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ABSTRACT

This report summarizes way in which computer technology and communications have been found to enhance learning in K-12 classrooms. This discussion of the learning-related outcomes of computer technology in K-12 education assumes: that the technology is used in appropriate ways, and that the technology is used in the course teaching, by a teacher who both knows the subject matter and understands the role(s) of technology-based methods in presenting subject matter and in encouraging and enabling students to explore. Information summarized here reflects published and unpublished sources and direct observation. The report consists of the following chapters: (1) Performance in Basic Skills; (2) Performance in Specific Subjects; (3) Preparation to Become Productive and Informed Citizens; (4) Development of Critical Thinking and Information Evaluation Skills; (5) Benefits of Being Able to Access Information in New Ways; (6) Overall Performance Enhancement; (7) Other Ways in which Technology Makes a Positive Difference. Project results show increased student learning for students with online use. (AEF)

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Learning-Related Outcomes of Computer Technology in K-12 Education

By Kenneth W. Umbach, Ph.D.

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(916) 654-5829 fax

Prepared at the Request of Assembly Member Kerry Mazzoni

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CONTENTS

This paper summarizes ways in which computer technology and communications have been found to enhance learning in K-12 classrooms. Information summarized here reflects published and unpublished sources (both formal and informal) and direct observations.

Introduction

This paper has been prepared at the request of Assembly Member Kerry Mazzoni, Chair of the Assembly Education Committee, to support the work of the Commission on Teacher Credentialing in developing computer technology training standards for teachers. Those standards will respond to requirements of Assembly Bill 1023 (Chapter 404, Statutes of 1997).

This discussion of the learning-related outcomes of computer technology in K-12 education assumes:

(1) That the technology is used in appropriate ways, and

(2) That the technology is used in the course of teaching, by a teacher who both knows the subject matter and understands the role(s) of technology-based methods in presenting subject matter and in encouraging and enabling students to explore.

That is, technology may be productive in K-12 schools when it is applied within an appropriate educational framework under the direction of a teacher, and taking into consideration the needs of the students and what is appropriate to the subject. This discussion does not speculate on any abstract contribution of "technology."[1] Instead it sees computers, software, digital information resources, and the Internet in the context of the teacher's role. The centrality of the teacher's role underlines the importance of training in the effective and appropriate use of technology in the classroom. The literature unambiguously agrees with this point.

As students mature, they learn to direct their own learning and may apply many types of tools and resources in achieving learning objectives. One of the goals of education is to foster this capacity for self-directed learning, a capacity that is both strengthened and complicated by the new resources provided by technology.

Computer technology and computer-mediated resources have changed radically in the last five years. The power of desktop computers has grown enormously in that period and is amplified by the growth of local area networks. Even that growth is overshadowed by the revolutionary growth of the Internet and the explosion in information resources available by way of the Internet and on CD-ROM disks.

The rapid growth and increasing sophistication of the technology available renders older evaluations of the impact of technology obsolete or incomplete in many respects. A major report published in 1995 by the U.S. Congress's Office of Technology Assessment noted, "most schools lack connectivity, administrative and organizational support, and technical expertise to integrate electronic networks into the teaching and learning process."[2] Since then, however, schools have increased their access to and understanding of computer technology and communications in the curriculum.

Despite the dross on the Internet, resources of genuine value – the digital equivalent of 24-karat gold – have multiplied and have become freely available. The growth of the Worldwide Web and the ease with which it may now be accessed through graphic browsers have radically expanded opportunities for teaching and learning.* It would be difficult to overstate this fact; it is possible to communicate it fully only through experience.

This report is brief and makes no pretense of being a systematic or exhaustive review of evidence. Nonetheless it introduces a large, scattered, and widely varied set of reports, both formal and informal, and provides a bibliography that will help the reader to find numerous related documents. The bibliography includes annotations and hyperlinks to pertinent Web sites or to the documents themselves. The annotated bibliography is part of this report, not just an addendum to it, and I encourage readers to peruse it.

Evaluation of the impact of technology on educational outcomes is difficult. I have taken the liberty of including some of my own comments as to why this is so and of including information on types of computer-technology-based opportunities for K-12 learning even where outcome measurement data are not yet available.

Acknowledgements

This report has benefited from insights offered by members of the LM_NET discussion list and discussion and visits with teachers and librarians in several California schools. Among these are Brian Wood, teacher on special assignment for technology, Redlands Unified School District; Dave Anderson, teacher, Redlands East Valley High School; Mark Thompson, teacher, Redlands East Valley High School; Kevin Hough, teacher, Redlands High School; Mark Williams, librarian, Colton High School; Steve Peterson, librarian, Cope Middle School; Jeanette Dow, librarian, Olive Drive Elementary School; Carl Martz, librarian, Yucaipa High School; and Bob Laramee, librarian, Arvin High School. It has also benefited from access to a demonstration copy of SIRS Researcher, a full-text article database popular among schools.[3] Special thanks go to Chloe Bullard, Executive Fellow with the California Research Bureau, 1997-98, who tracked down valuable source documents, and to Dan Mitchel, of the California Research Bureau, for his assistance in locating information on educational-technology-related dissertations.

* See my *Computer Technology in California K-12 Schools: Uses, Best Practices, and Policy Implications* (Sacramento: California Research Bureau, 1997), especially pp. 2-6 and 21-27, for examples.

1. Performance in Basic Skills[4]

Basic skills include the traditional three R's of "reading, writing, and 'rithmetic." A report published in June 1996 by the U.S. Department of Education describes ways in which computer technology has enhanced performance in those areas. "In a decade-long series of studies," the report states, "students in classes that use CAI [computer-aided instruction] outperformed their peers on standardized tests of basic skills achievement by 30 percent on average." The report also states, "Video and audio technologies [enhance] students' ability to remember and understand what they see and hear . . . multimedia significantly enhances students' recall of basic facts, as well as their understanding of complex systems . . . [and] technology has helped students master the traditional basic skills of reading, writing, and arithmetic . . . ."[5]

Reading

Although a computer screen is a poor medium for sustained reading, it is excellent for scanning short pieces of text. The computer offers the opportunity to use hypertext connections between documents and other types of computer files, including sound and graphics. A multimedia computer can recite the document aloud or show animations when the user clicks the mouse cursor on a word or an image.

In addition to their multimedia capacity, digital media have vast text storage capacity. For example, the entire 30-volume *Encyclopaedia Britannica* (plus sound and video clips and animations) fits on two CD-ROM disks. (Smaller multi-volume encyclopedias fit on a single CD-ROM disk.)

Reading software has a place in school, as it does in many homes. Such programs as "Reader Rabbit" and "Just Grandma and Me" help children learn to read in an interactive, entertaining way. Programs of that sort enable children to learn at their own pace and to repeat sections as needed or as interest dictates. I have, as of this writing, not found recent evaluations of the effectiveness of such programs in teaching reading or improving reading performance. This is an area in which software has changed considerably over the past several years, with the growth of multimedia and increased sophistication of design and content, so older evaluations are not necessarily reflective of current practice and impacts.

A report published in 1989 found that "[Chapter 1 students] who worked with the ESC [Education Systems Corporation] software (experimental groups) demonstrated significantly greater increases in achievement both in reading and in mathematics than those Chapter 1 students who did not have access to computer laboratories (control groups)." The gains were noted at grade 2 and 3 levels.[6] The researchers noted that the "results coincide with numerous other research studies on the effectiveness of computer-assisted instruction and achievement . . . ."[7]

A program called "Daisy Quest" was reported to have contributed to reading ability: "In two separate studies and five different measures of phonological awareness, the computer-based approach was found to be significantly more effective than regular instruction."[8]

Computers, digital resources, and electronic communications contribute to the teaching and learning of reading in indirect as well as direct ways. One of the indirect but significant contributions is the role of online communications in helping teachers and school librarians to select and locate books to meet specific curriculum needs and to meet the needs of particular students. Teachers and librarians who participate in e-mail discussion groups may obtain assistance from other teachers and librarians around the world in pinpointing appropriate print resources and in locating sources. Quick access to publishers and booksellers online provides additional assistance and expedites the process of ordering materials. Although I am unaware of any studies of this phenomenon or its impact, I have observed this process over an entire school year, and believe that it is valuable, and likely to become increasingly so.

Another type of indirect contribution is made by computer-based reading incentive programs. One of these, Accelerated Reader (AR) consists of a large selection of fiction and non-fiction books, computer-based multiple-choice tests, and an incentive system to encourage reading. Reading AR-listed books and success on tests on those books earn students points that they may redeem for merchandise or other awards. Some users of the system have found that it encourages more and better reading among students. One teacher commented, "I've used Accelerated Reader for 2 years and I have never seen first graders so excited about reading. It has really improved their scores."[9]

Writing

Some teachers report that word processing software improves students' writing by removing the drudgery of revision, easing editing and correction, and speeding the process of getting the words onto the page. Anyone who recalls the days when a paper had to be retyped from beginning to end in response to some reorganizing or other revisions certainly understands this.

As so often, with respect to writing computer technology allows new ways of doing old things. Impacts of new methods may not be fully known for some time to come. Students have learned to write without the aid of computers in the past and can do so today. But it has become typical for writers to use word processing software and have access to digital information sources (reference works, periodicals and databases, and information of all types on the Web); this is the norm in higher education and business. Standardized tests do not capture the benefits of early mastery – before college, before entry into the workplace – of the skills and methods used now for writing.

Ilana Snyder's overview of the literature outlines the different approaches to evaluating the impact of word processing software on writing.[10] The picture that she found in the

literature is complex, and there is not room to explore it all here. In part, however, she found:

> In the studies that combined word processing with effective writing pedagogy, the findings were uniformly positive: when instruction involved teaching students strategies aimed at improving their writing skills, writers using word processors achieved at a higher level than similar writers not using word processors . . . .[11]

Snyder also cites positive anecdotal reports from the early phase (1978-88) of studies of computer-aided writing instruction.

Turning to the more recent period, 1988 to present, Snyder observed that "The findings were . . . more persuasive," citing a series of positive outcomes.[12] She also discusses positive impacts achieved through use of hypertext methods (links from one document to another). For example, "Interactive hyperfiction [researchers Kaplan and Moulthrop argue] has considerable potential for those who teach 'writing through literature, or literature through writing.'"[13] Such techniques require planning and understanding on the part of the teacher.

Snyder cautions, "it . . . may be that reading and writing are such complex cognitive, social and cultural practices that we may never fully understand the influences of these technologies."[14] She also warns of the risks to which teachers must be alert in exploiting computers as aids in teaching writing.

The U.S. Department of Education, in its *Getting America's Students Ready for the 21st Century*, noted that "Numerous studies have demonstrated that technology is particularly valuable in improving student writing," and cited a variety of sources for that finding, including work of the Apple Classrooms of Tomorrow project.[15]

Also see "English (Language Arts)", in section 2, below.

Arithmetic

While computers and software may be useful in teaching arithmetic – especially through drill and practice programs – they are now essential to the teaching and use of mathematics and to the teaching of subjects that depend on mathematics. (K-12 mathematics encompasses algebra, geometry, trigonometry, statistics, analytic geometry, and calculus. Arithmetic is, in essence, the "training wheels" stage of mathematics.)

A report published in 1989 (also cited above under "Reading") found that "[Chapter 1 students] who worked with the ESC [Education Systems Corporation] software (experimental groups) demonstrated significantly greater increases in achievement both in reading and in mathematics than those Chapter 1 students who did not have access to computer laboratories (control groups)." The results were even more favorable for mathematics achievement than they were for reading.[16]

One of the key benefits of computer programs is that the student may work at his or her own pace, review sections as needed, and progress quickly when material can be mastered quickly.

2. Performance in Specific Subjects

Much evidence regarding specific subjects is focused more on what is possible and on descriptions of what is being done than it is on objectively measured outcomes. Nonetheless, evidence is accumulating of the productive role that technology is increasingly playing in a wide range of subjects. The comments below touch on only a few of the available reports.

English (Language Arts)

Stephen Marcus summarizes the role of technology in language arts in "A Friend for the Language Arts: How technology can enrich reading and writing instruction."[17] Marcus is the coordinator of the National Writing Project Technology Network at the University of California, Santa Barbara.

Marcus observes, "Whatever the shortcomings of specific language arts software packages, researchers and practitioners agree that integrating various technologies with traditional teaching methods and goals has definite advantages." He also notes,

> The key to successful teaching with technology is to combine smart tools with smart instruction. Teachers and students regularly report that computers and related hardware such as CD-ROMS, laserdiscs, camcorders and digital cameras, and scanners enrich teaching and learning. Smart teaching with smart technology pays off by helping students master and go beyond any one lesson or unit.

Several examples of student work (planned, in progress, or completed) aided by computers and digital resources may be seen at The Interactive University California Heritage Pilot Project site.[18] Among the projects is "Contribution of Chinese-Americans to the Development of the United States," by students of Abraham Lincoln High School, San Francisco.[19]

A similar type of project, but one that is not part of the California Heritage Project, is a report on historic Davis (California) by students of Birch Lane Elementary School, in that city.[20] The students combined research (including use of primary sources) with writing in order to develop an informative Web presentation.

Broadly comparable projects are becoming common, although concerns about privacy or other issues may prevent many from being posted on the Web for general access. The proliferation of such projects demonstrates that students can successfully combine research and writing with the use of technological tools. Some teachers report increased

motivation among students to do quality work when it will be posted for worldwide access.

The following informal message received from a high school librarian in New York shows a first hand view of computer technology in the teaching of writing and research and touches on several themes found in the literature:

> In our high school we use the computers as a tool. Students are using them for writing, and the teachers stress writing as a process. Students are much more inclined to follow the process writing path, and make corrections, etc., to their work because the computers make it so easy to do. Students understand what it is to do their best work and are more focused on that than past generations were. I think that for many students, the quality of their writing has improved.
>
> In terms of research and class assignments the computer technology (along with FAX, e-mail, etc.) has dramatically improved a student's ability to locate information. From my observation, they locate the information much faster, which allows them to keep to the task. (Previously, the hunt was the thing, and it was distracting and frustrating). Now that the frustration factor has been lessened, students stay on task better and complete assignments, rather than giving up.
>
> I also have observed that the technology is the great equalizer. Capable students have always been able to research in the library. Now, a larger group of students can successfully complete the research portion of their assignments. I see special success for the "lower" level student.
>
> However, the technology has shifted paradigms. Now, librarians do not only store information and teach location skills; we also have to teach critical thinking skills, because the user has to differentiate between information which is/isn't useful to the problem. [This process contributes to development of h]igher level skills [among students].
>
> Finally, I have observed more students at the computers working in groups. When I and an English teacher asked them some questions (because kids in groups at computers look notoriously like they're blowing off class time), we found there was a lot of collaboration going on. Brainstorming search terms, evaluating search paths. Nifty stuff – yet it looks, to the casual observer, like these kids are having too much fun.[21]

The section on "Writing" in section 1, above, also addresses this topic.

Science

Computer technology affords students expanded opportunities for learning in many areas of science. These opportunities range from computer or videodisc-based dissections[22] to remote operations of a real, 100-foot radio telescope[23] and "virtual" participation in an

archeological expedition.[24] These opportunities are too new to allow much possibility of published evidence for learning outcomes yet, at least by any standardized measures. Over the long run, though, it seems reasonable to expect some interesting and positive results, both in terms of measurable learning and in terms of the expansion of interests among students who might otherwise never have been exposed to these areas of science.

Douglas Gordin and others describe several Web-related efforts to strengthen school science programs.[25] Students may not only draw upon scientific resources online but may also contribute their own measurements and observations (of weather data, for example) to international databases used by scientists. Prominent in this type of effort is the Global Lab Project of the Technical Education Resource Center (TERC).[26] TERC has a wide range of projects in science and mathematics, many of which involve students directly and some of which work with teachers in developing course materials.

A similar type of project is GLOBE (http://www.globe.gov), to which TERC is contributing:

> Global Learning and Observations to Benefit the Environment (GLOBE) is a worldwide network of students, teachers, and scientists working together to study and understand the global environment. Students and teachers from over 5000 schools in more than 70 countries are working with research scientists to learn more about our planet.
>
> GLOBE students make environmental observations at or near their schools and report their data through the Internet. Scientists use GLOBE data in their research and provide feedback to the students to enrich their science education. Global images based on GLOBE student data are displayed on the World Wide Web, enabling students and other visitors to visualize the student environmental observations.

Projects of this type contribute to "authentic" learning – sometimes called "learning by doing" – based on real activities and direct participation rather than only on lecture and demonstration.[27]

History and Social Studies

The growing Internet archives of historical documents, images, maps, and other resources useful in the study of history enable teachers to supplement textbooks and print resources and allow students to pursue expanded paths in exploring the subject.

To cite just one example of Internet-based resources, "Teaching World History in Georgia," http://www.ngc.peachnet.edu/academic/arts_let/history/TWHIG/TWHIG.htm. This is:

> a website established in 1997 by the University System of Georgia to advance teaching, research and service in the field of World History. Future plans for this

site include a gallery featuring sample world history course syllabi, effective classroom instructional techniques and a bulletin board. These galleries will be designed to assist educators at all levels of instruction in sharing their experience in teaching world history in the state and to help them stay current with new developments in the field.

This site in turn has links to further resources, each of which leads to more resources.

The University of California, Berkeley, "Librarians' Index to the Internet" (http://sunsite.berkeley.edu/InternetIndex) offers easy access to a massive set of history-related links. While many or most may be best suited to the college level, some will be of value to high school and even middle school students, and certainly to teachers at all levels seeking to supplement their print resources.

It is not clear what impact these resources are having on learning outcomes in history. The resources on the Internet, though massive and varied, are difficult to navigate, of uneven quality, and in no way integrated into a meaningful whole. Nonetheless, it can be anticipated that the availability of such resources will facilitate teaching and learning.

The California Instructional Technology Clearinghouse's online listing includes more than 1,000 items (many of which are videos and other non-software materials) pertaining to history and social science. Of these, 141 are CD-ROM products covering a wide range of topics and methods in history and social science. An additional 39 products are interactive videodiscs. (CITC's listing puts the areas of history and social science together.)

Given the volume and variety of digital resources for the study of history and the countless ways in which teachers and students might choose to use them, it is not possible to generalize reliably about the outcomes of computer-based media in this area of study.

Foreign Language

Access to foreign language periodicals[28] and Web sites provides varied, current resources for classes. E-mail exchanges with students and teachers in other countries provide additional support for foreign language programs. One Iowa teacher concluded a report on an e-mail-assisted international program this way: "International communications and exchanges are firmly in place and have become the backbone for two Iowa K-12 Spanish-language programs."[29]

Other foreign-language-teaching resources include a variety of software designed for all ages and levels. The California Instructional Technology Clearinghouse lists 20 CD-ROM and interactive videodisc programs in the area of "World Languages."

The key to impact of such resources is, as with so many other resources, the ways in which teachers integrate them into the curriculum. The resources themselves do nothing. They have to be used, and used in appropriate ways.

Technology

Technology-dependent subjects do not just benefit from, but rather *absolutely require*, the presence and use of technology in the classroom. Such subjects include computer programming, business technology (word processing, computer-based accounting, graphics, and so on), computer technology itself, and a wide variety of industrial technology programs. As one teacher pointed out, "the old wood shop and metal shop that we remember are irrelevant today."

Workstations and equipment in a high school Industrial Technology lab (Redlands East Valley High School)
Photo by the author

Visual and Performing Arts

An enormous variety of information online for teachers and students pertains to visual and performing arts. Museums, teachers, and arts organizations have posted every sort of resource. Here, again, measurement of outcomes is difficult and probably premature. There are many facets to the technology-arts education connection. On one hand, computer technology may serve directly as a means of creating artworks. This is an area of growing significance as art gains a place online. On the other hand, the Internet is a source of information on art curricula and resources and is a repository of images and tools of value in arts education.[30]

Evaluation of the impacts of these tools and resources will be a complex matter, especially as they will typically be mediated through a teacher (or selected by students in the course of a project) and integrated into classes that encompass much more than the technology itself or the resources (images, curriculum information, background discussion, and so on) available online or through software.

3. Preparation to Become Productive and Informed Citizens

Within the last few years, substantial archives of government information have appeared on the Worldwide Web. These archives include state and federal laws and pending legislation, bill-related documents, executive branch reports and analyses, and court documents. Information that was difficult, costly, or time-consuming to obtain only a few years ago may now be found in minutes online via an inexpensive and quick Internet connection.

The relative newness of these resources online suggests that there is likely to be little or no meaningful reporting of their impact on learning in the schools or on the quality of preparation of students for civic participation. And, needless to emphasize, much rests on the skill with which teachers integrate the access to such resources into appropriate classes and assignments.

Nonetheless, it is reasonable to expect the ready availability of so many public documents to enhance the ability of teachers to present classes related to laws and government operations and of students to find such information for use in their studies.

4. Development of Critical Thinking and Information Evaluation Skills

If students are to learn to separate the wheat from the chaff among the varied information sources of today, they must have the opportunity to hone that skill by working with those sources (in accordance with any district-adopted policies regarding appropriate use of the Internet*). Abstract discussions of information literacy and of evaluation of sources are no substitute for directly grappling with a broad range of print and digital sources while conducting research and writing.

Acquiring "information competency" in K-12 prepares students for expectations they will encounter in college. The Academic Senate of the California Community Colleges issued a paper outlining the need for information competency.[31] The paper defines information competency as, "the ability to: a) recognize the need for information, b) acquire and evaluate information, c) organize and maintain information, and d) interpret and communicate information . . . ."

* Many districts adopt "Acceptable Use Policies" (AUPs) to which students must agree in order to use Internet access, and some use some type of filtering or blocking system to prohibit access to inappropriate sites. In this section I am speaking of access to resources that are *within* district- and school-adopted policies.

Computer-based catalogs and indexes supplement books in this Library Media Center
Photo by the author

The paper states, "*Information competency is a critical skill for student success.*" (Emphasis added.) To the extent that computer technology (digital reference compilations, online communications, the Internet, and so on) are available to students and are introduced and used in the course of their school work before they reach college, that technology can contribute to the development of information competency that may be put to use immediately *in* college or in the workplace. Students who develop a basic level of information competency *before* college may work on developing more advanced skills during their college years rather than needing an introduction at that time. The Academic Senate's "Information Competency" paper recognizes this: "There must be a concerted effort made among all levels of public education so that information competency skills are emphasized – and funded – from elementary through four-year institutions."

Even the ability to access shoddy information online may be of value. One popular inquiry on the LM_NET discussion group pertains to "bad Web sites" – those that are misleading, inaccurate, or otherwise unreliable, but that may give the impression of validity. Such sites are valuable in helping students to evaluate what is and is not valid and reliable information.[32] While I have not seen evidence of the educational outcomes of this technique, the fact that such inquiries are even being made suggests that some teachers and librarians are alert to opportunities to help students develop critical analysis skills with respect to online information sources.

Given the relative recentness of the Worldwide Web (especially of widespread graphic access to it) and of the slow progress of bringing access to the schools, it is premature to

expect systematic analyses of the impact of Web access on student achievement, although reports of classroom and library media center experience suggest that many students and teachers are making good use of Internet resources.

5. Benefits of Being Able to Access Information in New Ways

The delay in going from completed manuscript to print may be lengthy – from a few weeks to many months or even years. In part, this delay reflects review processes that contribute to the reliability and quality of the published product. In part, however, the delay is the result of the complex mechanics of scheduling, producing, and distributing books, magazines, journals, and monographs. By reducing the delay between writing and publishing (availability), the Web facilitates access to current research and writing. However, this reduced delay may come, in part, at the cost of reduced reliability of the documents, as they may have been posted without rigorous review and editing.[33]

Despite the dubious material on the Internet, there is also an enormous and varied set of resources to supplement and update textbooks, reference books, and other print resources used in and in support of regular classroom work. Magazines, newspapers, academic and organizational research papers, and discussion group archives are legitimate resources for students. Much of that information is essentially identical (other than format) to what is found in recognized print sources of unquestioned value in the curriculum.

Regularly updated commercial CD-ROM resources such as SIRS Researcher[34] and the EBSCO products[35] provide quick access to selected research and reference material. Schools that do not have the space or budget for a large number of print periodicals may be able to substitute (or supplement with) digital resources on CD-ROM or accessed via fee-based online services (dial-up or Internet based) and made available through stand-alone or networked computers. These kinds of resources serve teachers as well as students. However, as they are basically old types of resources in a new format, it is not clear that educational outcome measures would reflect the change from paper to computer-based formats.

These resources do not come without their own challenges, among which is the increased potential for plagiarism and for the pastiche-style compilation of material by students without adequate analysis or synthesis. At the same time, however, the ability to retrieve documents rapidly without the need to locate printed periodicals and other sources that may be checked out, difficult to obtain, lost, or damaged, does offer benefits to students who are attempting to find and appropriately use a range of source material.

6. Overall Performance Enhancement

I have found few documents addressing links between technology and overall performance measures such as grade point average (GPA), Scholastic Assessment Test (SAT) scores, and subsequent college performance. However, Charles Grimm, in his

doctoral dissertation entitled "The Effect of Technology-Rich School Environments on Academic Achievement and Attitudes of Urban School Students," did report higher academic achievement and "higher attitude-toward-school scores" among the students in the technology-rich schools.[36]

The Software Publishers Association issued a report[37] summarizing evidence on the impacts of educational technology. The research was conducted by an independent consultant, Interactive Educational Systems Design, Inc. (IESD).[38]

The SPA/IESD report[39] found:

> Technology is making a significant positive impact in education. Important findings in these studies include:
>
> - Educational technology has demonstrated a significant positive effect on achievement. Positive effects have been found for all major subject areas, in preschool through higher education, and for both regular education and special needs students. Evidence suggests that interactive video is especially effective when the skills and concepts to be learned have a visual component and when the software incorporates a research-based instructional design.
>
> - Educational technology has been found to have positive effects on student attitudes toward learning and on student self concept. Students felt more successful in school, were motivated to learn and had increased self-confidence and self-esteem when using computer-based instruction. This was particularly true when the technology allowed learners to control their own learning.
>
> - The level of effectiveness of educational technology is influenced by the specific student population, the software design, the teacher's role, how the students are grouped, and the level of student access to the technology.

Given the paucity of reports found specifically on the topic of impacts on grade point averages and achievement test results, a few informal comments on the difficulty of correlating these measures with the use of computer technology may be in order.[40]

Computer technology in K-12 for the most part provides new or different ways of doing things that have long been done by other methods. Before computers were even an option in schools, students conducted science experiments, performed mathematical manipulations, did research for term papers and reports, and studied foreign languages. But now computers enable students to conduct experiments with the aid of digital devices and to directly record and display results, to lay out formulas and do calculations with the aid of spreadsheet software, find periodical articles by way of CD-ROM indexes and compilations (not to mention the Internet), and read foreign language newspapers online and communicate with students in other countries through e-mail. The result, especially in the near term, is not necessarily measurably higher learning or increased test scores,

but may well be comparable levels of learning accompanied by mastery of tools that are increasingly typical in education, business, and personal life outside of K-12. That is, the skills acquired through the integration of technology-based tools into the curriculum will have long-term value and impact not captured by short-term tests.

For many students, the most likely impact of computer technology in K-12 (and especially middle school and up) is improved college performance through a head start in using technology for research and writing. Technology is a moving target, having changed rapidly in just the last few years and continuing to evolve rapidly. Clear impacts from exposure in secondary school to the tools and resources afforded by computer technology may emerge over a period of years. Impacts may be expected to appear as increasing numbers of students who "grew up on" Internet-based resources and other digital research tools, word processing, spreadsheet, and graphics software, and electronic communications enter college and use those tools there in a more demanding and competitive environment.

A widely circulated report published by the Educational Testing Service (the organization that produces the SAT) addressed this point explicitly:

> Evaluations of educational technology applications must confront a number of methodological problems, including the need for measures other than standardized achievement tests, differences among students in opportunity to learn, and differences in starting points and program implementation.

Nonetheless, the report's authors found evidence of positive outcomes for educational technology, although not all of the evidence is yet conclusive, and added:

> Many ongoing educational technology projects are in the process of documenting and recording measures of student motivation, academic outcomes, and other outcomes such as increased skills in problem-solving and collaboration.[41]

While evidence regarding measurable, testable outcomes is limited at this point, research does suggest that educational impacts are real where technology is used well. Offering at least some support for this observation is a 1997 survey of U.S. teachers conducted by Wirthlin International for Tenth Planet, an educational software company (http://www.tenthplanet.com).

The survey found that 76 percent of respondents answered "yes" to the question "Has your use of computer technology improved student achievement?" Seventeen percent answered "no" and 7 percent "don't know - refused to answer." A related question asking the respondents to "grade Computer Technology on how well it has improved teaching and learning of core curriculum in your classroom" found only 16 percent giving a grade of "A," 42 percent "B," 30 percent "C," 6 percent "D," and 4 percent "F" (with 3 percent "don't know - refused to answer"). The responses on this question were lower for the Los Angeles sample (although the margin of error was larger than for the entire national sample). Only 5 percent of the Los Angeles teachers gave a grade of "A," 41 percent

"B," 36 percent "C," 9 percent "D," and 5 percent "F" (with 5 percent in the "don't know - refused to answer" category). The favored option for improving the grade, selected by 49 percent of the national sample, was "accessibility/more computers in the classroom," with "more quality software" coming in second at 25 percent. A clear majority of the national sample (75 percent) answered "yes" to the question "Would you like to be able to increase the amount of time you spend using the computer to help you introduce and teach new concepts in core curriculum like math and literacy?" There was strong support (82 percent) for "more educationally sound software in order to effectively integrate computers into core curriculum."[42]

One probably should not attempt to make too much of the Tenth Planet survey results, but they do suggest that teachers find value in computers in the classroom and feel that increased availability would contribute to teaching and learning. This interpretation is consistent with other evidence reviewed for this paper.

7. Other Ways in Which Technology Makes a Positive Difference

Many observers have noticed that students are often enthusiastic about technology, and that this enthusiasm generates greater interest in classroom work.

Proficiency with computers (hardware, software, and communications) is increasingly critical to studies in college. Students who enter college already competent with the basic tools have a head start – possibly a large one – over those who do not.

Observers have also commented on improved cooperation among students using technology-based resources – for example, working in groups on multimedia reports. This, too, is a phenomenon that (if true) is unlikely to be captured in customary types of tests and assessments, although it is widely regarded as valuable nonetheless.

Another interesting development is the capacity of students to develop marketable information technology skills in such areas as computer programming, database management, and Web site management. For example, a report in the online edition of the *San Jose Mercury News*, June 9, 1998, cited the example of an Atlanta high school class that developed prototype business management software that was highly praised by a local business manager.[43] Although the prototype was not yet complete or commercially viable, it demonstrated that the students had acquired a substantial start in understanding commercial software needs. In an economy in which information technology and electronic commerce are important and daily becoming more so, this is not a small matter.[44]

These kinds of skills fill more than one role. They serve a vocational education purpose as immediate preparation for employment, but they also provide tools that students can use in college for doing research, managing projects, and otherwise supporting their class work and can build on in more advanced classes in management, technology, and business.

Technology can assist students with disabilities. For example, a teacher who works with blind and visually impaired students pointed out:

> There are now Braille printers that Braille faster than humans, computer programs that will translate print into Braille, scanners that will read print text aloud, and portable "Braille N' Speaks" and "Type N' Speaks" that a VI [visually impaired] person carries around to type notes, letters, work you name it. You just need to find a print station to print out what you've put into that machine.[45]

Although this technology is relatively expensive, as the market is small by comparison with standard products, it can make an important contribution toward "leveling the playing field."

The U.S. Department of Education, in *Getting America's Students Ready for the 21st Century*, noted that "Learning-disabled students can master complex problem-solving skills as well as nondisabled students with the support of educational technology. . . . Studies of students with disabilities [cited in the report – see its notes] show that technology can expand access to educational resources and enhance students' ability to process and remember information."[46]

Telecommunications offers opportunities for students and teachers alike. A Master's thesis by Kathy Zajac Schaw, "Effective Learning Within Telecollaborative Environments," outlines varied projects implemented with a group of students age eight to ten.[47] Projects included "key pals" (e-mail exchanges among students from distant locations), "pooled data" projects (contribution of data observations from students in many locations to a centrally managed project), sharing of students research and writing, video conferencing, tele-mentoring (distance teaching through technology), and a cooperative product design project among students at widely separated schools.

Ms. Schaw found:

> Each project presented unique successes and challenges. . . . As a result, several common themes emerged regarding telecollaborative experiences and their ability to help children learn. In broad terms, these themes are classified into three distinct categories: Communication, Self-esteem, and Engagement/Interest in Learning.[48]

In each of these areas, Ms. Schaw's experience in the classroom showed positive outcomes from the telecollaborative opportunities.[49]

The Center for Applied Special Technology (CAST), in its report *The Role of Online Communications in Schools: A National Study*, observed that:

> Of all the new technologies, online communications has the strongest potential to break down the barriers and inequities encountered by students of different socioeconomic, racial, linguistic, and disability backgrounds. Networks expand

the limits posed by time and space, giving students and teachers more equitable access to expertise, information, and tools . . . .[50]

The CAST study of online communications in schools found, *inter alia*:

- "Analyses of 9 learning measures indicate that online use can increase student performance."[51]

- "Overall, students in the experimental classes produced better projects than students in the control classes . . . The positive impact of online communications on student learning is corroborated by analyses of student reports on pre-study and post-study questionnaires."[52]

- "Students with online access became more confident and students without online access became less confident, over the course of the study, in activities that relate most closely to the main thrust of the Civil Rights Unit – *carrying out and presenting a research project.*"[53] (Emphasis in original.)

The results of the project were not unmixed, possibly in part as a result of the short time available, so the report should be read as a whole. Nonetheless: "In sum, increased student learning for students with online use is clearly demonstrated by their performance on student projects and changes in their subjective reports on pre-study and post-study questionnaires. Increased student learning due to online use is further substantiated by teacher reports in telephone interviews."[54]

Bibliography

Some of this paper reflects my extensive observations and participation on the Internet. This observation and participation have encompassed both school-related Web sites and education and technology-related discussion groups, generically called "list servers."[55] *The most important of these groups for this research have been LM_NET and EDTECH. LM_NET serves school library media personnel (including certificated library media teachers), and EDTECH serves people involved in educational technology. Both lists have international membership. At the time of this writing, each group has approximately 10,000 members. Archives for LM_NET, EDTECH, and many other education-related discussion groups may be searched via http://ericir.syr.edu/Virtual/Listserv_Archives/, the "AskERIC Education Listserv Archive."*

I have also drawn from visits to several schools and school district offices in northern, central, and southern California.

The following list of sources includes many documents that have extensive bibliographies. Some items cited in the endnotes to this paper or used as general resources (not specifically cited) have been omitted from this list.

Apple Computers, Inc. "Changing the Conversation About Teaching, Learning, & Technology: A Report on 10 Years of ACOT Research." 1995. Available at http://www.research.apple.com/go/acot/acotresearch.html#anchor25466881

Barnes, Bill, et al. *Tales from the Electronic Frontier: first-hand experiences of teachers and students using the Internet in K-12 math and science*. San Francisco: WestEd, 1996. Although this publication focuses on Internet resources and use, the principles can reasonably be inferred to apply to comparable resources available through CD-ROM and other non-Internet media. At many points, the vignettes laid out in *Tales* touch on observed beneficial outcomes of the technology.

California Instructional Technology Clearinghouse. The online version of the Clearinghouse, http://clearinghouse.k12.ca.us, provides free public access to reviews and information on 2,000 recommended software products, searchable by seven categories (keyword, subject, technology, platform, language, grade level, and "other criteria"). Quoting from the site, "The Clearinghouse's evaluation of electronic learning resources is a statewide collaboration which eliminates unnecessary duplication of effort, ensures consistency of evaluations, and provides publishers and producers with one central contact point for evaluation of electronic learning resources in California. Every Clearinghouse evaluation is conducted by one of the Clearinghouse's 19 Evaluation Satellites, each specializing in a particular subject area. Each of these Satellites is operated by a California county office of education and is supported by the California

Technology Assistance Project." Evaluation criteria are posted at http://clearinghouse.k12.ca.us/c/@okSq_sBNm9aAU/toc.html.

Center for Applied Special Technology. *The Role of Online Communications in Schools: A National Study*. Peabody, MA: CAST, 1996. "The goals of the study [conducted in seven major American cities in 1995-96] were: 1) to measure the effects of online use on student learning including information processing, communication, and presentation skills, and 2) to gain insights into what it takes to use online communications effectively in the classroom." Available at http://www.cast.org/stsstudy.html. Unfortunately, when printed, every page of the body of the pdf file is numbered "Page 20." I have renumbered the pages by hand, and cite those numbers in references to the paper.

Christman, Edwin, John Badgett, and Robert Lucking. "Progressive Comparison of the Effects of Computer-Assisted Instruction on the Academic Achievement of Secondary Students." *Journal of Research on Computing in Education*, Summer 1997 (Vol. 29, No. 4), pp. 325-37. Quoting from the discussion section of the paper (at page 331): "It can be concluded that CAI is more effective than traditional methods of instruction in raising the overall academic achievement of students in grades 6 through 12." There are a number of *caveats*, though, including evidence that computer use is losing its comparative advantage over time. That observation may, however, not take into account the variety of ways in which computer technology is being used in schools and the growing role of computers in work and in society at large. The paper looked only at "computer aided instruction," a narrower view than taken in the present paper.

Coley, Richard J., John Cradler, and Penelope Engler. "Computers and Classrooms: The Status of Technology in U.S. Schools." Princeton, N.J.: Educational Testing Service, [1997]. "This report is about technology in the classroom. It is not an argument for or against technology, nor a how to do it manual." One of the topics addressed is "the effectiveness of educational technology." Among the key points is that "Evaluations of educational technology are really evaluations of instruction enabled by technology, and the outcomes are highly dependent on the implementation of the instructional design." The paper is posted at http://www.ets.org/research/pic/compclass.html.

Follansbee, Sari, Bob Hughes, Bart Pisha, and Skip Stahl. "Can Online Communications Improve Student Performance? Results of a Controlled Study." *ERS Spectrum*, Winter 1997, pp. 15-26. Several circumstances (explicitly acknowledged by the researchers) limited the reliability of the study. Nonetheless, the researchers concluded: "The results of this study suggest that online communications can be an important tool for both [students and teachers]." Also see the report listed above under Center for Applied Special Technology, for which Sari Follansbee was the project director.

Glennan, Thomas K., and Arthur Melmed. *Fostering the Use of Educational Technology: Elements of a National Strategy*, MR-682-OSTP. Santa Monica, CA: RAND Corporation, 1996. From the summary: "Research and practice suggest that, appropriately implemented, computer- and network-based technology can contribute significantly to improved educational outcomes. Most of this experience is in small trials in one or a few settings, but research has aggregated these experiences into a significant body of literature that illuminates the potential of technology in a variety of settings." Available at http://www.rand.org/publications/MR/MR682/contents.html, and in printed form from RAND. Especially note Chapter 2, "The Use and Effectiveness of Educational Technology Today."

Gordin, Douglas N., et al. "Using the World Wide Web to Build Learning Communities in K-12." Posted at http://www.covis.nwu.edu/Papers/k12web.html. The authors are with Northwestern University, School of Education and Social Policy. The paper focuses more on the opportunities afforded by the Web than it does on documented outcomes. An extensive bibliography is included. Among the authors' observations: "To date most resources on the WWW [have] been developed without the specific goal of fostering K-12 learning communities. Yet, as the above examples show, even without this aim WWW resources have been developed that are of extraordinary value to schools and learning communities."

Hancock, Vicki E. "Innovation with Technology: Promises and Practices." Posted at http://www.ascd.org/pubs/articles/techart.html. Dr. Hancock is regional field director, Northwest Region, Association for Supervision and Curriculum Development (ASCD). Among the "final words" in this brief paper: "Technology can act as a catalyst for changing the learning environment. It stimulates more interactive teaching, effective grouping of students, and cooperative learning . . . More flexible, student-centered, exploratory environments are evolving in our schools over time, and with them we are only beginning to realize the promise of emergent technologies for learning."

Lazarowitz, Reuven, and Jehuda Huppert. "Science Process Skills of 10th-Grade Biology Students in a Computer-Assisted Learning Setting. *Journal of Research on Computing in Education,* Spring 1993 (Volume 25, No. 3), pp. 366-382. From the discussion section (at page 379): "The integration of the CAL [computer-assisted learning] helped students in the experimental group achieve higher academic performance. These results support the notion that CAL motivates students and enables them to improve their mastery of the knowledge."

Margherio, Lynn, project director. *The Emerging Digital Economy.* Washington, D.C.: U.S. Department of Commerce, 1998. Although this document does not pertain directly to the impact of computer technology on learning, it does clearly establish why it is important for students to become familiar with digital tools and lays out their importance in the economy today. As the introduction notes, "If the trends suggested by this preliminary analysis continue, IT [information technology] and

electronic commerce can be expected to drive economic growth for many years to come. To realize this potential, however, the private sector and governments must work together to . . . endow students and workers with the skills necessary for jobs in the new digital economy." The document is posted at http://www.ecommerce.gov/emerging.htm.

Melmed, Arthur, ed. "The Costs and Effectiveness of Educational Technology: Proceedings of a Workshop," November 1995. Available at http://www.ed.gov/Technology/Plan/RAND/Costs/. The section on "effectiveness" reviews the literature. Although recognizing the uncertainties and the lack, to date, of much needed data, the view presented in the section is positive.

Oppenheimer, Todd, and David Dwyer (Patrick Houston, Moderator). "Audio: Are Schools Suffering 'Computer Delusion'?" RealAudio file (23 minutes), available at http://www5.zdnet.com/zdnn/content/zdnn/0815/zdnn0001.html. Oppenheimer is the author of the widely read article "The Computer Delusion," in the July 1997 issue of *The Atlantic Monthly*. Dwyer is vice president of Advanced Learning Technologies at Computer Curriculum Corporation.

President's Committee of Advisors on Science and Technology Panel on Educational Technology. *Report to the President on the Use of Technology to Strengthen K-12 Education in the United States*. March 1997. Often referred to as "The PCAST Report." Available at http://www.whitehouse.gov/WH/EOP/OSTP/NSTC/PCAST/k-12ed.html.

Réginald Grégoire, Inc., Robert Bracewell, and Thérèse Laferrière. "The Contribution of New Technologies to Learning and Teaching in Elementary and Secondary Schools: Documentary Review." A collaboration of Laval University and McGill University. August 1st, 1996. Posted at http://www.fse.ulaval.ca/fac/tact/fr/html/impactnt.html. This is a concise (36 pages, including references) overview of pertinent literature. The authors note that, "Most of the research that is reviewed comes from studies that included either a) a separate control group of students against which results obtained from an experimental treatment group can be compared, or b) pretest measures of results from the experimental group against which post-test measures can be compared." This report is the most systematic overview of evidence for the impact of technology on K-12 learning that I have found.

Schaw, Kathy Zajac. "Effective Learning Within Telecollaborative Environments" (Master's thesis, St. Michael's College, Colchester, Vermont, 1997). This paper, by a classroom teacher, includes a literature review, bibliography, and analysis (the latter focusing on telecommunications). Among the author's observations, "Researchers are acknowledging strong academic growth with basic skills (reading, writing, mathematics, and oral communication) when students become involved in purposeful communication via telecommunications and when creating

computer presentations . . . ." The paper reports on "research [with third and fourth grade classes] . . . to test and assess how three of the seven types of telecollaborative projects addressed in the Literature Review affect learning: key pal communications, pooled data analyses, and interactions with field experts." Posted at http://www.cvu.cssd.k12.vt.us/wcswww/lighth/thesis/thesis.htm.

Schools of California Online Resources for Education (SCORE). The SCORE sites do for online resources roughly what the California Instructional Technology Clearinghouse site does for software products. There are four SCORE sites: History-Social Science (http://www.rims.k12.ca.us/SCORE); Mathematics (http://www.kings.k12.ca.us/math); Language Arts (http://www.sdcoe.k12.ca.us/score/cla.html); and Science (http://scorescience.humboldt.k12.ca.us). The sites are searchable by grade level and subject.

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Strauss, Richard T., and Mable B. Kinzie. "Student Achievement & Attitudes in a Pilot Study Comparing an Interactive Videodisc Simulation to Conventional Dissection." *The American Biology Teacher*, October 1994 (Vol. 56, No. 7), pp. 398-402.

Tenth Planet. "1997 Tenth Planet Teachers & Technology Survey." Survey results, posted by a well-known educational software company. See http://www.tenthplanet.com/Company/news/97survey. The survey itself was conducted by Wirthlin Worldwide, a long-established survey research firm: "The survey contains the results of 1,000 telephone interviews conducted in June 1997 with a randomly-selected sample of K-6 teachers in the United States. The nationwide sample of 600 teachers was supplemented by 100 teachers each in four specific locations: Los Angeles, Miami, New York City and Chicago." Results of the previous (1995) survey are also available at the site.

Umbach, Kenneth W. *Computer Technology in California K-12 Schools: Uses, Best Practices, and Policy Implications.* Sacramento, CA: California Research Bureau, March 1998. Please see Appendix II ("Selected Educational Web Sites") and Appendix IV ("Sources and Selected Further Reading") for additional sources. Available in Adobe Portable Document (pdf) format at http://www.library.ca.gov/CRB/98/03/98003.pdf.

Umbach, Kenneth W. *The Internet: A California Policy Perspective.* Sacramento, CA: California Research Bureau, March 1997. See Chapter 4, "Libraries and

Education on the Internet." Available in HTML format at http://members.unlimited.net/~kumbach/internet/cvr2intr.html. Also available in pdf format via the California Research Bureau's site, http://www.library.ca.gov/html/statseg2a.cfm.

U.S. Congress, Office of Technology Assessment. *Teachers and Technology: Making the Connection*, OTA-EHR-616. Washington, D.C.: U.S. Government Printing Office, April 1995. Although OTA no longer exists, this widely cited report remains available online. One source is http://www.wws.princeton.edu/~ota/disk1/1995/9541_n.html.

U.S. Department of Education. *Getting America's Students Ready for the 21st Century: Meeting the Technology Literacy Challenge, A Report to the Nation on Technology and Education.* Washington, D.C.: the Department, 1996. Posted at http://www.ed.gov/Technology/Plan/NatTechPlan. See especially the section titled "Benefits of Technology Use."

Ward, Kevin, and Kar-Tin Lee. "Use of Information Technology in the Technology Key Learning Area." This is Chapter 10 of a report posted by the Australian Professional Development Program. For information on that program see http://www.sofweb.vic.edu.au/lt/research.htm#casc. The Ward and Lee chapter is posted at http://www.sofweb.vic.edu.au/lt/research/casc/chapt_10.pdf. In part, the abstract reads: "This chapter contains three parts: a summary of local and international literature on the use of computers in teaching and learning; specific summaries on the use of information technology in the Technology curriculum (locally and overseas) in line with the Curriculum Standards Framework (CSF); and, key issues for consideration in professional development programs for the area. It gives a description of what leading schools in Victoria are presently engaged in, how teachers have integrated information technology in their teaching and why these have been successful."

"Washington State Technology Plan for K-12 Common Schools – Appendix D: Technology in Schools: What Does the Research Say?" Posted at http://inform.ospi.wednet.edu/edtech/app-de.html. This brief report summarizes evidence and includes an extensive bibliography.

The Well Connected Educator (http://www.gsh.org/wce). This is part of the Global Schoolhouse site, a partnership between Global School Net and Microsoft Corporation. Numerous articles posted at the site reflect teachers' experience in the classroom and illustrate ways in which technology has contributed to learning. Although all of these reports might be considered "anecdotal," there are many of them, covering widely varied perspectives and applications.

Notes

Please see the bibliography for additional information on sources cited in the notes.

[1] The abstract contribution of technology to learning is a concept I have sometimes called "sprinkling Techno-Dust over the schools."
[2] U.S. Congress, Office of Technology Assessment, *Teachers and Technology: Making the Connection*, OTA-EHR-616, April 1995; p. 90.
[3] The reader will note that, as a professional researcher and writer, I make extensive and irreplaceable daily use of the very tools and techniques that are of growing importance in K-12 schools. This fact itself inclines me to see familiarity with these tools as important and to see access to digital resources as vital to learning today.
[4] A summary of evidence on computers and "the basics" is provided in a 1997 Master's thesis titled "Effective learning Within Telecollaborative Environments," by Kathy Zajac Schaw. (Posted at http://www.cvu.cssd.k12.vt.us/wcswww/lighth/thesis/thesis.htm.)
[5] U.S. Department of Education, *Getting America's Students Ready for the 21st Century* (section on "Enhanced Student Achievement" in the chapter on "Benefits of Technology Use"). The document is posted at http://www.ed.gov/Technology/Plan/NatTechPlan/benefits.html.
[6] Alan Zoltman, et al., "Effects of Computer-Assisted Instruction on Reading and Mathematics Achievement of Chapter 1 Students," National Educational Resources Information Center (ERIC) microfiche, ED 313 024, pp. 7, 9.
[7] Zoltman, et al., p. 13. Also note the bibliography to the Zoltman, et al., paper.
[8] This statement is quoted in "Washington State Technology Plan for K-12 Common Schools – Appendix D: Technology in Schools: What Does the Research Say?" That document cites the Software Publishers Association's "Report on the Effectiveness of Technology in Schools 1990-1994" as the source.
[9] http://www.eduzone.com/_language/0000005b.htm. Although I have not verified the quoted message, I have heard a similar report first-hand from an elementary school librarian in Bakersfield, California, and have seen comparable comments posted on the LM_NET discussion group. The AR program is, however, not without controversy, as some have found that the program tends to cause students to avoid non-AR books, however good they may be, in favor of reading only books for which they may earn points. Additional information on the program is available at http://www.sbfmedia.com.
[10] For a discussion of this topic, see Ilana Snyder, "Towards Computer Mediated Literacy in the Secondary School," and note the many sources cited in the bibliography to that publication.
[11] Snyder, "Towards, Computer Mediated Literacy," p. 12 (as printed in pdf format).
[12] Snyder, "Towards, Computer Mediated Literacy," p. 13 (as printed in pdf format).
[13] Snyder, "Towards, Computer Mediated Literacy," p. 18 (as printed in pdf format). See Snyder's bibliography for the citation to Kaplan and Moulthrop's article.
[14] Snyder, "Towards, Computer Mediated Literacy," p. 20 (as printed in pdf format).
[15] U.S. Department of Education, *Getting America's Students Ready for the 21st Century* (section on "Advanced Skills Instruction" in the chapter on "Benefits of Technology Use").
[16] Alan Zoltman, et al., p. 7.
[17] http://www.electronic-school.com/0198f4.html. The article originally appeared in the January 1998 issue of *Electronic School*, published by the National School Boards Association.
[18] http://sunsite.Berkeley.edu/CalHeritage/k12project/schools.html.
[19] http://sunsite.berkeley.edu/CalHeritage/k12project/lincoln.html.
[20] The Birch Lane site is http://www.birchlane.davis.ca.us, although it was unavailable at the time I was preparing this section.
[21] E-mail message from Carolyn Gierke, librarian at Sweet Home High School, Amherst, New York, May 15, 1998. I have quoted the message at length because it nicely summarizes themes found in scattered literature on the subject.
[22] A quick search on the keyword "dissection" at the California Instructional Technology Clearinghouse site found eight programs selected, reviewed, and recommended by CITC. For example, "Operation: Frog" is described this way: "This simulation provides an on-screen laboratory for dissecting a frog and learning about its anatomy. The dissection and reconstruction are conducted in the natural, layered order of a real

dissection. Background information about frogs and toads includes both commonly asked questions and interesting little-known facts." For more information, see http://clearinghouse.k12.ca.us. Also see Richard T. Strauss and Mable B. Kinzie, "Student Achievement & Attitudes in a Pilot Study Comparing an Interactive Videodisc Simulation to Conventional Dissection," *The American Biology Teacher*, October 1994 (Vol. 56, No. 7), pp. 398-402. Strauss and Kinzie found, "Results of this study suggest that the Interactive Frog Dissection can be as effective as traditional frog dissection in the high school biology laboratory . . . ."

[23] I observed a radio telescope session during a visit to a science class at Redlands East Valley High School, Redlands, California, on the morning of May 29, 1998. What was striking was that by simply observing for an hour, not even participating hands-on, I gained insight into how a radio telescope is used to take measurements of astronomical objects and how to interpret some basic data. I would anticipate that the students' learning was enhanced by the opportunity to direct the measurement process and to interact with the onscreen controls. For more information, see the Goldstone-Apple Valley Radio Telescope site, http://www.avstc.org/astro/gavrt.htm.

[24] See http://www.kv5.com/intro.html, the Theban Mapping Project (Valley of the Kings, Egypt).

[25] Douglas N. Gordin, et al., "Using the World Wide Web to Build Learning Communities in K-12" (posted at http://www.covis.nwu.edu/Papers/k12web.html); see esp. section 7.

[26] See http://www.terc.edu for more information. The site's page at (http://www.terc.edu/projects/projects.html#anchor510853) notes: "TERC's mission to improve math and science education is pursued through project work. TERC currently has over forty-four active projects that are funded by government agencies, private foundations, and industry. The projects form clusters in which the work of one project informs and builds on the work of others." Oddly, the site seems only to identify itself as "TERC," and never spells out what the acronym stands for.

[27] For one view of "authentic learning" and some related concepts see http://www.iriskylight.com/Assess/htaali.htm. Also see related comments at http://www.evl.uic.edu/mariar/THESIS/CHAPTERS/212socio.html, a portion of a 1997 Master's thesis (University of Chicago) titled "Issues in the Design and Evaluation of a Virtual Reality Learning Environment" by Maria Roussos. Also see Reuven Lazarowitz and Jehuda Huppert, "Science process Skills of 10th-Grade Biology Students in a Computer-Assisted Learning Setting," *Journal of Research on Computing in Education*, Spring 1993 (Vol. 25, No 3), pp. 366-82.

[28] See, for example, the Internet Public Library "Online Newspapers" site, http://www.ipl.org/reading/news. This site, with access to over a thousand newspapers around the world in many languages, is an endless source of authentic, current language learning materials. The resources available via that site are also of value in other classes, most notably those related to world affairs and the study of other nations or regions.

[29] Al Bode, "Developing International Student Exchanges from E-Mail: An Iowa Experience," The Global Schoolhouse, http://www.gsh.org/wce/bode.htm.

[30] "The Art Teacher Connection" (http://www.primenet.com/~arted) for example, by art teacher Bettie Lake, has links to countless resources. ARTSEDGE: The Kennedy Center's National Arts and Education Information Network (http://artsedge.kennedy-center.org/aetext.html) is another source of information and links described as follows: "The mission of ARTSEDGE is to help artists, teachers, and students gain access to and/or share information, resources, and ideas that support the arts as a core subject area in the K-12 curriculum."

[31] See http://www.academicsenate.cc.ca.us/Senate/Papers/InfoComp.htm.

[32] My own parody paper about challenges facing California's mythical "Velcro Crop" is occasionally recognized as a good example of a "bad Web page," as it has a veneer of authenticity yet not an iota of reality. See http://members.unlimited.net/~kumbach/velcro.html.

[33] The clear distinction between a "reliable" print venue and a less reliable Internet venue was, in the eyes of some observers, reduced by the recent affair of Stephen Glass's bogus journalism, published in *The New Republic* and other respected print periodicals. Although the extent of Mr. Glass's fraud is not yet fully known, as of late May, 1998, *The New Republic* had disavowed as fraudulent three articles he had written for the magazine and was investigating the authenticity of dozens more. A May 18, 1998, article titled "Hack Heaven" published in *TNR* was exposed shortly after publication as a complete fabrication. Confidence in editorial review and fact checking of print publications (certainly of *TNR* and any other publications that carried Mr. Glass's work) is likely to have been reduced by this fiasco.

[34] See http://www.sirs.com for information on SIRS researcher and other products.

[35] See http://www.epnet.com for information on EBSCO full-text databases and other products.
[36] Old Dominion University, 1995; abstract from Dissertation Abstracts Online, via Dialog; see *Dissertation Abstracts International*, Volume 56/08-A, page 3057.
[37] "Report on the Effectiveness of Technology in Schools, 95-96." The executive summary is posted at http://www.spa.org.project/edu_pub/summary.htm.
[38] This report, according to its executive summary, reflected 176 studies (of which 70 had been published in professional journals and 33 were doctoral dissertations) selected from over 1,000 studies related to the subject of technology in schools. Needless to emphasize, the report is the product of an interested party (the Software Publishers Association), so its conclusions should be weighted accordingly, especially given the unavailability of the full report for review during preparation of the present paper. Nonetheless, there is nothing in the executive summary that conflicts with other evidence at my disposal, and I have no reason to question its conclusions, especially in view of the included *caveats*.
[39] I base my comments on the posted executive summary. The full report was not available for use in preparing this paper.
[40] The following comments reflect my own synthesis of observation, exchanges (in person and by phone and e-mail) with educators, and wide, eclectic reading online and off.
[41] Richard J. Coley, John Cradler, and Penelope Engler, "Computers and Classrooms: The Status of Technology in U.S. Schools" (Princeton, N.J.: Educational Testing Service, [1997]). The quoted passages are from the "Summary and Highlights" section.
[42] For more information, see http://www.tenthplanet.com/Company/news/97survey.
[43] "Students create computer program for firm," AP report datelined Atlanta, posted at 6:21 a.m., PDT, Tuesday, June 9, 1998; http://www.sjmercury.com/breaking/docs/027660.htm.
[44] See Lynn Margherio, project director, *The Emerging Digital Economy* (Washington, D.C.: U.S. Department of Commerce, 1998).
[45] E-mail message dated May 13, 1998, on file with author.
[46] U.S. Department of Education, *Getting America's Students Ready for the 21st Century* (section on "Advanced Skills Instruction" in the chapter on "Benefits of Technology Use).
[47] Master's thesis, St. Michael's College, Colchester, Vermont, 1997, posted at http://www.cvu.cssd.k12.vt.us/wcswww/lighth/thesis/thesis.htm.
[48] Schaw, "Effective Learning," p. 24 (as printed from posted HTML file).
[49] Ms. Schaw also addresses the difficulties encountered in the projects: "Upon analyzing the problems and pitfalls of each project, several lessons come to mind. Among them [are] the need to be flexible with time, avoiding too much 'teacher-directedness,' and providing for frequent, regular opportunities to communicate." She elaborates on each of those points in the "Lessons Learned" section of the thesis (beginning at page 27 of the printed HTML version).
[50] Center for Applied Special Technology (CAST), *The Role of Online Communications*, p. 2.
[51] CAST report, p. 10.
[52] CAST report, p. 13.
[53] CAST report, p. 14.
[54] CAST report, p. 21.
[55] Note that "Listserv" is a trademarked name for one popular electronic mailing list management program.

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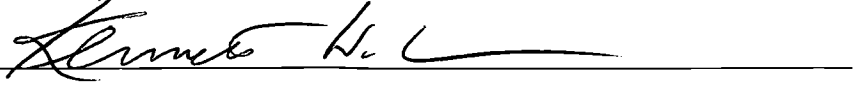
Sign Here, Please 

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