make the system "work"? It is useful to think of an ITS as a structured environment for practicing a skill, with a tutorial or coaching presence "watching over your shoulder" as you practice. In the case of mathematics instruction with an ITS, imagine trying to do a geometry proof and being able to ask for help

[1]See Wenger (1987) for a good introduction to ITSs. Other good sources of information about intelligent tutoring systems are Sleeman and Brown (1982), Kearsley (1987), and Polson and Richardson (1988). An interesting collection of reading about ITSs is found in Psotka, Massey, and Mutter (1988).

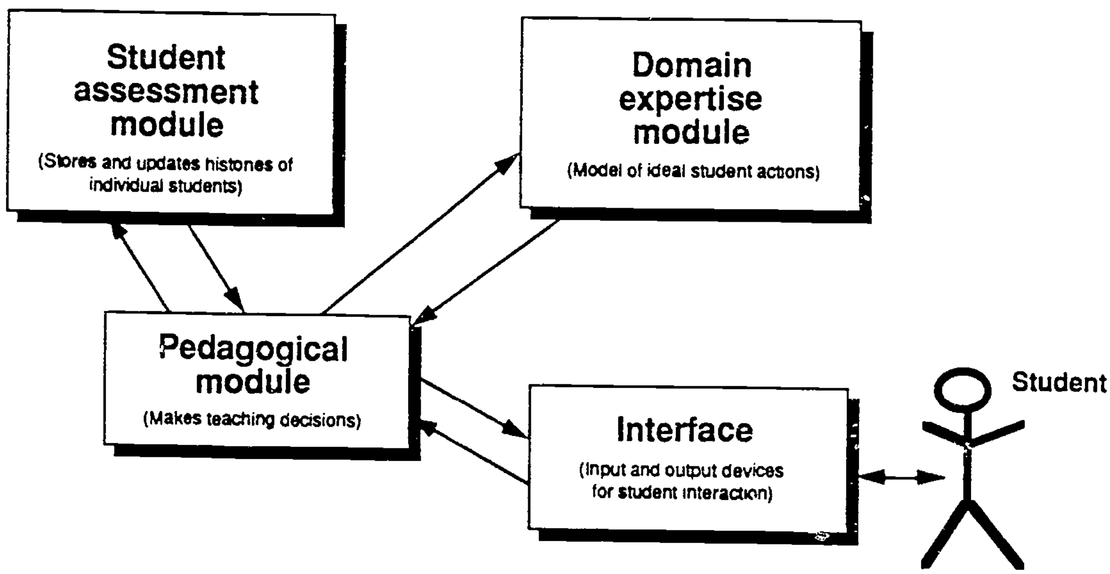

Figure 1—Components of a Prototypical Intelligent Tutoring System

or have a tutor interrupt when you wander too far from one of many possible successful solution paths (Anderson, Boyle, and Yost, 1985; Anderson et al., 1990; McArthur and Stasz, 1990).[2]

If the student requests no help, the ITS simply follows the student's progress by matching his or her problem-solving actions to one of the possible correct, incorrect, or nonoptimal actions automatically generated by the simulation of human problem-solving skill. The students are free to solve the problem in any way they care to try. Optimally, the designers build a simulation that can generate all possible known solution paths.

If the student's action matches one of the incorrect actions or "cognitive bugs" that are also simulated, the pedagogical component chooses whether to interrupt or let the student go down an incorrect path, perhaps providing information about this error later. If the student asks for help, the ITS can assist either in planning a solution or help the student work through the solution itself.

[2]For a teacher's account of using such a system in a public-school geometry classroom, see Wertheimer (1990). Another good example of an intelligent coach for a computer-based math game can be found in Burton and Brown (1982).

The ITS goal of providing individualized instruction maximizes the effectiveness of a student's time spent in problem-solving practice. This more efficient use of time has been one of the cost-effective selling points of the technology: Studies have shown evidence that students both perform better and cover material more quickly than in traditional education (Anderson et al., 1990; Lesgold, Eggan, Katz, and Rao, in press). The cost of providing the strong diagnosis and guidance through the course of a problem solution is that little exploration is allowed. The number of different explorations students might engage in is unlimited, so they cannot be explicitly simulated. Also, the narrowness of the domains for which ITSs can be built is certainly a limitation of their usefulness: Expertise in most domains is not narrow enough to allow explicit computer simulation.

The difference between CAI systems and ITSs is not black and white (as Wenger [1987] points out); there is a continuum between completely fixed preprogramming with total flexibility and pedagogical autonomy on the part of the system. ITS research is still far from the goal of producing a system that reasons autonomously. Still, ITSs have shown some strong results, including improvements of a standard deviation in student learning (Anderson et al., 1990), which begins to approach the effectiveness of human tutors (Bloom, 1984). We will see in the next section that very interesting examples of ITSs have been built for vocational domains, primarily in the military sector.

ITSs in Vocational Education

Given the high cost of developing ITSs, it is not surprising to see that most systems developed for work-related education are supported by military funds. Although some of the military systems are specific to military tasks (e.g., Ritter and Feurzig's [1988] work on training F-14 radar intercept officers), other work is more general, such as the work on circuit debugging (Lesgold et al., 1989) and mechanical and electrical troubleshooting (Massey, de Bruin, and Roberts, 1988).[3] In particular, the work of Towne and Munro (1988) on the Intelligent Maintenance Training System (IMTS) is a strong example of the potential for tutorial support in learning a complex domain. IMTS contains a dynamic simulation of interacting hydraulic, mechanical, and electrical systems, as well as the expertise to do some diagnosis of these systems and the pedagogical knowledge to teach limited diagnostic skills.

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[3]See Gray, Pliske, and Psotka (1985) for a summary of the application of ITSs to training in general and to military training specifically. Also see Garcia (1990) for a brief, recent update.

Interesting work has also been done in nonmilitary vocational education areas. This work includes developing an ITS for teaching troubleshooting for problems with electrical generators (Johnson, 1989, 1990). A simulation and tutor to help train steam engineers running boilers for papermaking plants has also been developed (Woolf et al., 1986). These projects are still in the experimental stages and have yet to appear in mainstream vocational education.

Evaluation of ITSs

Guidance provided to students by the tool: Explicit and extensive.
Opportunities for individual exploration: Low.
Generative instruction? Yes.
Type of knowledge emphasized: Mastery of specific skills.
Adaptation by system to individual student: High.
Cost to develop: High.

Other Interesting Features: Some ITSs provide extensive guidance on both planning and execution of a skill. They are able to tutor a student through each step of a complicated solution to a problem. They are also able to give help at a variety of levels by providing different levels of hints or specific explanatory feedback to students about where their planning or execution of a solution went wrong. ITSs also provide a tool for the problem-solving activity and a structured curriculum in which to use that tool.

Potential Drawbacks: ITSs can only be developed for narrow domains that are well understood and well structured. Developers must be able to write a computer simulation of the underlying expertise. This process is costly and time-consuming and generally requires powerful computers to operate.

Summary of ITSs

The main strength of ITSs is the capability to make the instruction of well-defined skills efficient by providing strong guidance. The main weakness of such systems is that they are limited in the domains and the style of learning they can support. For example, ITSs do not allow much exploration because the pedagogical component would likely not be able to diagnose errors that occurred during novel explorations. ITSs also cannot be built for content areas that do not have well-defined correct answers, e.g., creative interior design ideas.

MICROWORLDS

> An electrical repair worker at an employee-owned steel mill is considering the different plans for the future of her plant. To educate herself so that she can better understand the economic environment of her plant, she has enrolled in a computer simulation-based training program. Using the computer-simulated "microworld" that includes her plant, the competition, and different scenarios for the global steel market, she experiments with different management decisions about reinvesting profits in new machinery versus paying dividends. She can look at the outcomes of various possible decisions not just from the perspective of the end of the next fiscal year, but 10 and 20 years later. These outcomes are expressed in more than simply profits and losses: They include expansions, layoffs, and plant closings. She then decides to carry out an experiment to test her understanding: She changes the rules of the economic microworld to make it an unrealistic situation. She is testing her understanding of the costs of raw materials by changing the behavior of the coal suppliers to actually pay the mill to take their coal, instead of vice versa. After a series of explorations, she believes that she understands the effects of an American oil shortage on steel production and is then prepared to take the test on this lesson.

Computer simulations or microworlds similar to this hypothetical steel mill have been used to educate students in business schools for some time. They could be adapted to provide such education in the workplace. What separates a microworld from a simulation is that in microworlds the users can change the underlying rules that govern the simulation.

Lawler (1987) describes a microworld as a virtual, interactive subset of the world, limited to a specific domain. In the case of the example above, the domain is the process and costs of steel production. Microworlds offer interesting environments that students can creatively explore. The purpose of such environments is to teach students "to transfer habits of exploration from their personal lives to the formal domain of scientific theory construction" (Papert, 1980). Said simply, you learn to use your natural exploratory behavior in more systematic ways. Microworlds presume that discovery learning is highly efficacious: Information is learned "more deeply" and remembered longer if discovery is involved.

Early development of microworlds took place at the MIT AI Laboratory in the early 1970s (Lawler, 1987) and the concept was later popularized by Seymour Papert (1980) and the LOGO programming environment. LOGO is a simple but powerful computer programming language, emphasizing graphics, that was designed for use by children. Papert developed it for discovery learning about mathematical relationships. Using LOGO, children can write simple programs that require the use of mathematics to draw pictures. Examples of other educational microworlds are contained in Lawler and Yazdani (1987), a microworld for learning economics (Shute, Glaser, and Raghavan, 1988), work on optics (Reimann, Raghavan, and Glaser, 1988), and work on DC electrical circuits (Glaser, Raghavan, and Schauble, 1988).

Microworlds resemble computer simulations (such as flight simulators) and "virtual" environments, "realities," or "cyberspace."[4] However, microworlds simulate more than just a "real" situation, since they allow students to manipulate or redefine reality. For example, the Alternate Reality Kit enables students to learn about the basic physics and the effects of gravity by experimenting with objects in different gravitational environments (Smith, 1987). Students not only can simulate throwing a ball on different planets but also can actually reverse the force of gravity, so that the ball and planet repel each other.

Close relatives to microworlds are simulations that allow the user to violate the rules of the simulated situation for educational purposes. In military training, one system allows multiple tank crews to interact in a simulated tank battle; certain "observation tanks," piloted by instructors, can fly over or crawl under the simulated battlefield to watch other tanks' performances (O'Neil and Fletcher, 1990; Nelms, 1988; Ropelewski, 1990). Another close relative of microworlds is simulations that can be tailored by the student: Students can construct working simulations of systems they are learning about, but at levels of abstraction that cannot be found in the real system. For example, a student could build a functioning simulation of an automotive fuel system that had only three major components, whereas the actual system might have eight actual components.

New interface technologies, in combination with microworlds or simulations, are potentially powerful additions to computer-based learning. For some time, NASA has been funding and carrying out research in how to build simulated work environments. An example of an existing application provides a student with training on virtual NASA control panels and involves a head-set that has computer-controlled, three-dimensional visual displays and sound. Other examples include allowing people to explore the structure of a molecule by crawling around through it (Fisher, 1990), play racquetball in an empty room without a real ball, or train on a virtual simulation of the interior of the space shuttle, but do

[4]For fascinating reading, complete with photos of the views of such environments and the hardware needed to provide these environments, see Fisher (1990) and a Scientific American article by Foley (1987). Also of interest is a piece by Walker (1990).

so in an empty classroom. The images presented to the user can be simulated spaces, such as corridors in buildings, or they can be abstractions, such as the pattern of air flow over a model in a wind tunnel. Either way, the user can interact with these images as if they existed in reality. The images can be picked up, turned around, or observed from different angles by moving the user's perspective.

A general design goal of microworlds is that they should suggest objectives and activities to the learner and be easy to manipulate to carry out those explorations. In some cases, like LOGO, the microworlds can be changed or extended by the learners themselves. Microworlds differ from ITS technologies in that they are not meant to teach a well-defined set of skills, but instead to stimulate more general exploration and learning about how a target domain is structured or behaves (e.g., the laws of gravity).

Microworlds in Vocational Education

Given the technical definition above, no examples of microworlds for vocational education existed in the literature at the time this report was written. However, a notable example of a simulation that the user can tailor is a simulation of an extremely large and complicated steam-generation plant for powering a naval vessel (Hollan et al., 1986). This simulation and graphical interface allow learners to operate, view, and interact with various systems and subsystems of the plant at various levels of abstraction. For example, in the same way that an automobile can be described as a set of simple systems without the details (e.g., fuel system, electrical system, brake system), the steam plant can be viewed and the simulation can be run at simple or complex views of the underlying components. This simulation was also eventually used as the core of a simulation-based training system.

Nasman (1987) describes an interesting computer-based simulation in a nonmilitary application that allows people to experiment with oxyacetylene welding:

> This system uses a videodisc player, a computer, a horizontally mounted television monitor with a touch-sensitive screen, and a welding torch that has a photoelectric eye and potentiometers instead of the usual oxyacetylene mixture. As the controls are adjusted on the simulated torch, the computer causes the disc player to display photographs of the kind of flame the torch would have with each adjustment of the controls. (Nasman, 1987, p. 7)

This microworld allows the student to vary the controls and observe the simulated flame's reaction. The student can perform experiments such as "does the flame get more orange or blue when you increase the oxygen?" However, the system can also provide feedback by matching the student's final adjustment to the prestored correct mixture. After the flame is adjusted, the act of welding is also simulated:

> As a rod of filler is moved over the touch screen, a picture of a weld is displayed which is appropriate to the position of the rod. The photoelectric eye detects how far the torch head is from the screen and the computer causes the disc player to display a picture with the appropriate characteristics of a weld in the process. (Nasman, 1987, p. 7)

Students can experience some of the physical aspects of welding: the distance of the torch from the surface, the speed of movement of the molten bead of the weld. If the movement is too slow and the metal thin, then a hole would be burned through the metal, which can be presented from the prestored library of images on the disc. Students do not have to wear goggles or endure the smoke, heat, and risk of burns that are part of real welding. Once the proper level of performance has been developed, students can begin welding with the actual materials and tools in a shop.

A variety of computer-aided engineering (CAE) or computer-aided design (CAD) tools are also marketed as educational aids. These are simply simulations that allow you to construct models of physical systems without changing the realities they represent. Examples in the vocational education area include commercial software to build and test simulations of hydraulic, pneumatic, and electrical circuits. There are no pedagogical components to these systems, but they do allow exploration. They do not appear to offer the possibility to change aspects of the simulation for educational purposes—e.g., they do not allow you to simulate a reversal of negative to positive charge or experiment with superconductivity as if the temperature of the circuit were approaching or reaching absolute zero. Neither do these simulations allow the student to represent sets of components at a more abstract level. Other simulations used in vocational settings include a system to teach cardiopulmonary resuscitation via a total system that includes videodisc images and a sensor-equipped mannequin (Hon, 1982) and a IVD-based simulation to teach sales techniques (Graham, 1990).[5]

Microworlds, by their design, are meant to implicitly guide or structure activities by suggesting or supporting certain types of explorations. More explicit guidance of the use of microworlds can certainly be provided through curricula or human tutoring. Since they are

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[5]Other examples of educational computer-based simulations were found in a number of industrial and military applications, as noted in the Appendix.

interactive simulations, the experimentation that students can undertake are unlimited (within the bounds of the microworld itself).

Evaluation of Microworlds

Guidance provided to students by the tool: Implicit, much less extensive than ITSs.

Opportunities for individual exploration: High.

Generative instruction? Yes.

Type of knowledge emphasized: Exploratory skills and domain knowledge.

Adaptation by system to individual student: Low.

Cost to develop: Moderate.

Other Interesting Features: Microworlds provide interactive environments for exploration that can be quite motivating. Well-designed systems are alleged to have "obvious" explorations to carry out. Microworlds allow students to take the initiative and responsibility for their learning.

Potential Drawbacks: Microworlds require students to take the initiative, which implies that learners with certain sets of preexisting skills (e.g., well-developed skills to carry out scientific method-based explorations) or motivations will benefit to a greater extent than less skilled learners, who might flounder or need assistance to carry out fruitful discovery learning.

Summary of Microworlds

The moderately strong reliance on student initiative for success with microworlds is a potential weakness in real educational environments and may require development of curricular supports. However, the skills of problem formulation, decisionmaking, and scientific reasoning supported and allegedly engendered by this tool are increasingly in demand. This ability to provide rapid interactive exploration is the strength of microworlds. Proponents of microworlds claim that the need for high levels of student motivation to learn using such tools is ameliorated by the cleverness of the design of the microworlds themselves: Students want to interact with them. However, some external guidance to student exploration may provide more constructive use for many students. Such guidance could be provided either through curricula by instructors, or through the addition of automated tutorial components.

HYPERMEDIA

> Holding pistols with both hands outstretched, the police kick in the door, and you are right behind them as they go in. A young woman in the apartment begins screaming. The search warrant is based on the allegation that a cocaine dealer lives there. He is not present; but cocaine is, lots of it. This is a major drug bust. Still, it could all wash out in court if someone in the group doesn't safeguard citizens' constitutional rights. That person is you. (Lambert, 1990, p. 43)

The student learning about the legality of police conduct watches the arrest and pursuit into a neighboring apartment displayed on a video monitor from images stored on an optical disc. The student's job is to stop the action by pressing a key whenever he or she thinks the police have acted illegally and jeopardized the arrest. The computer forwards this signal he videodisc player, which freezes the screen image. The student can then access legal information about that point in the video drama, examine questions that are relevant to that point, or choose from a series of other options using a second computer monitor. These include accessing constitutional texts, case citations, and judicial opinions, all available from simple key strokes. Using a hypertext feature, sections of these documents could be linked to other relevant documents for direct access or personal elaboration to document the legality argument the student will make. This is one possible example of an application of hypermedia in conjunction with an interactive videodisc-computer lesson on law, produced by the Harvard Law School (Lambert, 1990).

The term *hypermedia* refers to a new structure for multiple organizations of related entries of various types of media (print, image, audio, audiovisual). One definition of the prefix *hyper* means "over" or "above," and refers to the organizational structure of the materials. For example, all written material is linear, with one sentence following another on the page. Using hypermedia, students can move from one topic to another by following prestored informational links. This ability to navigate through a body of material "nonlinearly" by following links contrasts sharply with how we normally move through printed material, like books. Generally, we read books "linearly," or from front to back in the order that the author wanted the reader to read.[6] This ability to move from topic to topic is similar to being able to access the contents of a book easily via its table of contents, its index, or an abstract map of the topics or themes in the material. Apple Computer, Inc.,

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[6]For a well-written overview and review of hypertext systems, see Conklin (1987). Dede (1987b) provides a short, very readable description of hypermedia.

includes a popular hypertext system with many of its computers. In the words of John Scully, Chairman and CEO of Apple:

> In broad terms, hypermedia is the delivery of information in forms that go beyond traditional list and database report methods. More specifically, it means that you don't have to follow a predetermined organization scheme when searching for information. Instead, you branch instantly to related facts. The information is eternally cross-referenced, with fact linked to fact, linked to fact.
>
> Hypermedia is particularly true to its name when it links facts across conventional subject boundaries. For example, when studying chemistry, you may wish to study the life of a chemical compound's creator. One hypermedia link would connect that compound to the chemist's biographical information located in an entirely different reference work. Another link might connect the chemical compound to a list of grocery store products that incorporate the compound, or to long-term health studies on the compound. We can focus more on content, while ignoring the organization. (Goodman, 1987, p. xvii)

Research into educational applications of hypermedia is becoming widespread. Brown University's Institute for Research on Information and Scholarship (IRIS) is one of the oldest hypertext research groups. Recent work at IRIS has focused on the Intermedia project, a hypermedia environment designed to allow professors to organize their lesson materials and present them via computer (Conklin, 1987; Garrett, Smith, and Meyrowitz, 1986). The same environment is available to students to study the materials, annotate them for other students, work cooperatively, and store student reports (Landow, 1990).

The Perseus Project at Harvard (Lambert, 1990) allows a student to explore famous archaeological sites, such as the Acropolis. As the student moves a cursor around a map, the display shows stored video images as seen from the various positions. The student can zoom in to examine details or can view related museum pieces and look up historical or literary references to the site. The same system can traverse software links between a variety of media. For example, a student finding a reference to a character called Herakles in an on-line Greek play could quickly find other references to Herakles in other on-line texts. After looking up the name in a classical dictionary, the student could view the drawings, paintings, and sculpture of Herakles.

A similar system called "Palenque," aimed at elementary school children, provides a chance for a similar exploration of an Aztec temple. Access to references materials and museum artifacts is available as the students roam the archeological site, following trails on a map, moving the simulated eyes up and down, and zooming in to view different parts of the ruins (Wilson, 1987).

Hypermedia systems can generally be either "fixed" (no additions or modifications allowed) or "tailorable" (the user can create any links or additions). The capability to tailor a hypermedia environment by making explicit nonlinear associations (i.e., learner-created links from one part of a text to other parts or to other media) has interesting educational implications. Students and teachers can use a hypermedia system to customize their own texts, as they learn, by making explicit associations to worked problems they have completed, to their notes, or to other texts. In this way, students and teachers will be able to share or communicate a more direct "mental model" of their understanding of a domain. Both students and teachers could show and compare the structure of their hypermedia links (Kahn, 1988).

Because hypermedia environments have only been available for widespread use and experimentation for the last few years, evaluation studies of the educational benefits are just beginning to appear (McAleese, 1989; McAleese and Green, 1990). As with the other technology classes, final commitments to such a technology should await a larger body of positive results.

Hypermedia Environments in Vocational Education

Few reports were found of hypermedia environments applied to vocational education. Those included were in the areas of professional schools (law and public policy), the legal aspects of police conduct, and crisis management (Lambert, 1990). An interesting example of a hypermedia environment for educational assessment and accreditation in the area of architecture is in use by researchers at the Educational Testing Service (Braun, 1990). Candidates for accreditation are placed in a "virtual office" with various tools at their disposal, including computer-based design tools and a complete set of on-line technical manuals and building codes. The test-taker is given a task to complete using the available materials. All stages of the design work are done in the hypermedia environment, and many aspects of the evaluation of the design are also automated. Although this is an application to testing, it demonstrates the educational possibilities of such a workbench-like system.

Hypermedia technology has low start-up costs: The hardware is inexpensive and the development tools are easy to use. Because of increasingly easy access to the technology, educational uses of hypermedia are spreading rapidly, with applications being developed by individuals in many fields and project reports appearing in increasing numbers in conference proceedings.[7] Whole conferences are now devoted just to applications of hypermedia. Many new applications of hypermedia are likely for vocational education.

Evaluation of Hypermedia

Guidance provided to students by the tool: Implicit, low.
Opportunities for individual exploration: High.
Generative instruction? No.
Type of knowledge emphasized: Exploratory, organizational, and communication skills.
Adaptation by system to individual student: Low.
Cost to develop: Low.

Other Interesting Features: The exploratory, constructive nature of this tool encourages active engagement in the learning of the domain. It also encourages students to reflect upon the structure of their own knowledge and aids communication.

Potential Drawbacks: Users of such systems can get lost in the interconnections and become confused about how to navigate through the web of information they are exploring. Extra effort and concentration are required to maintain simultaneous exploration tasks.

Summary of Hypermedia

Hypermedia's strengths lie in the flexibility to present a variety of knowledge about a domain (which need not be well understood or structured) in a variety of media, including sounds, written words, and static or video images. It allows the potential for rapid access to diverse on-line information sources. Hypermedia systems have been used with optical discs as output devices to present a wide range of feedback and information. This access to a rich interconnection of information allows the practice of a variety of skills demanded by the changing workplace, including critical thinking about the relative quality of the different materials that are provided, problem formulation to create a question that will be answered with the system, and plenty of practice in information seeking.

[7]For example, in the proceeding of the thirteenth annual Symposium on Computer Applications in Medical Care (Kingsland, 1989), there is a "Hypermedia and Education" subsection of papers.

The educational weaknesses of hypermedia environments center on management of the environment itself (e.g., not getting lost in the web) and the initiative required of the student. Although both microworlds and hypermedia environments require student initiative, the management skills required by the two tools differ: Learning with microworlds requires management of discovery and scientific method. The management skills required to learn with hypermedia environments center around methods for helping to manage the complexity of the linked knowledge that can be represented. As is true of microworlds, the requirement for strong student initiative provides a challenge for the curriculum developers and teachers. Unless the student engages the system, there is no interaction or instruction.

Regardless of their perceived weaknesses, hypermedia environments are beginning to appear as reference manuals to software, and reportedly, they will soon begin to replace hardcopy manuals for such tasks as automotive repair (J. Speigelberg of IVID Communications, personal communication, February 15, 1991).

COLLABORATIVE LEARNING TOOLS

> A student from an inner-city high school has always been fascinated with plants and horticulture. Her desire to work at a nursery and eventually get involved in landscape architecture is strong. When she logs onto her personal computer after school, there is electronic mail waiting for her, but this is no surprise. It is from her boss at the suburban nursery and it includes her next task as part of the month-long landscaping project in which she has been involved, mostly via electronic mail; it involves researching drought-resistant plants for her design of the planting on the hillside that she has been assigned to landscape. In her electronic mail response the next day, she reports about the library work she has done on plants, makes her suggestions for good candidates and sends this message back to the boss. She and her boss will carry out her plan this summer at the site when she works as a full-time employee at the nursery.

This is a hypothetical example of a vocational "teleapprenticeship" (Levin, Waugh, et al., in press). It is one example of how computers might be used to support collaborative learning or support group processes in educational settings.[8] Such tools are part of a young

[8]For the purpose of this paper, we circumscribe the applications of computer-supported cooperative work research to education using computers as part of the mediation process. This deliberately excludes other tools of distance learning, such as one- and two-way television and radio-based education. It also excludes the use of microworlds and hypermedia explicitly in the context of group learning, although some systems were deliberately designed for use by multiple students in groups. It does include software systems that are explicitly designed to aid communication, problem solving, and learning in

but rapidly expanding field called computer-supported cooperative work (CSCW).[9] CSCW systems, in both educational and work settings, aim to provide useful tools to help people learn and work with other people. These tools enhance communication and cooperative skills (Sproul and Kiesler, 1988). Three types of CSCW systems are described below. From the outset, it should be noted that the majority of these tools provide no implicit or explicit pedagogy or guidance to the learner. Instead, the tool provides a framework or conduit for communication and hence for collaboration.

Asynchronous Computer-Based Interaction

These systems allow communication across space and time barriers by setting up an "electronic mail" network among participants: In the case of educational applications, this is among learners and teachers. "Electronic mail" is use of computer hardware, software, and a communication network to compose, send, and receive electronic messages from a terminal or computer. These messages can be sent to other users of the system or on a network of computers. Messages are transmitted electronically over local area networks or via the telephone lines to other computers, which eventually route the addressed message to the proper computer and user. The message then is automatically stored in a computer file until the addressee logs onto his or her computer and reads it. He or she then responds by sending electronic mail back, if appropriate. Users can send messages back and forth to individuals on the network, small groups, or the entire set of users on the network. Such electronic mail networks are in heavy use in some corporate and government settings.[10] Global networks of electronic mail now allow users, mainly in universities and corporations, to send and receive electronic mail worldwide.

Interest in distance learning has grown in recent years (Office of Technology Assessment, 1990). An example of the educational use of such a system is the collaboration among groups of school children working together at a distance, via electronic mail, to gather data and jointly carry out a science project on water shortages (Waugh and Levin, 1989). Groups of students in different time zones and in different parts of the world worked independently and then communicated with each other to sum their results. In individual

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groups. This class of software is also known as "groupware" (Ellis, Gibbs, and Rein, 1991; Grief, 1988; Grudin, 1990). Such software includes several categories, outlined briefly in the text.

[9]See Greenberg (1991) for a comprehensive annotated bibliography of publications on computer-supported cooperative work.

[10] See Stasz, Bikson, et al. (1990) for an interesting assessment of the large impacts on the U.S. Forest Service of a distributed information system that included electronic mail.

classrooms, electronic mail networks have also been used to support cooperative science learning (Newman, 1988).

A kind of "apprenticeship" is taking place via exchanges of electronic mail between students (apprentices) in remote sections of the country and members of industry (mentors). The work of Levin, Riel, et al. (1987) and Levin, Waugh, et al. (in press) on "teleapprenticeship" provides an interesting example of the possible uses of electronic mail networks for educational purposes. Given the newness of this project, no results have been published to date.

Shared Workspaces and Shared Data Systems

Shared workspace systems include aids to allow people (either face-to-face in a meeting room or in different cities) to dynamically interact with a shared workspace, simultaneously visible to all participants via their computer screens. Hence, several people could be learning or collaborating in real time, either in the same room, or at a distance. Such systems have been experimented with for educational purposes in college settings (Hiltz, 1988), but very few educational applications have appeared.

A version of asynchronous shared workspaces called "data sharing" is specifically designed to aid in the "social construction of knowledge." Interesting results are appearing from the use of a data-sharing system with elementary-age students. This system is the Computer-Supported Intentional Learning Environment (CSILE), a hypermedia environment designed for group learning (Scardamalia and Bereiter, 1991; Scardamalia, Bereiter, et al., 1989). Students use CSILE to record the research that they do for projects on computer "note cards" that are stored in a central database. Other learners engaged in related projects can search for relevant information on other student's cards and then examine, annotate, or elaborate those cards. They are also free to incorporate relevant information into their own research cards.

One impact of shared workspace and data is that no single person controls what gets written into the shared workspace. This contrasts with many classroom settings, in which one person at the chalkboard determines what is worthy of recording. Instead, any person can control the cursor and input information into the shared workspace. The cooperation that could be achieved for educational purposes includes allowing each participant equal access to the workspace without the need to take over the conversation. Having such equal access could have real benefits for certain less aggressive learners who do not want to compete to share their ideas.

Finally, the tools mentioned in this section on collaborative learning share a common feature: Each subclass involves a computer-based medium imposed between direct person-to-person interaction and a shared environment that shapes the process of interpersonal communication. The goal in each case is to provide tools that enhance the collective learning of the people involved, as well as enhance each of their individual accomplishments.

Collaborative Learning Environments in Vocational Education

This area of application has few examples and unknown potential. To date, the only example of the application of cooperative learning environments to work-related education is taking place at the University of Illinois, Champagne-Urbana, where a study of "teleapprenticeships" is underway (Levin, Riel, et al., 1987; Levin, Waugh, et al., in press). The study examines the possibility of using electronic mail to allow students in rural or inner-city environments to participate in training or work with adults who are distant from them. Examples include science instruction and teacher education. In stages, K-12 students become working members of teams involved in actual science research or in solving classroom problems faced by student teachers. At first, students just read the electronic mail messages to learn the language and style of interaction. Students are assigned to a mentor who gradually assigns increasingly difficult tasks for the apprentices. The solutions to these tasks are communicated, via electronic mail, back to the mentor. Students do miss the face-to-face interactions in work, but get a feel for the flow of an actual project, because they are a part of the process.

An increasing amount of work is being done via electronic communication (electronic mail and faxes) in many sectors of the American economy, particularly in large firms and high technology firms. Since this mode of interaction is increasingly used in parts of the world of work, that aspect of work should also be increasingly integrated into curricula, perhaps in the same ways that traditional internships are used.

Evaluation of Collaborative Learning Environments

Guidance provided to students by the tool: Implicit, small amount.
Opportunities for individual exploration: Moderate.
Generative instruction? No.
Type of knowledge emphasized: Communication skills, cooperative learning, collaborative problem solving.

Adaptation by system to individual student: Low.

Cost to develop: Low to moderate.

Other Interesting Features: These tools provide the potential for a variety of ways for students to interact and collaborate with other students or teachers with whom they might never have come in direct contact. Potentially, these tools provide less-aggressive or less-outgoing students greater access to conversations or learning situations.

Potential Drawbacks: Most collaborative learning tools provide no explicit educational structure or pedagogy: They are merely a communication medium. Learners must provide the structure or get instruction from fellow collaborators or teachers.

Summary of Collaborative Learning Environments

The potential strength of collaborative learning tools is that they can bridge distance and time to provide learners with interaction or instruction to which they normally would not have access. The primary weakness is that these tools do little besides provide a framework or conduit for collaboration. In general, negligible guidance is provided by the tool itself.

4. FOCUS GROUP RESULTS: POSSIBLE APPLICATIONS OF NEW TECHNOLOGIES AND POTENTIAL BARRIERS

To assess the potential educational applications and benefits of the four educational technologies outlined in this paper, we conducted a focus group with vocational education professionals. The goal was to brief a set of practitioners, planners, and administrators about the classes of emerging technology, discuss the classes, and then ask them to assess the potential benefits and possible barriers to implementing them. For the last area, we provided a questionnaire (Appendix B) that had three sections, each with a different focus.

The first section focused on the demographics, including job responsibilities, work and teaching experience, and computer experience. The second section asked respondents to individually brainstorm about how, if at all, they thought the different kinds of new tools might benefit students in their fields of vocational education. They were encouraged to try not to focus on the pragmatic issues associated with attempting to integrate new computer-based tools into classrooms. Instead, they were encouraged to focus on what applications might be useful to their students. The third section asked the respondents to think realistically about ways to help integrate beneficial educational technologies into their classrooms. They were encouraged to give their honest opinions as to what they saw as the biggest roadblocks or hurdles that would have to be overcome in implementation and how those hurdles might be overcome.

The briefing was carried out in a workshop setting and consisted of a series of four short overviews and discussions, one of each technology. Attendees each received a set of materials, including copies of the briefing charts. The short overviews consisted of a brief description of the technology, a short videotape presentation of a working application of that technology, and a discussion.

The 15 attendees then spent spent between 30 and 50 minutes answering a series of demographic and short-answer questions. The attendees' primary duties included classroom instruction (eight people), curriculum planning (three people), and supervision (four people). Attendees represented a wide variety of areas in vocational education, and all had extensive occupational and teaching experience in their areas.

We were first interested in assessing if, from the view of the planners and implementors of instruction, there are natural roles for future technologies to improve instruction in vocational education. Explicitly included in their instructions was the statement that we did not expect that any technology would necessarily be appropriate for any area of vocational education. They were explicitly instructed to "try to ignore the realities of actually implementing such tools." Second, we sought to assess the possible barriers to integration into classrooms of any technology perceived to be effective.

FOCUS GROUP TOOL RATINGS: NEW TECHNOLOGIES VIEWED AS POTENTIALLY BENEFICIAL

Respondents rated the "potential educational benefits to your students" of the four different classes of educational technologies on a five-point scale (1: High, 2: Moderate, 3: Some, 4: Low, 5: None) with the following results:

- ITS: 1.7
- Microworlds: 2.1
- Hypermedia: 1.4
- Collaborative learning environments: 1.9

These ratings suggest that, based on the small amount of information presented in the briefing, each of the new technologies was perceived as potentially useful to vocational education students from a variety of areas. When we asked the educators to brainstorm about possible uses for these technologies in their specific fields of vocational education, many interesting possibilities surfaced. Below is an example of a suggested application for each class of technology:

- An ITS for banking procedures to provide initial training and follow-up: Special transactions could be practiced, and potential errors could be diagnosed.
- A microworld for experimenting with various marketing strategies: Different advertising methods (which involved different "costs") would be used to experiment with different products, aimed at different populations, with different impacts on sales.
- A hypermedia application for environmental tours of hospital facilities: Students could enter patients' rooms, look up their records, consult nurses, access medical reference books, handle simulated phone calls, and generally explore (e.g., behind closed doors, in cabinets, and in drawers).

- Use of electronic mail to allow students to collaborate with contractors on real-world construction jobs: Both student and contractor would have the same computer-based tools for estimating costs and planning phases of a construction project. The contractor could give part of the planning or estimating to students and exchange information and critiques via electronic mail.

FOCUS GROUP QUESTIONNAIRE RESULTS

The final section of the questionnaire dealt with the realities of implementing new technologies in the classroom. Attendees were asked what they viewed as the biggest hurdles or roadblocks to using the emerging technologies in vocational-education settings. Their concerns included

- **Limited funding**: Eleven out of fifteen respondents mentioned this as the primary potential barrier to implementation. Most respondents elaborated on this bottleneck to innovation in later responses.
- **Lack of time for teacher education**: This included time to become educated about computers or be trained to use computers in classrooms.
- **Limited access to computer hardware and higher quality software**: This barrier was cited by four respondents as a primary barrier to future use.
- **Negative attitudes toward technology and unwillingness to change teaching style**: Eight out of the fifteen responded that attitudes toward computers were a barrier, both on the part of teachers who would use them and on the part of the vocational-education community as a whole. One respondent also noted that student attitudes need to change: They too need to be familiar and comfortable with the use of computers in educational settings.

These barriers are similar to those cited by users of more traditional approaches to computers in classrooms (Brady, 1991). Sheingold and Hadley (1990) report that exemplary computer-using teachers cite lack of development time for computer-based curricula by individual teachers, lack of access to computer hardware, lack of computer hardware in general, and the administrative barriers of lack of financial support and help with supervising computer use. The importance of appropriate teacher education and depth of teacher exposure to the hardware and software is echoed from the fielding of an ITS into a high school algebra I classroom (Robyn et al., 1989), as well as in the hypothesized barriers to be met when attempting future implementation of ITSs into training settings (Dede, 1987a).

In sum, based on a brief presentation, a small sample of vocational educators from a variety of areas saw many potential applications of the emerging technologies and pointed out some potential barriers to implementing and integrating such tools into vocational settings. These barriers are similar to those cited by teachers using more traditional computer-based educational tools and are similar to the barriers to new technologies cited by academic researchers. In the next section, we address how some of these barriers might be addressed and their impact minimized.

5. FINDINGS AND RECOMMENDATIONS

This section summarizes the research findings and offers recommendations for the vocational education community. The findings are reported and summarized in three subsections: findings from the review of general literature on emerging technologies and education, findings from the vocational education and technology literature review, and findings from the focus group. Recommendations based on these findings are discussed in a fourth subsection. We conclude with an overall summary.

FINDINGS FROM THE GENERAL TECHNOLOGY AND EDUCATION LITERATURE REVIEW

Four classes of tools are emerging, each appropriate for different goals, subject areas, and learners.

An analysis of the technology and education literature suggests that four classes of computer-based instruction are emerging from laboratories and beginning to appear in classrooms: ITSs, microworlds, hypermedia environments, and collaborative learning environments. Each has a central, unique educational feature, with other features that help distinguish it as a class. Each class also addresses a different set of educational variables, including setting, outcome, prior knowledge, and pedagogical style. As the technologies mature, increasingly hybrid systems will be developed to capitalize on the separate educational benefits. These classes are similar to those put forward by other reviewers (Dede, 1987b, 1989; Hannum, 1990), but are specifically chosen to describe applications that have not yet appeared widely in classrooms and that are specifically educational in nature.

Table 1 summarizes the various attributes of each class of tool that were discussed in Section 3. The table also includes other information about each tool that may help the reader better understand the tool's strengths and weaknesses. Note that in each case the prototypical "systems" referred to in this table include only the hardware and software, not the contributions of other collaborators or instructors. Each class of tool has its own special features and applications:

- ITSs' unique educational feature is the inclusion of artificial intelligence that simulates some of the decisions and actions of human teachers to tune instruction to individual learners and individual problems in complex ways.

Table 1

Evaluations of Emerging Computer-Based Tools

	Intelligent Tutoring Systems	Microworlds	Hypermedia	Collaborative Learning Environments
Amount of guidance provided to the student	High	Moderate	Low	Low
Type of guidance provided to the student	Explicit	Implicit	Implicit	Implicit
Opportunities for individual exploration	Low	High	High	Moderate
Generative instruction	Yes	Yes	No	No
Structure of content areas supported	Completely mapped, narrow domains	Well-understood variables and dynamics	Associative web of data	Any
Type of knowledge emphasized	Mastery of specific skills	Exploratory skills and domain knowledge	Exploratory and organizational skills, communication	Cooperative skills, communication, problem decomposition
Adaptation by system to individual student	High	Low	Low	Low
Cost to develop	High	Moderate	Low	Low to moderate
Emphasis on time savings	High	Low	Moderate	High
Prior knowledge of content area required	Low	Moderate	Low	Moderate
Level of student initiative required	Low	Moderate	High	Moderate

ITSs are most appropriate for supporting the acquisition of well-specified skills by providing strong guidance (when appropriate) and making few demands on the learner for learning initiative: The system itself can take the initiative to prompt or question the learner. Time savings are a primary benefit. Current instructional uses of ITSs are still largely experimental but are expected to broaden significantly as the technology matures and personal computers continue to decrease in cost and increase in computational power.

- Microworlds' unique educational feature is the ability to interactively manipulate some environment, with control over some of the variables in that environment. Such systems strongly support exploratory learning of well-understood situations while supplying limited, implicit guidance. Microworlds make moderate demands on the student, and the primary benefits are a deep understanding of the underlying relationships in the microworld and practice with discovery skills. Unlike their close relatives, computer simulations and simulators, microworlds have not been widely developed or applied to education and training. However, with the shift in desired employee skills towards more critical thinking and higher-order thinking skills, wider development and application of microworlds is expected.
- Hypermedia environments' unique feature is that they supply learners with a rich, tailorable, and extendible knowledge base for learning. The multiple structures or linkages of facts and data support the exploration, construction, understanding, and communication of complex webs of related concepts. However, hypermedia environments require a good deal of student initiative and provide little guidance. Applications of hypermedia environments are growing rapidly and widely.
- Collaborative learning environments' unique educational feature is the explicit, designed-in social support: They strongly support cooperative learning, communication, and group problem solving. Any guidance is provided by human instructors, mentors, or the other learners, rather than by the system itself. These systems can support the learning of any domain with moderate demands on the learner. Educational applications of asynchronous conferencing via electronic mail and data sharing are beginning to be applied to education with promising preliminary results.

The evidence of CAI effectiveness suggests benefits from the emerging classes of computer applications.

Frame-based CAI has existed since the 1960s and has been used in a large number of settings and with a large variety of learners. As such, it has had the opportunity to be implemented and tested in a variety of ways and hence has gone through a maturation process. Evidence of this maturation can be found in numerous publications on fielding and testing. Metanalyses of the effectiveness of CAI in general (Kulik, Kulik, and Bangert-Drowns, 1985; Bangert-Drowns, Kulik, and Kulik, 1985) and of CAI with adult learners (Kulik, Kulik, and Shwalb, 1986; Kulik, Kulik, and Cohen, 1980) show significant educational benefits, relative to more traditional classroom instruction. Similar results appear to be true under certain conditions with military training and CAI-based uses of optical disc technologies (Fletcher, 1990; Winkler and Polich, 1990).

This finding of general CAI effectiveness, in combination with both the preliminary findings of some educational benefits from certain examples of the emerging classes of technology and the theoretical reasons behind the unique educational features of the emerging classes, provides reason to be optimistic about their educational benefits. Certainly one should maintain a highly skeptical view of results as they accrue and carefully weigh evidence of benefits. However, there appears to be an argument for the future usefulness of these classes of tools, and potentially greater benefits than from CAI.

Skills demanded by changing workplaces may be supported by new educational technologies.

The emerging technologies described in this paper may support the development of a variety of the skills increasingly demanded by the changing workplace (Bailey, 1990). The relationship between different changes in the work environment and the increased skill demanded by those changes is summarized in Table 2. Also in Table 2 are the classes of tools that potentially support each area of skill development. Strengthening or weakening this finding requires empirical evidence of the tools supporting or not supporting acquisition of these skills as specified. Such evidence will accrue as the technologies are studied and fielded more widely.

A separate but related point is that some of these classes of tools and the computer hardware that supports them are themselves appearing in work settings as training tools (Graham, 1990). Hence, familiarity with computer technologies generally, or the emerging classes of tools specifically, can provide a potential benefit.

Table 2
Learning Tools Supporting Skills Demanded by the Changing Workplace

Changes Taking Place in Workplace	Knowledge, Skills, and Dispositions Required to Adapt to Change	Emerging Classes of Education Technologies to Support Skill Acquisition
Wider participation in management	Critical thinking	Microworlds, hypermedia, collaborative learning
	Cooperative problem solving	Collaborative learning, microworlds
	Decision making	Microworlds, collaborative learning
	Problem formulation and solutions	Microworlds, hypermedia
	Basic economics	ITS, microworlds
	Communication	Collaborative learning
Work is becoming more distributed	Self-management	Microworlds
	Self-reliance	Microworlds
	Resourceful information seeking	Hypermedia
	Problem formulation and solutions	Microworlds
	Communication	Collaborative learning
Up-skilling for flexible specialization in manufacturing	Creative problem solving	Hypermedia, collaborative learning
	Communication	Collaborative learning
	Technology-specific skills	ITS
Participation in quality control	Statistical reasoning	ITS, microworlds
	Scientific reasoning	Microworlds, ITS
	Communication	Collaborative learning
Technology rapidly changes tasks	Fast acquisition of new knowledge	ITS
	Adaptability: Learn-to-learn	Hypermedia
Technology makes the workings of devices less observable	Abstract reasoning	ITS, microworlds
	Scientific reasoning	ITS, microworlds
Expensive to get actual tools or experience for training	Use of simulators	Microworlds, ITS
On-the-job training is using new tools	Skills specific to optional learning from technologies	ITS, microworlds, hypermedia, collaborative learning

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Collaborative learning environments potentially benefit geographically isolated populations.

Based on the "teleapprenticeship" work of Levin, Waugh, et al. (in press) the use of computer-based communication for learning at a distance via teleapprenticeships has interesting possibilities for rural or inner-city vocational education students who may have limited access to opportunities for actual apprenticeships in fields of their choice. This work is still young, and the results should be closely followed and evaluated. The concept of teleapprenticeships is a potential source of inexpensive work-related education that can help bridge barriers of distance and time for students without other options for apprenticeships.

Developing mastery of classroom use of computers takes time.

Developing expertise with computers in classrooms has two components: mastery of the technology itself (existing hardware and the educational software, e.g., CAI software) and mastery of the integration of technology into classrooms. These two components take time and resources (Sheingold and Hadley, 1990). Brady's (1991) summary suggests a time scale of five to six years. The magnitude of this start-up cost should be accepted and planned into development efforts by vocational educators if they intend to incorporate new technologies successfully as they mature.

FINDINGS FROM THE VOCATIONAL EDUCATION AND TECHNOLOGY LITERATURE REVIEW

Many uses of computers exist in vocational education.

The literature on applications to vocational education domains of CAI and computer-based tools not specifically designed as educational software (e.g., spreadsheets, programming languages) is rich (see Appendix A). These applications have been generally reviewed for the vocational community, and issues of effectiveness and use have been raised by several authors (Herschbach, 1984; Matthews and Winsauer, 1984; Nasman, 1982, 1987; Rodenstein, 1983; Simpson, 1984; Zahniser, Long, and Nasman, 1983).

The vocational education community currently makes only limited use of new tools.

The literature on new technologies and vocational education (see Appendix A) indicates that there is limited use or experimentation with these tools in the domain of public vocational education. This appears to be due, in part, to the limited funding and lack of appropriate expertise in the community to support research and development.

FINDINGS FROM THE FOCUS GROUP

Before discussing these findings, the caveat must again be stated that although this group represented diverse vocational-education domains and roles, the number of respondents (15) is small and their exposure during the focus group was limited. Hence, the results should be taken only as preliminary and suggestive findings.

Vocational educators perceive the new tools as potentially appropriate and beneficial.

Based on an introductory description, vocational educators from diverse domains articulated a variety of potential educational uses for these tools.

Potential barriers to using the tools resemble those cited in other settings.

The practitioners who participated in the focus group cited a variety of potential barriers to the future implementation of these tools, including limited funding, lack of training, availability and access to hardware, and the need for changes in attitudes about computers as parts of educational environments. Herschbach's review (1984) cites similar barriers to implementation of earlier educational technology for vocational training and retraining.

RECOMMENDATIONS

Again, these recommendations are tempered by the understanding that the classes of technologies reviewed in this paper are not yet mature from a standpoint of demonstrated educational effectiveness. However, preliminary reports of benefits from the literature and the demonstrated effectiveness from earlier uses of computers in education, as cited earlier, provide good reason to believe that such applications will show similar, if not greater benefits. Granted the immaturity of these technologies and the need for more evaluation and demonstrations studies, the findings reported above suggest four recommendations to prepare for and support the possible future roles of these technologies in vocational education.

Prepare now to exploit new technologies as they emerge.

If the promises of education benefits are borne out by evaluation studies, the vocational community should be prepared to integrate the tools as they become available. That preparation should begin with vocational education community and funding support for general and teacher education about the realistic capabilities of the future tools, and should include the communication of knowledge upon which to base hard-nosed "consumer" questions about educational effectiveness.

One finding, according to Sheingold and Hadley (1990), is that using computers effectively in classrooms requires two kinds of expertise: (1) general knowledge of and proficiency with computers and (2) knowledge and experience in integrating computers into lessons. Hence, the community should also begin to allocate resources to support both kinds of expertise: general, hands-on education about computers and support (via workshops, small grants, and minigrants) for the integration of existing educational applications into classrooms. Community members should also be encouraged to seek forums (conference proceedings, newsletters, on-line interest groups, etc.) for sharing their evaluations of current software applications to vocational education.

Hence, while waiting for relevant, high-quality educational software to be developed in vocational areas, members of the community should build or increase their microcomputer expertise and continue efforts to integrate computers into their classrooms. By gaining more computer expertise, vocational educators will be positioned to take full advantage of emerging computer-based educational tools as they become available.

Address the "infrastructure" issues surrounding the implementation and support of computers in classrooms.

Related to the first recommendation for providing teacher education is one to prepare for other aspects of implementing computers into classrooms: how to efficiently install and provide ongoing support for computers and related hardware (e.g., optical discs and local area networks). Research into successful models of implementation and support should be funded.

In addressing issues of implementation, support, and costs of beginning to use the emerging technologies, many of the problems confronted are not specific to the vocational-education community or its settings. Indeed, the findings and recommendations for how to carry out implementation and support are of interest to a wider audience and for a wider variety of tools than just the emerging classes. The use of computer-based educational tools, such as CAI and computer-based multimedia, in academic settings faces the same issues. By directly addressing these issues from the outset, the development work done by the vocational-education community will have both a higher chance of promoting smooth integration and a potentially wider impact.

Encourage funding of research and demonstration projects of applications in vocational education domains.

The finding that these technologies are currently in only limited use for vocational education motivates this third recommendation. Members of the community should urge policymakers to support the funding of more developmental and "high risk" projects in specific vocational areas (Dede, 1989). Such funding can support some examples of projects from within the vocational-education community, as well as partnerships or collaboration with ongoing projects developing academic or military educational applications. Such activities begin to establish a community of developers who can also help with the evaluation of future commercial applications.

Vocational educators should be included in all phases of this research through requirements that grants be awarded to teams explicitly comprising vocational-education researchers and practitioners paired with educational technology researchers. This would engender more research targeted at building systems directly focused on the needs and goals of vocational educators, such as the ITS development work that Johnson (1990) is doing on teaching diagnostics and repair of generators.[1]

Encourage members of the vocational-education community to participate directly in software development.

Direct participation in software design and development can take two forms: The first form is direct ties to university-based research projects with large teams and high levels of financial support, such as those recommended above. The second form is through funding small grants for software experimentation and development by motivated individuals or small groups of innovators or "entrepreneurs" in the vocational community.

Clearly, there needs to be sufficient financial support in such grants to cover the costs of hardware, software, and generous amounts of developer time to learn about the technology, experiment with it, produce some educational product, and then do outreach to the community. Also recommended are electronic-mail links between innovators and gatherings of the grantees. Both would provide social and technical sharing and support. The two classes of tools that provide the lowest start-up costs for individual innovators are hypermedia environments and collaborative learning environments.

[1]Also funded by the National Center for Research in Vocational Education, Peter Pirolli and Dan Russell of the University of California, Berkeley, are engaged in developing a computer-aided instructional design environment (IDE). IDE provides a variety of hypermedia, a relational database, and AI functionalities for performing analyses and specifications of instructional designs in vocational education.

- Hypermedia technology offers perhaps the best point of entry into software development, given the well-developed hypermedia tools that are commercially available for microcomputers. First-hand experience developing an application using a hypertext or hypermedia tool would provide a feel for the way in which information can be structured for use in a classroom. People with development experience provide the community with highly skilled information sources and consumer advisors when future professionally created software becomes available.
- Collaborative learning tools offer another excellent point where vocational educators can immediately begin to participate. Many private and public electronic bulletin boards and electronic-mail networks can be easily accessed. By becoming familiar with the hardware (a modem and telephone) and simple communications software needed to experiment with this public forum of information exchange and informal education, vocational educators can begin to assess the value of applying such tools to their domains.

SUMMARY

These tools are moving out of laboratories and into academic classrooms and training centers, both in America and around the world. This movement is accelerated by dramatic drops in personal computer prices and increases in computational power. The educational tools we describe run on such machines and have the ability to help teach a variety of important general, work-related skills, including critical thinking, cooperative problem solving, communication, and information seeking. Such skills are being increasingly demanded of workers, who must adapt to meet the challenges of an increasingly dynamic, competitive world market. The machines are becoming affordable; the educational tools are emerging; and there is a rising demand for the skills these tools appear to be capable of helping teach.

Given the growth of these classes of tools and their potential for demonstrable educational benefit, the question does not appear to be "if" they will affect work-related education: They already have and continue to do so. These tools are being developed and refined and are appearing in corporate and military training. The question is how the vocational-education community can position itself most effectively to use the tools as they mature, as well as how it can help shape those tools to make them feasible for vocational classrooms.

The vocational-education community can achieve this positioning through supporting development of two kinds of foundational expertise necessary for successful classroom use of future tools: basic computer knowledge and experience integrating existing educational software into instruction. The community should also begin to address the realities of carrying out implementation and support by exploring how to build an infrastructure of technical knowledge, teacher education, and hardware support. Inherent in this and earlier discussions is the issue of who will fund the recommended research, teacher education, implementation, and support. Finally, interested entrepreneurial members of the community should involve themselves in shaping the development of tools through different kinds of direct participation, either through pairings with university research or through using appropriate tools for more local, smaller scale, software development. Funding such technology-based research in vocational domains will help the community to build research and development expertise of its own, providing a more critical and informed foundation for successful integration of effective computer-based educational tools as they mature.

Appendix A

SUMMARY OF SELECTED LITERATURE

To identify the scope and content of previous research and development of emerging technologies for vocational education, we searched the general education, vocational education, and training literatures. We discovered a large number of references to the use of microcomputers in vocational education, but a limited number to the use of the computer as a teaching tool. This summary is broken into two sets of references: those that generally discuss applications of CAI systems (Table A.1) and those that relate to applications of the emerging technologies (Table A.2). The goal of these summaries is to provide readers with a starting point from which to pursue literature in their field of interest.

Table A.1

Vocational Literature on CAI, Interactive Videodisc (IVD), and Computer-Managed Instruction (CMI)

Type of Publication	System Type	Setting	Domain	References
CAI effectiveness evaluation	CAI	Various	Various	Kulik et al., 1986
Survey of teacher practices	Various	4th-12th grade	Various	Brady, 1991
Software evaluation tool	CAI and simulation	Various	Various	Matthews and Winsauer, 1984
Software evaluation tool	Microcomputer application	Various	Various	Oregon State University, 1983
Policy overview	Various	Various	Various	Herschbach, 1984
Overview of uses in Arizona	CAI	Public voc ed	Various	Simpson, 1984
Overview of uses in Ohio	CAI	Public voc ed	Various	Lantz, 1984
Overview	CAI	Public voc ed	Forestry/surveying	Watson and Scobie, 1984
Overview	CAI	Various	Various	Nasman, 1982
Overview	CAI CMI, and IVD	Various	Various	Nasman, 1987
Overview	CAI and CMI	Various	Various	Zahniser et al., 1983
Overview	CAI and IVD	Industry, medicine	Various	Kerka, 1986
Overview	CMI	Public voc ed	Agriculture	Neason and Miller, 1982
Software review	CAI	Public voc ed	Nursing/nutrition	NCRVE, 1986
Brief project description	CAI with IVD	Industry	Safety	Graham, 1990
Overview of in-service training	CAI	Community college	Health, business	Dunn, 1985
Overview of CAI methods	CAI	Corporate	Banking	Clark, 1990
Project report	CAI and videotape	Public voc ed	Lathe/fuel injection	Smith, 1985
Overview	Various	Various	Various	Snyder and Carroll, 1990
Project report	Instructional technology	Universe	Various	Mitchell, 1990
Project report	Auto instruction design: VISTA	Military	Military, various	Ahlers, 1990
Overview of hardware	Various hardware	Various	Various	Sherman, 1990
Overview of evaluation	Various	Various	Various	Webster and Finney, 1990
Project reports	Various	School	Agriculture, industry	Rodenstein, 1983

Table A.2

Vocational Applications of Emerging Tools

Type of Publication	System Type	Setting	Domain	References
Overview	ITS and CAI	Military	Elec. diag./ troubleshooting	Gray et al., 1985
Review	ITS	Military, industry	Various	Garcia, 1990
Project report	ITS	Military	Mechanical maint.	Towne and Monroe, 1988
Project report	ITS	Military	Computer programming	Shute et al., 1989
Project report	ITS	Military	Radar repair	Massey et al., 1988
Project report	ITS	Military	F-14 radar intercepts	Ritter and Feurzig, 1988
Research report	ITS	Industry	Generator troubleshooting	Johnson, 1990
		Military	Avionics repair	Gitomer et al., 1989
Software review	Simulation: int. design simulator	Various	Interior design	Worts et al., 1987
Brief project report	Simulation with IVD	Corporation	Retail sales	Graham, 1990
Project report	Simulation	Medical	CPR	Hon, 1982
Overview (description)	Simulation	School	Welding	Nasman, 1987
Overview	Hypermedia	Prof. school	Police conduct	Lambert, 1990
	Hypermedia	Prof. school	Crisis management	
Review	Distance learning	Home, work, school	Various	Brock, 1990
Project report	Distance apprenticeship	Public school	Corporate	Levin et al., in press

Appendix B

QUESTIONNAIRE USED WITH THE FOCUS GROUP

Computer-Based Tools for Future Vocational Educational
LACROP Discussion and Questionnaire
Wednesday, 13 June 1990

Matthew Lewis
Information Sciences Department
The RAND Corporation

Instructions

First, let me sincerely thank you for assisting me with my research by taking the time to join in the discussion and thoughtfully fill out this questionnaire. The results of my literature review, our discussion, and your input on this questionnaire will be developed into a paper for distribution by the National Center for Research on Vocational Education.

This is a three-part questionnaire, each part with a distinct purpose:

1. The collection of information about you and your experiences that will be helpful in analyzing this information later.
2. A section asking you to individually **brainstorm** about how, if at all, you think different kinds of applications of computers to education might benefit students in **your field** of vocational education. In this part please try **not to focus** on the pragmatic issues associated with attempting to integrate new computer-based tools into classrooms. Instead, focus on what might be applications useful to your students.
3. A section asking you to think **realistically** about the ways to help integrate beneficial educational technologies into your classrooms. Here I would like to get your honest opinions about what you think are the biggest roadblocks or hurdles that would have to be overcome, and how they might be tackled.

Feel free to look back over the copies of the vugraphs used in this talk. As a reference I have provided a page with the names of the different categories of computer-based educational tools referred to in the discussion and a reference to the project demonstrated in the relevant video clip.

View your answers to these questions as a chance to communicate with the funders of vocational education research about your feelings and ideas and the future uses of educational technology in your classrooms. The final page of this questionnaire lists my address and phone number and is meant for you to tear off and keep, in case you have any follow-up comments or questions.

Please feel free to ask questions at any point!

(6 inches of blank response space included on actual questionnaire)

Part 1: Professional Information

Name: ____

Position: ____

Area of voc ed: _____________________________________

Number of years you have taught: _______

Number of years you have worked in your field: _______

In a few sentences, describe your responsibilities on the job:

(1.5 inches of blank response space included on actual questionnaire)

NOTE: *The next set of questions are meant to assess your personal and professional history using computers.*

Do you use a computer at work or as part of your job? _______

If yes, what tasks do you carry out by computer?

____

Have you ever used computers to **help you teach** in your voc ed classes? _______

If "yes," how?

____

Number of classes in computers or programming that you have completed: _______

Do you own a personal computer? _______

If "yes," what manufacturer and model?

____

If you own a personal computer, what application is it **primarily** used for (e.g., word processing, games, spreadsheets, programming)?

____

Computer-Based Instruction for Future Vocational Education: Brainstorming Questionnaire

In this section I would like you to "put on your rose-colored glasses" and creatively brainstorm about how each of the kinds of tools you were briefly exposed to might be useful in your classrooms. In general, I would like you to think about these technologies as if you could, with the wave of a wand, have a system of your choice with machines of your choice in your classroom for teaching purposes. We will be directly addressing the realities of such changes in the next section of this questionnaire. For now, please try to ignore the roadblocks to such changes and brainstorm positively.

1. Using the 5 point scale below, please rate the **potential educational benefit** you perceive of each of the discussed tools. **AGAIN, FOR THE MOMENT, TRY TO IGNORE THE REALITIES OF ACTUALLY IMPLEMENTING SUCH TOOLS.**

Potential Educational Benefit to Your Students

1: High 2: Moderate 3: Some 4: Low 5: None

After rating each, briefly outline your ideas and the **specific ways** in which you think the applications could be beneficially used in your area.

A. "Intelligent" tutoring systems (e.g., Geometry Tutor, Maintenance Tutor)
RATING: _______
(3 inches of blank response space included on actual questionnaire)

B. Microworlds for self-directed exploration (e.g., Alternate Reality Kit, where you can change gravity) RATING: _______
(3 inches of blank response space included on actual questionnaire)

C. Hypermedia (e.g., English lit database, Palenque, the Aztec temple tour)
RATING: _______
(3 inches of blank response space included on actual questionnaire)

D. Collaborative learning environments (e.g., The Envisioning Machine, electronic conferencing) RATING: _______
(3 inches of blank response space included on actual questionnaire)

Computer-Based Instruction for Future Vocational Education: Pragmatics Questionnaire

The purpose of this section of the questionnaire is to bring us back to the realities of real students, in real classrooms, in real schools with real teachers, budgets, and time pressures. Do not feel compelled to be optimistic. **Please be as realistic as possible, based on your experiences and beliefs.**

1. List what you see as the biggest hurdles or roadblocks to implementing the kinds of computer-based educational tools that you have judged as potentially useful to voc ed. Then please rank these hurdles or roadblocks from 1 to the number you have listed, with 1 being the most important or greatest impediment. Use the back of this page, and the extra blank pages at the end of this questionnaire, if necessary.

   (6 inches of blank response space included on actual questionnaire)

2. Of the problems or roadblocks mentioned in your response to the previous question, what do you perceive as the best ways to attempt to overcome each impediments to successful implementation?

   (9 inches of blank response space included on actual questionnaire)

3. If there are existing computer applications in your area of voc ed, what is the **best** use or program to which you have been exposed, and why?

   (2.5 inches of blank response space included on actual questionnaire)

4. Of the existing computer applications in your area of voc ed, what is the **worst** use or program to which you have been exposed, and why?

   (2.5 inches of blank response space included on actual questionnaire)

5. If you could sit down with a group of people who are designers of computer-based educational tools for vocational education, what would you say to them about your concerns for the design of future tools to make them more usable and effective?

   (2.5 inches of blank response space included on actual questionnaire)

6. Any overall comments, questions, or observations you would like to share?

(3 blank pages followed on actual questionnaire)

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