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ABSTRACT

To understand the value and impact of technology, one must recognize that there have been three distinct phases in technology uses and expectations: Print Automation, Expansion of Learning Opportunities, and Data-Driven Virtual Learning. This report takes an in-depth look at these three phases and, for each, addresses two important and highly interrelated questions facing educators as they try to determine the best use of technology in K-12 settings: (1) What evidence is there that the use of computer-based technology in each phase has a positive effect on learning? and (2) What significance do the findings from each phase have for educators today as they try to make technology-related decisions that have an impact on student learning? The conclusions of this report provide cumulative findings over the three phases, which are intended to help informed educators, policymakers, school administrators, school technical coordinators, and researchers make research-based decisions regarding the most beneficial approaches to technology use in K-12 education. (Contains 106 references.) (AEF)

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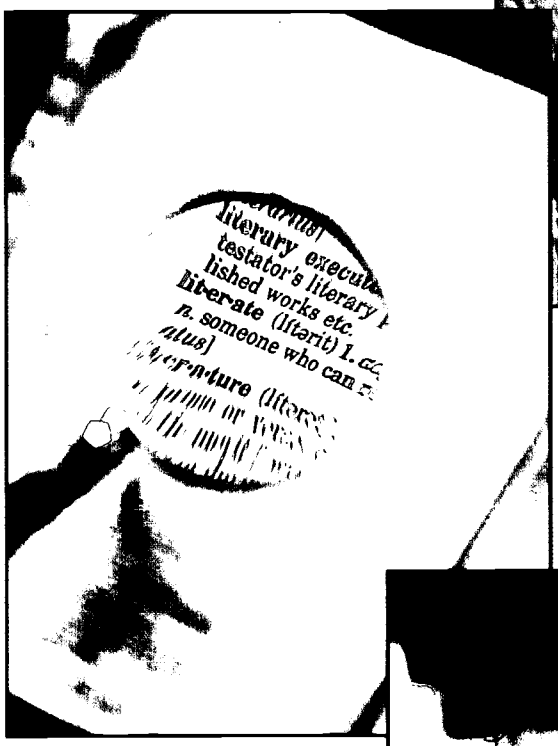

Evolving Uses and Expectations

By Gilbert Valdez, Mary McNabb, Mary Foertsch, Mary Anderson, Mark Hawkes, and Lenaya Raack

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Executive Summary

Introduction

The value and use of technology in K–12th-grade education continues to be debated even though computer-based technology is being credited as one of the major reasons for the increased work productivity and economic success of the United States.

The authors believe that to understand the value and impact of technology we must recognize that there have been three distinct phases in technology uses and expectations: Print Automation, Expansion of Learning Opportunities, and Data-Driven Virtual Learning.

This report takes an in-depth look at these three phases and, for each, addresses two very important and highly interrelated questions facing educators as they try to determine the best use of technology in K–12 settings:

1. What evidence is there that the use of computer-based technology in each phase has a positive effect on learning?
2. What significance do the findings from each phase have for educators today as they try to make technology-related decisions that have an impact on student learning?

In Phase I, instruction was characterized by the use of behavioral-based branching software that relied heavily on drill and practice to teach segmented content and/or skills. During Phase II, computers became tools for learner-centered practices rather than content delivery systems, helping teachers move from largely isolated learning activities to applications that involved working in groups. Phase III carries with it the additional expectation of making schools more effective through the use of data-driven decision making of a much more sophisticated nature than previously expected. Ideally both teachers and students have access to the data and use it to meet accountability expectations.

Summary Conclusions

The conclusions of this report provide cumulative findings over the three phases, which are intended to help informed educators, policymakers, school administrators, school technical coordinators, and researchers make research-based decisions regarding the most beneficial approaches to technology use in K–12 educational settings into the 21st century. Technology innovations are increasing the demand for reforms in teaching and learning approaches that, in turn, are having a significant impact on technology use expectations. In addition, the linkage between teachers' professional development in appropriate uses of technology and increased student achievement is very strong.

The report finds that:

1. Technology offers opportunities for learner-control, increased motivation, connections to the real world, and data-driven assessments tied to content standards that, when implemented systemically, enhance student achievement as measured in a variety of ways, including, but not exclusively limited to, standardized achievement tests.
2. Policymakers are demanding greater accountability for technology use, both because of resource expenditures and because research shows that the ability

to use technology effectively is now necessary for all lifelong learners.

3. Generalizing findings from technology research has been difficult because it is a rapidly moving target due to changes in technology and an educational vision.

Looking more specifically at conclusions drawn across findings, we find that technology has an important role to play in K–12 education, even though it will not solve all educational problems. Technology makes learning more interactive, enjoyable, and customizable, and this improves students' attitudes toward the subject and their interest in learning.

Minimally, for technology to play a positive role, the following factors must be considered:

- The success or failure of technology is more dependent on human and contextual factors than on hardware or software.
- The extent to which teachers are given time and access to pertinent training to use computers to support learning plays a major role in determining whether or not technology has a positive impact on achievement. Students of teachers with more than ten hours of training significantly outperformed students whose teachers had five or fewer hours of training.
- The success or failure of technology involves seeing it as a valuable resource. This requires determining where it can have the highest payoff and then matching the design of the application with the intended purpose and learning goal. The success or failure of technology-enabled learning experiences often depends on whether the software design and instructional methods surrounding its use are congruent.
- The success of technology depends on having significant critical access to hardware and applications that are appropriate to the learning expectations of the activity. Research and best practice indicate that one computer for every four to five students is necessary if students are to be able to use technology in a manner that will yield significant improvements in learning.
- Teachers' perception is that computers have improved the climate for learning, especially because technology increases student motivation in subjects for which they use computers.

Contents

Computer-Based Technology and Learning: Evolving Uses and Expectations

Overview

The value and use of technology in K–12th-grade education continues to be debated even though computer-based technology is being credited as one of the major reasons for the increased work productivity and economic success of the United States. It would seem that these same computers should have a similar impact on education; yet, debate about their value and cost-effectiveness continues. In fact, the debate has grown so important that even major television network programs, such as *Nightline,* and several national journals have turned a spotlight on this issue.

It is worth noting that the research on technology's effectiveness and educational uses is sparse and, in some cases, disappointing in quality. This is typical, however, of any new line of inquiry, and there is every reason to believe that it will improve in terms of both quantity and quality. One reason researchers have had a difficult time studying technology's impact on learning is that they have been studying a moving target. Rapid technological changes and advances in software development have made some findings obsolete even before they were published. Furthermore, contextual factors surrounding uses of technology have made generalizing findings difficult.

This paper reviews a theoretically and empirically well-grounded body of research on how technology can promote student learning. The discussion focuses on the three phases in the evolution of technology uses and expectations in schools. *Evolution* as defined here should be viewed as more than a flat historical time line charting technology's progress in schools. Today, all three phases are alive and well—sometimes in the same school.

Phases of Technology Use

We believe that to understand the value and impact of technology in education, we must recognize that there have been three distinct phases in the evolution of its uses and expectations: Print Automation, Expansion of Learning Opportunities, and Data-Driven Virtual Learning. As described in this report, each phase has different definitions and measures of success. And common terms such as "word processing," "content software," "programming," "student and teacher roles," and "learning task" have different expectations and describe different learning opportunities in each of the three phases. You will note that these phases are not mutually exclusive, and people may be in one phase on one variable and in a different phase on another, even in the same building. The phases are important as a means of discussing the "mainstream" evolution of the use of technology for educational purposes.

The three phases and the list of variables are noted in more detail in the chart below (see pages 3-4). The content of this chart is based on the concept of engaged learning, the focus of a document written by NCREL staff, *Plugging In: Choosing and Using Educational Technology* (Jones, Valdez, Nowakowski, & Rasmussen, 1995).

Effective, or engaged, learning means students are responsible for their own learning—they take

charge and are self-regulated. *Plugging In* used the best research available in 1995 to define what we knew about effective learning and effective teaching and put those conclusions into a planning framework. Numerous states based their technology grant programs on this document and, to some extent, it provided a common language with which to agree or disagree about the uses of technology.

No attempt has been made within this report to address every aspect of the chart. Rather, the focus of this paper is on how certain indicators or variables have changed over time. Also, the authors recognize that the chart seems to imply that Phase III is the most desirable state. We would caution that schools need considerable preparation before moving to Phase III. We believe they should do so only after they provide appropriate professional development and when there is sufficient high-quality technology and connectivity to make success probable.

There are many issues involved in implementing effective use of computer-based technology, and no single report will clarify this topic for all readers. This report, however, will address two very important and highly interrelated questions facing educators as they try to determine the best use of technology in K–12 settings. These questions will be answered at the end of the descriptions of each of the three phases.

1. What evidence is there that the use of computer-based technology in each phase has a positive effect on learning?
2. What significance do the findings from each phase have for educators today as they try to make technology-related decisions that have an impact on student learning?

While we hope that this report will be useful to many audiences, its primary target is informed K–12 practitioners. Readers are assumed to have some knowledge of current learning and teaching research as well as a general understanding of both curriculum and technology as it presently exists in K–12 settings. In addition, minimal effort was given to defining research methodology; however, we have included a reference section that identifies the extensive review of literature that provided the basis for this report.

Phase I: Print Automation

Though it was not very long ago, we need to remind ourselves that in the 1980s personal computers and their software were quite primitive. Early personal computers were stand-alone, desktop machines with an average of 16,000 bytes of memory. Today many personal computers are networked to intranets and the global Internet; some are portable; and most have 128,000,000 bytes of memory that process multimedia forms of information. Programming for personal computers was unstructured, and the limitations of languages, such as Basic, resulted in programs that were largely sequential routines limited by "If Then" and "Go To" statements that allowed for designing sequential branching programs primarily based upon principles of programmed instruction. Educational software was mostly textbooks presented in electronic print formats. Often the software was short, self-contained lessons created by noneducators with unintended results, such as third-grade math software with a tenth-grade reading level. Teacher roles consisted of finding time in the day to send students to a computer lab for drill and practice or electronic tutorials; and student roles usually consisted of selecting predetermined correct answers within such programs.

Phases of Computer-Based Technology and Learning

Variables	Phase I – Print Automation	Phase II – Expansion of Learning Opportunities	Phase III – Data-Driven Virtual Learning
Engaged Learning – Instruction – Student Roles	Students use technology that automates print-based practices with some increase in active hands-on learning.	Students use technology to organize and produce reports, often using multi-media formats.	Students use technology to explore diverse information resources inside and outside school and produce information for real-world tasks.
Engaged Learning – Instruction – Teacher Roles	Teachers have limits on structuring the learning due to the closed-end design of the software. The quality of learning depends on the intended learning outcomes set by software developers.	Teachers use technology to access information, model problem solving, and develop simulations that provide greater understanding of how technology is used in the work world.	Teachers continue to use technology to guide and engage students in self-directed learning activities. They model problem solving that reflects real work but focuses on areas that are otherwise difficult to teach.
Engaged Learning – Instruction – Grouping	Amount and quality of collaboration is highly dependent on the design of the software.	Learning approach is individual, but the outcome is sharing a product with classmates.	Learning approach is a developmental process that is enhanced by working with others inside and outside the classroom.
Engaged Learning – Content – Standards Based	Content is usually focused on skills and inert knowledge with little attention to standards or research.	Content reflects research and best practices but is usually not linked to national standards. Technology use focuses on finding and presenting information.	Content reflects national standards, research, and best practices. Technology use is aligned with standards to enhance application of content learning to real-life situations.
Engaged Learning – Content – Conceptual Integrity	Segmented skills or knowledge are emphasized without conceptual connections.	Conceptual integrity is considered important, but analysis of key understandings is usually limited.	Conceptual integrity is important; key understandings are defined; and a variety of resources and strategies are linked to integrated concepts.
Engaged Learning – Content – Authentic Tasks	Design of the software determines whether work reflects real-world problems and resources. Printed resources convey established knowledge.	Students are given opportunities to make real-world connections, but because access to outside-building resources is limited, true real-world connectivity is superficial and forced.	Students have greater opportunities to access up-to-date, real-world resources and experts, especially through the Internet and other telecommunication resources; focus is on solving authentic tasks.

Technology – Connectivity	Limited to electronic print. Information is transferred via exchanges of portable diskettes.	Electronic print with some limited multimedia and networking capacity. Information transfer largely limited to connectivity tied to a hard drive in a building.	Multimedia and global telecommunications network infrastructure enables unlimited information transfer and online collaboration.
Technology – Learning Access	Few opportunities exist to take online courses. Distance education is lecture driven.	Some courses delivered to schools via videoconferencing when access to qualified teachers is limited. Courses are traditional lecture mode with minimal interaction and summative evaluation.	Students and teachers anywhere can access learning experiences online as they need them; and engaged learning strategies are used in the instruction. Data-driven decision making helps determine the flow of instruction and appropriate uses of technology resources.
Systemic Integrity – Vision for Use of Technology	Vision is focused on obtaining technology hardware and software. Little attention is given to changing learning strategies.	Vision is focused on increasing learning opportunities and strategies to better succeed in an information-rich world.	Vision is focused on increasing learning opportunities by using data to determine priorities and strategic use of resources.
Systemic Integrity – Professional Development	Sites provide technology-focused workshops emphasizing basic hands-on skills. Typically workshops are "sit-and-get." Teachers have little time to practice and have little access to ongoing support.	Professional development is beginning to focus on instruction and learning as the driver to designing technology-based units. Efforts are still limited by poor access to technology and a poor vision of learning.	Professional development is aligned with research and best practices where teachers participate in just-in-time study groups, online seminars, action research, and collaboration with colleagues.
Systemic Integrity – Parent and Community Partners	There are few efforts to use technology to involve parents and the community.	Technology is used to inform parents and the community, but communication is limited primarily to technology-developed newsletters and multimedia presentations.	Web sites and interactive electronic systems are used to provide multi-tiered collaborations among educators, students, parents, and community members. Data-driven practices inform all levels of collaboration.
Systemic Integrity – Evaluation and Accountability	Many data-gathering efforts exist, but they are not tied to objectives. The results are not structured for technology use that would allow easy and customized analysis.	Objective data is available, but technology programs provide only district and classroom data with little disaggregation of data for formative evaluation.	Technology data tools are used in classrooms that provide both formative and program information to teachers, parents, students, principals, curriculum directors, and policymakers as appropriate for their individual and collective needs.

The behavioral learning approach

No period in time was exclusively devoted to a particular use of technology. However, if research is any reflection, the dominant use in the 1980s was for computer-based instruction characterized by the use of behavioral-based branching software that relied heavily on drill-and-practice to teach segmented content and/or skills.

Although the education field had a history of rudimentary philosophies and methods applicable to preparing teachers for technology-based education (Association for Educational Communications and Technology, 1977; Dale, 1965; Kinder & McClusky, 1954; McClusky, 1949; Saettler, 1990; Seels & Richey, 1994; Skinner, 1958), the educational practices at this time were heavily dominated by behavioral learning principles. Computer software reflected these principles.

The instructional software programs that ran on the personal computers of the early 1980s were at first based on Skinner's methods of branching: dividing into small units, rewarding collective responses, and teaching discrete facts. These early software programs tended to be prescriptive in nature. However, research shows that learners did benefit from the technology when the learning objectives were behavioral. "[Programmed instruction] opened up new possibilities for individualizing instruction, for teaching diagnostically, and for providing a real school situation for the scientific study of learning" (Saettler, 1990, p. 435). Newer software could be used for drill-and-practice, which did make learning somewhat less passive because it automated print-based learning practices, allowing learners to self-pace their movement through established lesson plans.

Berryman and others criticize American education for fostering inert knowledge, or passive learning, that has been identified as structured upon behavioral principles (Berryman, 1993; Besser, 1993; Popkewitz & Shutkin, 1993). Berryman (1993) defines passive learning thus:

> Passive learning means that learners do not interact with problems and content and thus do not receive the experiential feedback so key to learning. Students need chances to engage in choice, judgement, control processes, and problem formulation; they need chances to make mistakes (p. 375).

Berryman and others attribute passive learning practices to the system of industrial management in which each person's task is laid out carefully by the administrative powers. Each worker is told not only what to do but how to do it. Berryman claims that this industrial management style of education "places control over learning in the teacher's, not the learner's hands" (p. 375). Streibel (1993) criticizes preprogramming outcomes because it sets up a power relationship within the learning environment that does not foster "the growth of autonomy and responsibility in the identity of the learners" (p. 152).

We believe that programmed instruction did not change the dynamics of the industrial management model of education in regard to control of learning. Rather it took the control of learning out of the hands of the teacher and placed it into the hands of the computer software programmer. As a result, many teachers who encountered these early programs formed antitechnology attitudes.

The cognitive approach

Somewhat later in this period, advances in technology and learning sciences led researchers (Berryman, 1993; Streibel, 1993) to a different

point of view: They saw learning with technology as the means for building problem-solving skills and for achieving learner autonomy.

Cognitive science shifted psychological thought and research from a focus on "procedures for manipulating instructional materials to procedures for facilitating learner processing and interaction" (Saettler, 1990, p. 318). Unlike behaviorism, cognitive educational technology is a descriptive, not prescriptive, science. The cognitive approach to instructional technology emphasized looking at how we know rather than how we respond, and analyzing how we plan and strategize our thinking, remembering, understanding, and communicating (Saettler, 1990). It is during this phase that students develop skills in logic, solving problems, and following directions, with a clear emphasis on the augmentation of higher-order thinking skills.

Questions on instructional use

1. What evidence is there that the use of Phase I computer-based technology had a positive impact on learning?

Most of the studies undertaken during Phase I reflected the use of technology at that time: They examined the success of computer-assisted software in improving the learning of segmented content and/or isolated skills. A number of studies of students identified as at risk of failure reported dramatic improvements in student achievement after the introduction of technology into the classroom (e.g., Fuchs, Fuchs, Hamlett, & Allinder, 1991; Griffin, 1991; Wilson, 1993). For example, a study conducted by Sinatra, Beaudry, Pizzo, and Geisert (1994), which examined the effect of integrated learning systems on the achievement of fourth-grade students with reading disabilities, reported dramatic improvement in test scores. The sample consisted of 260 students drawn from six urban elementary schools. All students qualified for Chapter 1 reading instruction as a result of scoring below the 25th percentile on standardized reading tests.

A number of separate meta-analyses[1] were conducted during this time to determine the impact of technology on student achievement (see Table 1). Ten meta-analyses that synthesized research from 946 studies, ranging from the preschool level to college, were examined. These meta-analyses were conducted independently by different researchers, focused on the different uses of computers and multimedia technologies with different populations, and differed in terms of the methodology used to identify studies and analyze results. Nonetheless, each meta-analysis concluded that instructional programs that included technology show a positive impact on student achievement, resulting in higher test scores.

Key findings from these studies include the following:

- Classrooms in which computers were used to support instruction usually showed gains in student achievement as measured by standardized achievement tests. The magnitude of the gains varied from study to study.[2] There was usually a good match between the desired outcome of the treatment and the outcome that was measured.
- The effectiveness of different applications of computer-assisted instruction varied by

[1]Meta-analyses are procedurally objective presentations of study features and outcomes, employing statistical methods to summarize overall findings and explore relationships between study features and outcomes. Meta-analyses provide a means of identifying major themes in research (Kulik & Kulik, 1987).

the content area and the skill being taught. In general, applications fared better if delivered in a content area with a defined structure, such as mathematics.

Kulik and Kulik (1991) conducted one of the most comprehensive studies of the effectiveness of using computers to increase student achievement. In 81 percent of the studies examined, the students in the computer-based instruction (CBI) classes (experimental group) had higher exam scores than students who were taught by conventional methods without computer technology (control group). The typical student in an average CBI class performed at the 62nd percentile on achievement exams; the average student in a conventionally taught class performed at the 50th percentile on the same exam.

One type of computer application that usually results in positive gains in achievement at the elementary and secondary levels is computer tutoring (Kulik, 1994). According to Kulik, few innovations have effects as large as those of computer tutorials. Kulik also found that software classified as drill-and-practice significantly improved achievement test scores.

2. What significance do the findings from Phase I computer-based technology research have for educators today as they try to make technology-related decisions that have an impact on student learning?

While meta-analysts have consistently demonstrated that computer-based instruction tends to have a positive impact on standardized test performance, no one has reported that all types of computer-based instruction increase student achievement in all types of settings.

For Phase I, we conclude that research and educators' experiences attest to the value of some technology-supported, closed-ended learning activities in regular classrooms and when students need remediation. In a recent report based on an extensive review of research, Sivin-Kachela and Bialo (1996) state that evidence supports the claim that "low achieving students and students with little prior content knowledge are likely to require more structure and instructional guidance than other students" (p. 2).

Computer-assisted instruction appears more appropriate in settings where teachers' content knowledge and skills are quite low. Efforts to introduce more advanced interactive and open-ended technology applications will require significant professional development opportunities and a sufficient critical mass of technology resources before they can benefit students.

As indicated by the research findings from Phase I, technology is likely to be more successful when the software, the purpose for instruction, and the learning objectives match teachers' understanding of learners' needs to memorize and respond to predetermined answers. Equally important is an appropriate matching of the levels of student knowledge and prerequisite skills and the expectations of the software. There also has to be an appropriate matching of teachers' knowledge of both the content and appropriate uses of technology and the desired learning objectives (Valdez & McNabb, 1997).

[2]None of the meta-analyses concluded that all types of computer-based instruction increased student achievement in all types of settings. An important factor in determining the outcome of a study is the type of test used as a criterion measure. Findings on measures created specifically for a research study are usually clearer than findings on standardized measures of achievement. Kulik (1994) has suggested that differences between measures may be related to the fact that tests specifically created for a study may be biased in favor of the treatment or that standardized measures may be too broad to evaluate specific curricula adequately.

Table 1

Meta-Analyses Involving Technology and Achievement

Meta-Analysis	Grade Level	Type of Technology	Number of Studies
Bangert-Downs, Kulik, & Kulik (1985)	Secondary	CBI, CMI, CEI	51
Burns & Bozeman (1981)	Elementary & secondary	Drill & tutorial	44
Hartley (1978)	Elementary & secondary math	Drill & tutorial	33
Kulik & Kulik (1986)	College	CBI, CMI, CEI	119
Kulik & Kulik (1991)	Kindergarten to higher education	CBI, CMI, CEI	254
Kulik, Kulik, & Bangert-Downs (1985)	Elementary	CBI, CMI, CEI	44
Niemiec & Walberg (1985)	Elementary	Drill, tutorial, CMI, problem solving	48
Roblyer (1986)	Elementary to higher education	CAI, CMI, CEI	82
Ryan (1991)	Elementary to higher education	CAI, CMI, CEI	40
Sivin-Kachela & Bialo (1996)	Preschool through higher education	CAI, CMI, CEI	176

Note: CAI = computer-assisted instruction, CBI = computer-based instruction, CEI = computer-enriched instruction, CMI = computer-managed instruction

Phase II: Expansion of Learning Opportunities

Reform-savvy teachers learned that students who use any learning resource are likely to do better as learners if the learning experience is learning centered; that is, if it empowers them, enhances meaning, and augments their interests. Their focus on technology use shifted to the quality of learning during the early to mid-1990s. Computers became tools for learner-centered practices rather than content delivery systems. Phase II also is significant because computers helped teachers facilitate moving from largely isolated learning activities to applications that involved working in groups. Teachers emphasized that products would be produced and shared.

Uses of technology in Phase II can be characterized as providing information in interactive, hypertext, and hypermedia formats. Word processing evolved into a thinking tool and a means for providing desktop publishing that allowed information to be shared in ways previously available only to professional publishers. New databases such as Access, FileMaker Pro, Paradox, and DB2 allowed people to see the organizational possibilities available through the use of technology.

Technology provided a variety of information formats otherwise unavailable. CD-ROMs and other digital technologies brought a new richness of information into the classroom and provided students with access to multiple sources of information that could be used to craft answers to complex questions. Sound, pictures, video, graphs, charts, maps, three-dimension, and animation all made for interesting, exciting content. Advances in the processing power of computers permitted students to visualize phenomena formerly invisible and to instantly grasp relationships once obscure or difficult to understand. Pictures and graphics added new dimensions to ways of presenting information that was responsive to alternative learning styles. The Internet began to be a reality for some schools. However, it was not until the World Wide Web and the advent of Web Browsers (Phase III) that the Internet's potential began to be experienced.

The research suggested that computer-based technology could enhance learning. In a meta-analysis that examined the impact of technology on student learning, Statham and Torell (1996) found increased teacher-student interaction, cooperative learning, and, most important, problem solving and inquiry. Technology tools could amplify, extend, and enhance human cognition. They could facilitate access to human, material, and technological resources and help students to store, reshape, and analyze information. They enabled students to be hypothesis testers, with the result that the knowledge that was acquired could be used more effectively (Jonassen & Reeves, 1996). However, Statham and Torell (1996) cited one essential condition for student learning to take place: Computers should be used less for drill-and-practice in the classroom and more as open-ended thinking tools and content resources. The difficulty was that this approach required new kinds of professional development and shifts in both curriculum and instructional goals. Teachers needed to buy in to this teaching style and then learn how to use the technology to support it.

Technology provided a rich space for students to collect quality information from numerous areas of knowledge and to discover and understand conceptual relationships among content that were previously segmented and learned in isolated contexts. In collecting the information to answer their personal inquiries or to fulfill assignments from their teachers, students could

more easily communicate with others and interact with a variety of people and information. Afterwards, they could share their findings with this same wide audience. Technology also offered efficient ways to collect, store, and organize the information and could alleviate some of the tediousness of these tasks. The machine did the routine work, freeing the student to concentrate on higher-level concerns.

Unfortunately, if used inappropriately, computers also had the capacity to function as copy-and-paste plagiarism devices that actually lowered the quality of learning. They also could take time away from achieving desired objectives when their use was totally unconnected to meeting those ends. Educators needed to be certain that quality use was as important as expanded opportunities.

The following are advantages that technology advocates in Phase II noted were significant:

Access. As stated above, computer-based technologies offer tremendous amounts of information that can help students investigate and answer complex questions. Access to such a huge resource requires students to develop thinking skills to sort, evaluate, and synthesize the information.

Exploration and independent inquiry. Technology supports exploration, which helps students set achievable goals, form and test hypotheses, and make discoveries of their own (Collins, 1990). As Means and Olson (1995) remarked, students are free to roam around the information and discover answers to personal inquiries. With appropriate teacher guidance, such exploration promotes higher-order thinking skills and helps students contend with open-ended questions—the kind of questions they will encounter in their own lives after school.

Research studies that focused on technology and students' motivation to learn relied on self-reports of students' attitudes toward computers and found, in general, that most students considered computer activities to be highly motivating and interesting (e.g., Gregoire, Bracewell, & Laferriere, 1996; Heidmann, Waldman, & Moretti, 1996; Kendall & Broihier, 1992).

Communication—Teacher-student interaction. One characteristic of mediated instruction is interactivity. Students communicate with other students through formal presentations, cooperative activities, collaborative problem solving, and interpersonal exchanges. Students and teachers talk to one another, and teachers interact with content experts. Students have access to print and electronic information resources; they interact with experts with an "Ask the Expert" feature; and they interact with the community. Keypals, electronic appearances, electronic mentoring, impersonations, and global classrooms expand the learning environment to enhance communication. These are all activities that support a transformation of learning approaches rather than enforcing the status quo. In some cases, there were changes in classroom dynamics where students initiated conversations more often than in traditional classrooms, moving the dynamics away from teacher-led discussions (Garner & Gillingham, 1996; Kearsley, Hunter, & Furlong, 1992; Weir, 1992).

Shared knowledge and cooperative learning. Using technology to support collaborative knowledge integration includes tools that enable group thinking, problem solving, and task orientation. Sharing data also offers the opportunity to share with a wider and more authentic audience. The goal is to help students develop community knowledge bases and expertise instead of focusing only on individual student

learning. Shared data leads to larger and more accurate data sets. Sharing real data from primary sources with experts leads to students thinking and working the way experts do (Evard, 1996; Federman & Edwards, 1997; Jonassen & Reeves, 1996; Lonergan, 1997; Scardamalia & Bereiter, 1991; Wideman & Owston, 1993).

Efficiency and organization. The speed with which students can access information is a feature that can promote habits of efficiency and organization. Students can go to the Internet in the classroom and locate information rather than making a trip to the library. Search strategies can help them clarify their questions, and once they have found a potential site, they can evaluate the information for its validity, appropriateness, and perspective. They can then organize and analyze the data using mapping software or spreadsheets and organize their thoughts using a word processor. Project management software helps students identify and complete tasks for a project, and instructional management systems can help teachers keep track of student data, thus increasing the efficiency of instruction (Jonassen & Reeves, 1996).

Teacher productivity. Technology tools can free teachers' time so they can interact with students more. Teachers can leave fact-finding to the computer and spend their time doing what they were meant to do as content experts: arousing curiosity, asking the right questions at the right time, and stimulating debate and serious discussion around engaging topics (Hancock, 1997; Morrelli, 1990). Teachers are able to give students more control once they see what students are able to do with technology and how willing and able they are to take responsibility for their own learning (Means & Olson, 1995). While observing students working with computer applications, teachers can see the choices students are making on the monitor or printout, pose questions regarding students' learning goals and decision making, and make suggestions for revisions when needed. Technologies also can be designed to provide a window to the ways in which students construct meaning—their misconceptions, conjectures, and the connections they make among ideas (Collins, 1990). Teachers can use this information to revise and refine instruction.

Assemble, modify, organize, analyze, and study information. Technology can become a powerful tool for assembling, modifying, assessing, and studying information (Strommen & Lincoln, 1992). Modeling software represents a strategy that makes expert solutions visible and tacit knowledge explicit (Collins, 1990). Some tools, such as semantic networking, engage learners in reorganizing knowledge through the explicit description of concepts and their interrelationships. Using technology as a tool aids learning by requiring learners to analyze the underlying structure of ideas they are studying. Manipulating authentic data sets and thinking about and formulating explanations can foster the generation of new knowledge and deep understanding (Dede, Salzman, & Loften, 1997). Computing power makes it possible to create and manipulate authentic data through the use of scientific probes and graphing software or to manipulate large databases, such as census data, to seek answers to complex questions.

Computer-mediated communications. Sometimes called online communications or computer-supported communications, computer-mediated communications (CMC) is a generic term that describes a variety of systems that enable people to communicate with other

people by means of computers and networks (Romiszowski & Mason, 1996). More specifically, Kaye (1991) describes CMC as:

> The use of computers and computer networks as communication tools by people who are collaborating with each other to achieve a shared goal, which does not require the physical presence or co-location of participants, and which can provide a forum for continuous communication free of time constraints. (p. 5)

CMC includes such applications as the Internet, e-mail, newsgroups, listservs, multiuser structures, network-video conferencing, conferencing software, and electronic bulletin boards (Sproull & Kiesler, 1991).

Computer-mediated communications networks offer teachers access to a "professional community" where their expertise and experience can be shared and where they can be active participants in professional discourse about improving practice (Corcoran, 1995).

One of the earliest ventures systematically applying telecommunications to teacher learning is the Labnet project. In 1989 the Technical Education Research Centers (TERC) launched the Labnet project as "a technology-supported teacher-enhancement program aimed at high school physics teachers" (Roupp, Pfister, Drayton, & Gal, 1993, p. 4). Labnet consisted of a summer workshop for participating teachers, access to a proprietary telecommunications system, and supporting materials. Labnet organized 99 physics and physical science teachers from across the county into clusters of 6 to 10 teachers who shared a common interest in developing one of several curricular units suggested by the organizers. Teachers could participate not only with teachers within their network but with others in the network outside the cluster. Among the outcomes of this project, noted by the researchers, are feelings of growing confidence for teaching physics, increased enthusiasm for teaching, and a sense of belonging to the physics teaching community. The Labnet project is ongoing and has evolved as one of the broadest telecollaboration networks in the world.

Like Labnet, other online teacher development projects have successfully instituted small-group interaction as a part of their programming. The Mathematics Learning Forums, a collaborative effort of the Bank Street College and the Center for Children and Technology, facilitated teacher intercommunication via limited participant mailing lists. The project was designed to help teachers use and integrate new mathematics curriculum standards into their teaching. Researchers studying the project found that telecommunications helped teachers overcome a number of obstacles to professional development, most notably that of time for development activities (Honey, McMillan, Tsikalas, & Griswald, 1995). Researchers in the Mathematics Learning Forums Project also extol CMC's capacity to bring together new learners in a reflective and constructive fashion.

Questions on instructional use

1. What evidence is there that Phase II computer-based technology has a positive impact on learning?

If the criterion in Phase II was primarily facilitation of learning, then technology can be considered a success because technology resources can facilitate learning. They offer a range of applications to meet the learning goals of the instructor and the students, and the information available is vast, timely,

specialized, and can be presented in a multimedia format.

Several researchers in Phase II argue that technology studies that focus on the ability to creatively access, organize, display, and communicate information should not measure outcomes using standardized tests. These are tasks that computer technology has been specifically designed to improve and, therefore, the tasks are the more logical places to go when looking for the effects of computers on achievement (Means, Blando, Olson, & Middleton, 1993). It also has been argued that the traditional basic skills tests were not designed to show the value-added that educational technology represents.

Means and Olson (1995) noted that Phase II technology can be used for four things:

1. Tutorial uses, where the technology does the teaching and the system controls what material will be presented in a self-paced environment so students at different levels can move at appropriate, self-determined times.

2. Exploratory uses, where the student is free to roam around the information displayed or presented by the technology. Exploratory uses may promote a discovery or guided-discovery approach to learning facts, concepts, or procedures.

3. Tool uses—such as word processors; spreadsheets; database management programs; graphing software; desktop publishing systems; Internet browsers; and video recording, digitizing, and editing equipment—where the curriculum resides not in the software but in the instructional activity for which the tool is used.

4. Communication use, where the technology allows students and teachers to send and receive messages and information to one another through networks or other technologies, giving students and teachers access to a broad range of resources.

Meta-analyses of computer-based instruction and multimedia applications indicate that the effectiveness of educational technology on improving student achievement depends on a match between the goals of instruction, characteristics of the learners, the design of the software, the technology, and the implementation decisions made by teachers (Sivin-Kachala & Bialo, 1993).

There was at least one meta-study of the effectiveness of technology during Phase II. The Software Publishers Association (SPA) commissioned an independent meta-analysis of 176 studies focusing on the effectiveness of technology in schools. This report concludes that the use of technology as a learning tool can make a significant difference in, among other things, student achievement as measured by standardized tests (Sivin-Kachula & Bialo, 1996). Positive effects on achievement were found for all major subject areas, in preschool through higher education, and for both regular education and special needs education.

This SPA study had a mixture of Phase I and Phase II uses, and its conclusions must be understood to have implications for computer uses that are hybrids of the two phases.

As the authors were working on this study, the West Virginia Department of Education and the Milken Exchange on Education Technology released a very comprehensive study, entitled "West Virginia Story: Achievement gains from a statewide comprehensive instructional technology

program" (Mann, Shakeshaft, Becker, & Kottkamp, 1999[3]). Although the West Virginia program had some Phase I characteristics, we chose to designate it as Phase II because the program used state standards as its basis for curriculum inclusion and the total design had considerable systemic integrity, including extensive communication to students and parents on learning growth. Our main reason, though, for characterizing the West Virginia Study as Phase II was that students did much of their work in groups, and development and sharing of products was a major instructional strategy. In addition, West Virginia teachers were provided with relevant professional development and had access to sufficient technology and software to allow sustained use that often took place in individual classrooms.

Our conclusion is that the West Virginia program has evolved from where it was six years ago and the two designated vendors have attempted, through changes in software, to incorporate best practice as the program was expanded to the next grade.

The authors of the West Virginia study reported that "the Basic Skills/Computer Education (BS/CE) technology regression model accounts for 11 percent of the total variance in the basic skills achievement gain scores of the fifth-grade students over normal expected gains at the end of one year" (p.12). This study of 950 fifth graders from 18 elementary schools showed statistical significance gains at more than the .001 level.

Solomon, in an Afterword to the study, indicated "that not only is there a statistically significant relationship between BS/CE and test score gains; and not only can these gains be translated into effect sizes comparable to those of other interventions, but also, the gains from programs that update BS/CE's positive features can be achieved at a much lower cost than could similar gains from a currently very popular alternative intervention, namely, class size reduction" (p. 50).

The West Virginia program had considerable systemic integrity, including extensive communication to students and parents on learning growth. West Virginia teachers were provided with relevant professional development and had access to sufficient technology and software to allow sustained use that was often located in individual classrooms.

2. What significance do the findings from Phase II computer-based technology research have for educators today as they try to make technology-related decisions that have an impact on student learning?

Ely (1991) points out in a trend analysis that the National Governors' Association's *Results in Education 1989* report states: "Regardless of the current emphasis placed on computer use instruction, schools do not appear to be taking advantage of the unique uses of technology in teaching subject matter and in helping students develop higher-order thinking skills....The predominant focus seems to be on expanding access to technology with little or no attention given to using technology to restructure schools or to teach higher-order thinking" (p. 35). Phase II is characterized by educational change agents who made strides in finding ways to use technology to teach content and to help students develop higher-order thinking skills. However, many teachers were unprepared for this challenge, which has become a mandate in Phase III.

[3]The study is available at http://www.milkenexchange.org/research/wvirginia_article.html

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Jones, Valdez, Nowakowski, and Rasmussen (1995) determined that effectiveness is not solely a function of the technology, but rather of the learning environment and the capability to do things one could not do otherwise. Valdez and McNabb (1997) determined that the success or failure of technology-enabled learning is highly dependent on the appropriate matching of the software design to an intended purpose and learning goal.

Schools that have been successful in implementing educational reform measures have discovered methods for stimulating creative and critical thinking skills and the mind's seemingly endless capacity for learning. Reports of best practice and program evaluations (Boyer, 1995; Johnson & Johnson, 1996) show that students become energized and engaged when given the leeway to explore, inquire, and make connections between their prior knowledge and new-found answers to their questions about the way the world works. Teachers and professional experts often find themselves inspired by the questions children ask and the conclusions they draw from their collaborations. A very powerful rationale for using technology is that it gives license to try new open-ended and collaborative ways of teaching and learning. However, educational experiences show that efforts to introduce open-ended uses of technology require significant teacher professional development opportunities and a sufficient critical mass of technology before it benefits students.

Research in Phase II shows the need for learners to work cooperatively in order to benefit from open-ended instructional methods and technology tools. Findings from a study of the effects of network technologies conducted by Hartman et al. (1991) indicate that several characteristics of computer-mediated communication (CMC) are "uniquely suited to increasing interaction and to expediating collaboration among teachers and students," including the technology's ability to enable participants to overcome time and distance barriers to interacting. Throughout Phase II, CMC was found to permit peripheral members of a group more opportunities to interact with teachers and peers. More recent findings indicate that this effect has actually shifted the dynamics of the instructional process

Phase III: Data-Driven Virtual Learning

A third phase of technology research and implementation is emerging from the shift in classroom dynamics that resulted from learner-centered approaches to education and the unprecedented rate of technological development, especially Internet interactivity. The focus of Phase III is on two separate but related things: classroom changes and administrative (policymakers, parents, and accountability) changes. More and more, technology implementation requires a well-designed systemic plan, multiyear funding, and extensive professional development. Stand-alone computers that run short electronic lessons are no longer the norm. Access to the global network of multimedia information and online learning communities require building and maintaining an expensive technology infrastructure. Along with the high level of expenditures come questions from parents and policymakers, who require increased accountability and assessment and evaluation methods for ensuring that technology uses do indeed have a positive effect on student achievement. State legislatures and local boards now require proof that their technology investments increase both traditional and new learning.

This intersection of activities has led us to call this phase of computer-based learning "Data-Driven Virtual Learning." This complicated title is intended to communicate that leading-edge technology users have begun to use the vast resources found on the Internet (virtual learning) and the multimedia presentation capabilities of very powerful computers to address data-driven issues and opportunities that are the concerns of policymakers. Data-driven practices also are supported by the expanded capabilities of relational database programs that can produce applications that users can run over the Web or on an Intranet within a school. These Intranets offer places where teachers, parents, and students can access customized, personal progress data on a just-in-time basis for informing instructional decisions.

Phase III is in an early stage of very rapid development and is now accumulating quality research that shows that technology use is most successful when used for strategic purposes in particular contextual settings and content areas. Additionally, such uses of technology are successful when teachers and students function in engaged teaching and learning relationships that focus on data-driven content decision making and accountability. More detail about both the increased technology capacity and connectivity and data-driven accountability are noted below.

Increased technology capacity and connectivity

In the past few years, technology has experienced miniaturization and power previously believed impossible. Desktops now have the power requiring them to be classified as super computers (Hirsh, 1999). Portable computers weigh only a few pounds and are easy to carry and connect. Vast amounts of information available on the Internet are easy to obtain through use of Web browsers. There are new opportunities to learn in a worldwide context. Increased capacity and increased connectivity make learning with this new medium not only possible, but powerful. However, educators' knowledge of how to use that power requires considerable attention with regard to emerging research findings and best practices.

Teachers, through their Internet connections, have access to resources that even a few years ago would have been impossible even for university researchers. Henry Becker, at the Center for Research on Information Technology at the University of California–Irvine, recently conducted a survey of 2,250 teachers, representing a national sample. The survey revealed that as of spring 1998, 90 percent of schools had Internet connections and 39 percent of 4th–12th-grade public and private school teachers had Internet connections in their classrooms. Fifty-nine percent of the teachers had Internet access at home. This recent survey shows a dramatic increase in the use of the Internet by teachers. Of those with Internet access, 68 percent used the Internet to find information resources to use in their lessons; 28 percent used the Internet at least weekly for this purpose. Forty-six percent of teachers who had access to the Internet both at school and at home used the Internet on a weekly basis to improve lessons. Ninety percent of all teachers surveyed (with and without Internet connectivity) ranked Internet resources as either valuable or essential, demonstrating that teachers see the Internet as a significant resource (Becker, 1999).

The number of Web sites has increased as the number and quality of the connections has improved. Hobbes' Internet Timeline

(http://www.isoc.org/guest/zakon/Internet/History/HIT.html) noted that as of January 1, 1999, there were 43,230,000 Web hosts worldwide. Even if only 1 percent were of value to teachers, that would mean that 423,000 would be possible resources. However, teachers must be able to distinguish what information has validity and what is only personal opinion.

The Internet also began to have significance for professional communication among teachers. Sixteen percent of teachers communicated with peers outside their buildings on professional matters. The rate rose to 33 percent for those who had Internet access at home and at school (Becker, 1999).

Teachers also are using the Internet for student activities. Fifty percent of the teachers with classroom connections had their students use the Internet at least three times as part of a lesson. However, only 7 percent of the teachers had their students use the Internet to communicate with other students or to post their work (Becker, 1999).

Of great interest is the fact that, except for mathematics teachers, there was no statistical difference in use of the Internet in content areas. While studies show that math teachers are among the highest users of technology in their classrooms, they were the lowest users of the Internet. Only 20 percent accessed the Internet for their own use and only 9 percent had students use it on a regular basis (Becker, 1999).

Using all of this survey data, Becker was able to determine that certain variables had "important independent relationships to teachers' use and valuation outcomes" (Becker, 1999, p. 24) and some did not. Three factors were especially significant: quality connectivity, computer expertise, and teacher pedagogical beliefs and practices that were constructivist-compatible.

Three other factors—adequate professional development, home access, and younger age of teachers—were next in importance. Student ability and where teachers attended college were not significant variables determining Internet use (Becker, 1999).

Data-driven accountability

Policy research shows that legislators and state board members indicated that new technology expenditures will require demonstrated learning gains, including those measured by normed tests, if they were to continue funding technology. Policymakers required that technology be judged for its cost-benefits relative to other possible expenditures. This higher accountability occurred at the same time technological developments, especially those related to low-cost computer processing power and more-affordable Internet access, were virtually exploding with potential and opportunity.

In Phase III, educational technology has an additional expectation of making schools more effective through the use of data-driven decision making of a much more sophisticated nature than previously expected. Ideally both teachers and students have access to the data and use it to meet accountability expectations.

Greg Nadeau, chief technology officer at the Massachusetts Department of Education, noted that in addition to creating powerful new learning opportunities for both teachers and students, technology was expected to "increase administrative efficiency and effectiveness of schools" (Rivero, 1999, p. 53). Mark Kneidinger, chief information officer, New York State Department of Education, characterized this technology expec-

tation as assisting data-driven decision making that will result in "building applications that drive decisions based not on gut feelings and passionate anecdotes, but rather cold, hard, exhilaratingly efficient and tell-it-like-it-really-is data" (Rivero, 1999, p. 53).

Richard Whitmore, chief deputy superintendent for administrative services, California Department of Education, captured the essence of what we are calling Phase III expectations when he noted that technology offered the opportunity for "having real information about how your students are performing, rolling it up into the school and district level, and targeting your intervention to fix your problem and to bring every student (all your students) up to a core set of standards" (Rivero, 1999, p. 53).

Phase III data-driven decision making is much different from the instructional management systems found in Phase I software or integrated learning systems. Instead of tracking the mastery of isolated skills or knowledge facts, data-driven decision making now encompasses making systemic changes in curriculum, instruction, and assessment to the extent that it requires changes in student roles, teacher roles, and teaching and learning tasks and expectations. Data-driven practices help facilitate effective learner-centered practices.

Phase III, more than Phases I and II, recognizes that teachers are extremely important in any use of technology and they need new kinds of professional development assistance. John Bailey, director for the office of educational technology, Pennsylvania Department of Education, stated, "You may have the best computer, the most sophisticated curriculum software, and the fastest Internet connection...but if that teacher doesn't know how to use any of that, it's not going to improve education" (Rivero, 1999, p. 54).

Questions on instructional use

1. What evidence is there that Phase III computer-based technology has had a positive impact on learning?

Research does suggest that some applications of home and school computers, e-mail, and multimedia projects lead to success in advanced courses as well as to gains in the higher-order skills of thinking critically, solving complex problems such as multistep word problems, understanding the scientific method, and synthesizing different points of view.

In a study conducted in New Zealand, researchers found that the use of computers contributed, with other instructional innovations, to higher performance on English, mathematics, and science tests (McKinnon, Nolan, & Sinclair, 1996). The study was conducted with eighth-, ninth-, and tenth-grade students. Each student had a computer for at least three hours a week for extracurricular activities and the integration of learning across the basic subjects (English, math, science, and social studies). Learning activities focused on real-life problems and situations, mastery learning, and a combination of group and individual work. English, math, and science examinations of the National School Certificate project revealed that students participating in the project scored significantly higher than those who did not. With the many variables, it was difficult to attribute all the gains to technology.

Research reported by the National Center for Education Statistics (NCES) (Coley, Cradler, & Engel, 1997) indicated that the primary factor in test score differences was family/social backgrounds. The second most important factor was instructional opportunity. According to NCES, it is

the way that computers are used to change and enhance curriculum that represents the most important factor in determining whether or not computers have an impact on achievement. For example, they used word processing and semantic map structure for organizing reading selections and writing stories (Coley, Cradler, & Engel, 1997). One of the strengths of this study was that the control group received a valid, well-designed instructional reading program. Analysis of the standardized test scores pre- and post-treatment indicates that all groups improved to well above the mandated cutoff score by the end of the study. Mean scores for the two treatment groups (one used computers for a full year and one for half a year) were higher than the control group means.

The research summarized above provides examples of the kinds of encouraging results that are being observed in individual projects. There is a need for more classroom-based projects to provide data to inform the kind of theory-based research synthesis the field needs (Herman, 1992). It should be noted that most of the projects cited above benefited from the active, intense involvement of researchers; the extent to which these successes can be replicated remains to be seen.

Considered as a whole, a number of studies of technology within the context of an instructional framework suggest that technology has a positive impact on student achievement. For example, the Co-NECT Schools have state-of-the-art hardware and software, links to the Internet, and a computer available for every two to four students. In these schools, technology is viewed as a tool that can support learning. Co-NECT Schools have continued to participate in traditional models of testing (i.e., standardized tests) allowing them to be compared to other schools on the basis of nationwide scores on multiple-choice tests. Preliminary evaluation results show that the Co-NECT schools are beginning to show progress in a number of key areas, including raising standardized test scores (Goldberg & Richards, 1995).

An extensive study of 55 New York State school districts also points to the same conclusion: Increased technology supports, facilitates, and encourages student achievement (Mann & Schaffer, 1997). The gains span schools and districts with different educational policies and sociodemographic backgrounds. Over a three-year period, a consortium representing New York's Madison, Oneida, Herkimer, Jefferson, and Lewis Counties spent $14.1 million on computer technology and training—giving the region a student-computer ratio of seven students per computer. Virtually every one of the 6,000 students in the consortium now has access to a computer. Seventy percent of the teachers are using computer-related technology in their teaching, and one in four teachers has a CD-ROM drive in the classroom.

This study involved 4,041 teachers, 1,722 students, 159 principals, and 41 superintendents. In schools that had more instructional technology and teacher training, the average increase in the percentage of high school students who took and passed the state Regents (college preparatory) exam in math was 7.5; the average increase in the percentage who took the Regents English exam was 8.8. More important, using the reports from teachers and principals to determine the amount of technology available and in use in the schools revealed that 42 percent of the variation in math scores and 12 percent of the variation in English scores could be explained by the addition of technology in the school. In the elementary schools, the most significant gains were

reported in sixth-grade math tests where a strong relationship was found between increased technology and higher scores in the state's Comprehensive Assessment Report.

It cannot be said with certainty that increased technology was what caused higher test scores. To prove that, technology would have to have been withheld from some students in order to measure its comparative impact on others, or performance measures would have had to be available for students before they were introduced to computers. Neither of these conditions could be met in the New York State study. But access to technology appeared to be a significant factor in raising students' test scores.

Numerous studies reveal that technology offers some exceptional opportunities to give students more choice and control of their learning and a chance to develop higher self-esteem as both they and their teachers used data to diagnose and track achievement of required and desired learner expectations. Gregoire, Bracewell, and Laferriere (1996) in a meta-summary of relevant research concluded that:

> New technologies manage to develop students' interest in learning activities, at least for the time being, and to lead them to devote more time and attention to these activities than in regular classes. Moreover, it is not surprising that they also increase their confidence in their abilities. In turn, this confidence of the students in themselves undoubtedly explains, in part, their spontaneously receptive attitude that a large number of them adopt toward an activity in which technology plays a role and the perseverance that they show in accomplishing this activity. Of course a high level of motivation generally facilitates learning; but it is especially important in situations like the new technologically based learning environments where students are more active in directing their own learning (p. 33)[4].

In an early review of the research concerning the effect of computers on students' attitudes, Roblyer, Castine, and King (1988) concluded that:

- Computer use most affects attitudes toward school and subject matter.
- Computer use appears to have a positive impact on improving students' self-image and self-confidence.

Recently several researchers have suggested that technology serves as a catalyst to change content areas and for enhancing students' ability to learn specific content. The literature indicates that technology influences content areas in the following ways:

- Hypertext and hypermedia add depth, elaboration, and interactivity to content through associative, audio, dynamic visual, and video texts that affect the nature of reading and writing across the curriculum (Bolter, 1992; Griest, 1992; Gumpert & Cathcart, 1985; Landow, 1990; McKnight, Dillon, & Richardson, 1996; Reinking,

[4]Gregoire, Bracewell, and Laferriere based their conclusions on a number of studies: research conducted by Guthrie and Richardson (1995) at the Center for Research, Evaluation and Training (CREATE), in Burlingame, California; the report published by the Office of Technology Assessment (1995) confirming the motivation effect that the use of technology has on students of all ages (U.S. Congress, Office of Technology Assessment, 1995); a study conducted by Altun (1996) among junior secondary students that demonstrates in a different way the interest that technology creates among young students; and an assessment of an integrated learning system, CCC's Success Maker, conducted by Underwood, Cavendish, and Lawson (1996) with a group of elementary and secondary schools over a period of two years.

1994a/b; Rouet & Levonen, 1996; Selfe & Hilligoss, 1994).

- Interactivity of computers allows for adapting content to meet individual student needs (Hativa & Becker, 1994; Park, 1996; Reinking & Bridwell-Bowles, 1996; Shirk, 1991).

- Computer-mediated communication patterns differ from verbal face-to-face communication patterns traditionally found in disciplinary discourse about information, more widely disseminating the locus of control from the teacher to students (Cognition & Technology Group at Vanderbilt (CTGV), 1997; Geisler, 1994; Riel & Harasim, 1994; Scardamalia & Bereiter, 1992).

- Telecommunications and the Internet provide access to emerging disciplinary and interdisciplinary databases, real-time phenomena, and social communities not accessible through print-based curricula (CTGV, 1997; Riel & Harasim, 1994; Romiszowski, 1997).

- Computers and ancillary electronic devices facilitate the manipulation of data and the visualization processes invisible to the human eye or beyond human memory capacity, which assists with experimenting and understanding actual, futuristic, and hypothetical concepts, principles, relationships, and probabilities (Papert, 1993; Reinking & Bridwell-Bowles, 1996; Senge, 1990; Zuboff, 1988).

These findings describe emerging trends that can inform educators about the design and uses of content resources accessible through today's interactive, multimedia computer networks. Hughes and Coyne (1996), in their analysis of widely used design principles, suggest that technology applications must "allow customizable content to increase utility and relevance for people from varied social, cultural, ethnic, linguistic, [and] regional communities ... [as well as] provide core content and activities of general applicability" (p. 3). Overall, the literature addressing how technology enhances and/or changes disciplines or content areas indicates that teachers and students will need to know how to select and use electronic resources that provide (1) the core content for a given curricular area, (2) the interactive supports that adapt content to the individual's developmental and/or learning style needs, and (3) open-ended tools that allow teachers and students to modify content for contextual purposes.

Content area focus

Technology has changed and is continuing to change content. The following are some of the ways technology is changing content and how that content is taught and learned.

Information literacy. Computer-based technology research in content areas is sporadic, and quality research is largely limited to language arts and mathematics. Some research has been conducted by those in the fields of English language arts and reading to inform an answer to the question: How does technology enhance and change English language arts? Those involved with infusing computers into their classrooms agree that computer technology not only enhances the curriculum but also changes it (Selfe & Hilligoss, 1994):

> Computers complicate the teaching of literacy ... Technology, along with

> the issues that surround its use in reading- and writing-intensive classrooms, both physically and intellectually disrupts the ways in which we make meaning—the ways in which we communicate. Computers change the ways in which we read, construct, and interpret text. [We are] past the point at which we can be content to see and explain computers as good or evil (p. 1).

Selfe and Hilligoss explain that computer technology, for the foreseeable future, has and will continue to influence reading and writing across the curriculum. Authors of the English language arts standards (National Council of Teachers of English and International Reading Association, 1995) also recognize the influence technology is having on the discipline. Standard 1 acknowledges the need for students to be able to "read a wide range of print and nonprint text" (p. 25). The field's definition of text now explicitly includes multisensory forms of communication as well as print.

Seamless integration of word processing, hypermedia authoring tools with telecommunications through the Internet facilitates and supports meeting the English language arts standards on many levels. The more complex authoring capabilities of multimedia electronic authoring tools require students to apply knowledge of media grammars, current social literary conventions, and information literacy skills to create and share nonprint texts with teachers, peers, and authentic audiences. A recurring theme throughout the literature about these and other electronic technologies is a call for electronic literacy skills. Electronic literacy refers to literacy activities (e.g., in reading, writing, spelling) that happen to be delivered, supported, accessed, or assessed through computers or other electronic means rather than on paper. It is different from computer literacy, which refers to computer usage competencies (Topping, Bircham, & Shaw, 1997).

Research has indicated that eighth-grade students using word processing scored significantly higher on standardized writing assessment measures when they had a high level of keyboarding skills and online text manipulation abilities (Owston, Murphy, & Wideman, 1992). Owston et al. cited online text manipulation abilities as important prerequisite skills for computer-assist revision tasks. A lack of these prerequisite skills may increase the cognitive load on the student writer more than traditional paper-and-pen writing methods, contrary to the popular belief that word processing lessens the cognitive load on students (Joram, Woodruff, Bryson, & Lindsay, 1992). Obviously, with or without technology, good instruction requires teaching the writing process and students being given opportunities to practice.

In another study involving elementary-level students, student writing products and processes were studied over a three-year period. One group of students involved in the study had routine, daily access to word processors (high computer access). A comparison group of students at a nearby school had infrequent access to word processors (low computer access). A repeated measures MANOVA[5] showed a significantly greater improvement ($p<.00005$) in the holistic writing quality of students with high computer access over the three-year period com-

[5]A MANOVA, or multivariate analysis of variants, is a statistical technique for determining whether several groups differ on more than one dependent variable

pared to the amount of improvement shown in the holistic writing quality of students with low computer access.

Research is just beginning to be conducted regarding the processes involved in reading electronic texts (Kamil & Intrator, 1997; Reinking & Bridwell-Bowles, 1996). In fact, "the proportion of research articles published on technology and literacy has remained relatively constant over 11 years [between 1986-96]" (Kamil & Intrator, 1997, p. 394) in disproportion to the investment in technology resources according to a trend analysis conducted by Kamil and Intrator (1997). Research in this area is difficult given the wide range of media characteristics and lack of standard literary conventions applied to the authoring of electronic texts. Existing research findings about reading hypermedia are mixed. Meyers, Hammett, and McKillop (in press) reviewed early studies conducted on the role of hypermedia in education. The literature indicated problems of disorientation, cognitive overload, flagging commitment, and unmotivated rambling among readers of hypermedia texts. Meyers et al. identified a browsing strategy characterized by following links perceived to be relevant as ineffective for novice hypertext or hypermedia information researchers.

Mathematics. Changes in technology and the broadening of the areas in which mathematics is applied have resulted in growth and changes in the discipline of mathematics itself. Davis and Hersch (1981) claim that we are now in a golden age of mathematical production, with more than half of all mathematics having been invented since World War II. In fact, they argue that "there are two inexhaustible sources of new mathematical questions. One source is the development of science and technology, which make ever-new demands on mathematics for assistance. The other source is mathematics itself ... each new, completed result becomes the potential starting point for several new investigations" (p. 25). The new technology not only has made calculations and graphing easier, it has changed the very nature of the problems important to mathematics and the methods mathematicians use to investigate them.

Funkhouser (1993) found that high school algebra and geometry students who used commercially available problem-solving software scored significantly higher on tests of mathematics content than groups of students who did not use the software. The students using the software also made significant gains in problem-solving ability.

Harold Wenglinsky (1998), a research scientist at the Princeton-based Educational Testing Service and author of a study on the effectiveness of using technology to teach math determined that technology can have positive benefits if used in mathematics instruction. However, he cautioned that those benefits depend on how the technology is used. Until now, most research on technology's effectiveness has taken the form of small case studies, some of which examined just a classroom or two at a time. Wenglinsky breaks new ground by analyzing a national database of student test scores, classroom computer use, and other information, including school climate.

Wenglinsky's study, "Does It Compute? The Relationship Between Educational Technology and Student Achievement in Mathematics," used data of fourth and eighth graders who took the math section of the 1996 National Assessment of Educational Progress (NAEP).[6] The U.S. Department of Education has used NAEP to

[6]The study is available at http://www.ets.org/research/pic/technolog.html.

monitor student-achievement for over 25 years. Beginning in 1996, the NAEP assessment included questions about how computers were used in mathematics classrooms, thus allowing for studies of relationships between uses and achievement.

Wenglinsky (1998), after adjusting for class size, teacher qualifications, and socioeconomics, found that technology had more of an impact in middle schools than it did in elementary schools. He found that in eighth grade, where computers were used for simulations and applications, students had higher test scores than where computers were used for drill and practice. The differences were the equivalent of half a grade level. He found that fourth-grade students who used computers primarily for "math/learning games" scored higher than students who did not. Unlike the eighth graders' scores, fourth graders did not show differences in test score gains for either simulations and applications or drill and practice. In addition, students of teachers who had appropriate professional development in computers scored one-third of a grade level higher than students whose teachers did not.

The study revealed that overall, African-American students at the eighth-grade level used computers slightly more than white students. However, 31 percent of white students and only 14 percent of African-American students used computers mostly for simulations and applications. At the other end of computer use, 50 percent of African-American students used computers primarily for drill and practice in contrast to only 30 percent of students in primarily white student classrooms. In other words, though computer access was equitable, the use for those computers was quite different. African-American students, more often, were using computers in ways that appear less effective in raising test scores.

It is important to note that these results are a one-year look, and the results have not been replicated over several years. Though the study seems to be based on excellent methodology, other researchers have not examined the data in the same way. It could be that higher scoring students prefer simulations and applications over drill and practice.

An evaluation of Jasper videodisc adventures in 52 classes in nine states (Pelligrino, Hickey, Heath, Rewey, & Vye, 1992) revealed that as a whole, classrooms using Jasper videodiscs show significant advantages over control group classrooms matched in demographic characteristics in terms of student attitudes toward mathematics, mathematical concepts, and ability to plan their problem solving. Embedded research studies are examining the effects of factors such as working in two-person teams versus individually (Barron & Rieser, 1992).

2. What significance do the findings from Phase III computer-based technology research have for educators today as they try to make decisions that have an impact on student learning?

Statham and Torell (1996) have identified the essential conditions necessary to maximize student achievement:

- Better Access to Technology—In order to become an integral part of students' learning, computers need to be available for individual student use during extended periods of time. Currently, student access to computers is estimated to be less than one hour per week (4 percent of total instructional time).
- Updated Systems—Electrical and communication systems must be updated in

order to maximize the benefits of computer technology.

- Learning Environments—Computers must be viewed as learning environments with multiple capabilities to support and enhance student learning as an important medium for instruction.

- Professional Development—Teachers must be provided with instruction and practice in integrating the curriculum with the technology and become familiar with hardware and software.

Using computers to increase classroom resources is both an impetus for and outcome of transforming the role of the teacher in the classroom. Once known as the sole disseminator of information, teachers now identify themselves as guides, mentors, and facilitators whose roles are to motivate students and engage them in discussion and reflection. Computer-supported communication brings the content expertise of other professionals and community members into the classroom. Content experts provide real-world examples, model performances, and offer otherwise unavailable enrichment opportunities for students (Moller, 1998).

Noted below are some projects that are attempting to implement Phase III thinking as they attempt to increase the effectiveness of technology through use of data-driven decision making. Chris Dede, working through a grant for the National Science Foundation on educational applications of virtual reality, has concluded that "it's always a mistake having a solution looking in search of a problem. It's much better to start by looking at something teachers and learners really struggle with and then look at how a technology may help" (Standard, 1999, p. 48). Dede went on to note, "We know teaching-by-telling isn't a very effective method. Experiential learning is, if we can develop models and simulations that give people a real sense of what it's like to be involved with something complicated" (p. 48).

The Minnesota Department of Education and the North Central Regional Educational Laboratory (NCREL) analyzed data derived from the Third International Mathematics and Science Study (TIMSS) and concluded that Minnesota students were extremely competent on some key "gateway" concepts and lacked significant understanding of other "gateway" concepts. (Gateway concepts are those concepts so important to a content area that failure to understand them has a severe impact on learning of that subject matter.) At the same time, the Minnesota Legislature demanded that evidence be provided that technology and technology professional development were addressing important learning needs.

The Minnesota Department of Education decided that they would focus some of their technology professional development efforts on helping teachers use the "Gateway Concepts" Web site created by NCREL with the assistance of the Department and other Minnesota educators. This site—www.ncrel.org/msc/gateway/index.htm—targeted assistance to the four concepts in each of four areas (science, mathematics, writing, and inquiry) that data showed were most problematic to Minnesota students. The Gateway Concepts site provides assistance to teachers by describing the concept and the key understandings that students need to know if they are to fully grasp that concept. The site provides assistance on defining standards and objectives and incorporating into teaching and learning efforts especially useful print, Internet, software, and multimedia resources specific to each concept. The state

assessment will have specific questions directed to the difficult-to-understand concepts to see whether the targeted use of technology will result in better understanding of those concepts.

The Gateway Concepts site also is being used with the REAL Consortium in Southern Ohio. In this effort, the resources in the Gateway Concept site are supplemented with the use of another NCREL product called the Engaged Learning Safari that provides sophisticated virtual learning community support. Engaged Learning Safari also provides automatic individual home page access to very powerful databases that allow participants to both contribute and receive resources developed by both practitioners and researchers. This smaller but more intense application is expected to provide quality research that will explore the viability and effectiveness of Phase III computer use.

Conclusions

Research and trends show that technology applications have been heavily influenced by reform movements within education, cognitive science, learning theories, and societal/cultural demands. A review of research shows that technology can and does help students develop all kinds of diverse skills from the basics to higher-order thinking. However, for technology to be truly successful, schools need to maximize the effectiveness of their investments in technology by using it in a spectrum of ways. Effective technology uses minimally require employing research and best practices to match technology software to the curriculum and the developmental needs of learners; to customize content area learning; to enrich learning experiences with communications and links to others beyond the school walls; to offer new learning opportunities; and to help learners see the value of learning by applying knowledge and skills to real-world tasks.

In recent years, those responsible for integrating technology into educational practices have been working to apply the theories and techniques from the field of research to uses of microcomputers, cyberspace, and long-distance learning capabilities of modern mechanisms. Kamil and Intrator (1997) suggest that "it is important to monitor these trends because we are in danger of having rapid hardware and software development overwhelm any input that might come from educational research. The product life cycle of hardware and software is far shorter than the typical timeline for educational research studies" (p. 395). In many respects, their words sum it up. Teachers who use technology need to become action researchers who can produce and publish research findings on a more rapid cycle. Data-driven practices are key to helping this happen. One result is the feasibility of technology-based educational institutions. The structures and curricula, which could result from technology-based education, have far-reaching implications.

As noted in the introduction of this paper, looking at conclusions drawn across findings from all three phases, we find that technology has an important role to play in K–12 education, but it will not solve all educational problems. Technology can:

- Make learning more interactive.
- Enhance the enjoyment of learning.
- Individualize and customize the curriculum to match learners' developmental needs as well as personal interests.

- Capture and store data for informing data-driven decision making.
- Enhance avenues for collaboration among family members and the school community.
- Improve methods of accountability and reporting.

Ultimately technology may transform the educational content and motivate students toward lifelong learning.

Minimally for technology to play a positive role, the following factors must be given consideration (Means, 1994). (For more elaboration on this point see Valdez and McNabb, 1997.)

1. The success or failure of technology is more dependent on human and contextual factors than on hardware or software. The extent to which teachers are trained to use computers to support learning plays a role in determining whether or not technology has a positive impact on achievement. In a meta-analysis, Ryan (1991) examined 40 comparative studies and found that the amount of technology-related teacher training was significantly related to the achievement of students receiving computer-based learning. Students and teachers with more than ten hours of training significantly outperformed those students whose teachers had five or fewer hours of training.

2. The success or failure of technology involves seeing it as a valuable resource that requires determining where it can have the highest payoff and then matching the design of the application with the intended purpose and learning goal. The success or failure of technology-enabled learning experiences often depends on whether the software design and instructional methods surrounding its use are congruent. There are many uses for technology, but each use has design principles related to philosophies and theories of learning.

3. The success of technology depends on having significant critical mass numbers and types of technology applications that are appropriate to the learning expectations of the activity. Research and best practices indicate that one computer for every four to five students is necessary if students are to be able to use technology in a manner that will result in significant gains. Technology applications must be located in the classrooms or areas where the learning is taking place instead of housed in hard-to-access labs or resource centers. If students are to really benefit from technology, then sufficient connections to the Internet and other resources need to be available. Equally important, computer programs may require additional specialized equipment, such as probes for science classes, sound cards and electronic keyboards for music classes, video cards for art classes, and virtual reality and long-distance cameras for computer-mediated communications (see Means, et al., 1993; Sivin-Kachala & Bialo, 1996).

4. The most pervasive perception among teachers is that computers have improved the climate for learning by

increasing student motivation in subjects for which they use computers. Researchers who have examined differences in student perceptions of learning have typically found improvements in students' self-reports of their own motivation and learning in response to computer applications (Gregoire, Bracewell, & Laferriere, 1996).

Numerous recent events have pointed out how interrelated schools and society are and how we cannot think of education in isolation of society any more than society can consider itself in isolation of schools. The rapid and ongoing pace of technological changes has shortened the life cycles of products, processes, and information exchanges, leading to new discoveries and insights about the world. Today's children need to be connected to this world in order to receive a useful education and to prepare them to deal with it when they graduate. Computer uses and expectations in schools have been and are evolving as technology, connectivity, and software change. Schools will continue to be at different stages of technology implementation as long as there are disparities in access to professional development and resources. The research shows that political, educational, and public commitment is turning toward implementing technology more effectively to ensure that it does indeed enhance student achievement. Only then will supporters and critics be able to label Phase IV "Successful Integration and Use of Educational Technology" with the same credibility they see for uses of technology in banking, medicine, manufacturing, commerce, and so many other fields.

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