Research on Computers and Education: Past, Present and Future

Prepared for the

Bill and Melinda Gates Foundation

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Executive Summary

Computers and related technologies are now in almost every school across the nation. State reform efforts include the integration of technology in curriculum standards and sometimes make technology skills a separate standard for students to achieve. As the focus on technology expands, policy makers and tax payers are asking researchers in educational practice to provide the data for thoughtful decision making on the use of technology for learning. At this time the decision-making is often hampered by the lack of adequate research, although there is considerable work from previous years to guide future study.

The evolution of technology use

The computer was introduced into education in the 1970s and its first use had teachers and students learning to program. Since that time there has been an evolution of best practices. As software gained in sophistication, the computer became the tutor or surrogate teacher. Students followed the commands on the computer screen receiving rewards for correct answers. They also began to learn through playing games and simple simulations. Teachers of writing discovered the value of using a word processor and soon students were writing more and revising with ease. Other teachers saw the value of the computer in creating a rich learning environment and had students using databases, spreadsheets, presentation and research tools across all subject areas. Next the Internet impacted technology use. Suddenly there was a volume of knowledge available to students with access and a network of people throughout the world that enhanced communication and the exchange of ideas. Real problem solving in collaborative groups became the norm in some classrooms. Online courses were available and students in rural areas had expanded learning opportunities in a variety of subject areas. Previously abstract concepts could now be illustrated and manipulated because of technology advancements. A whole new learning environment became possible.

Does it make a difference? It depends…

Research in traditional classrooms has shown that technology can have a positive impact on student achievement if certain factors are present, including extensive teacher training and a clear purpose. In recent years researchers have found that the technology can be an important component for creating exciting new learning environments for students, once again dependent on other factors such as:

- Lower student to computer ratio;
- Teacher ownership of the reform efforts;
- *Extensive* teacher training and planning time;
- High levels of technological support.

Unfortunately, these factors are often missing in school technology implementation efforts, resulting in inconclusive research findings of the effects of these environments on student learning. Sometimes schools make large purchases of technology for classrooms but ignore the accompanying teacher training. At other times resources are wasted as teachers receive training only to return to a classroom with limited or no access for the students. This leads many observers to question the benefits of technology in the schools.

The research challenge is to construct viable studies where all the necessary factors are in place.

The critical questions for the future

As educators and researchers look to the future they are no longer asking the question, "*Should technology be used in education*?" Instead the focus is "*How should technology be used to help students achieve higher levels*?" Across the country there are fine examples of technology use in scattered classrooms and a few schools, but the challenge is to bring a technology rich learning environment to every student. In the era of new standards and high performance schools, technology must be linked not only to student learning but also the efficient management of schools and districts. Little research is available in this area. The potential of learning anywhere, any time is just beginning to be tapped. Online courses and virtual schools, learning communities, apprenticeships and internships will change the concept of school in this century.

More research is needed to answer several critical questions as technology is thoughtfully deployed throughout our schools. Ten critical questions for further study are:

- How can technology increase student learning and assist students in meeting the standards?
- Do students learn and retain more with the aid of computers?
- How does the use of computers affect classroom climate and student attitudes?
- What are the conditions that must be in place for technology to effectively improve student learning and especially the achievement of "at-risk" students?
- How can technology serve as an extension of human capabilities and cognitive functioning?
- What specific cognitive skills are enhanced by the use of technology for learning?
- How can online assessment be used to enhance student learning and accountability?
- What are the effective deployments for a technology rich learning environment?
- What constitutes effective and adequate teacher training?
- How can technology improve productivity in all aspects of district, school, and classroom management?

As researchers begin or continue their important work, their conclusions will provide a guide for educators and others to make good decisions about how to use technology for learning both inside and outside our schools.

The Bill and Melinda Gates Foundation plan

This current research and the questions for the future are consistent with the Gates Education Initiative that seeks to Help All Students Achieve. The foundation will work with leaders in fifty states to assure that principals and superintendents have the knowledge to create rich technology learning environments where all students can achieve at high levels. Our teacher project will create model classrooms and show the possibilities as we encourage and participate in the action to provide every student a quality teacher. Our work will also involve comprehensive support for schools and districts to create quality places where others can visit and learn the elements necessary for success. These will be scalable models that are possible for all schools to achieve.

Finally we will conduct evaluation and action research to answer the critical questions and also to adjust our programs as we learn together with educators and their communities across the nation.

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Introduction

As the new millennium begins schools throughout the country are in the midst of reform efforts—the term "restructuring" often being used to imply a deeper, more fundamental change in the nature of schools and schooling than that implied by "reform." These efforts often involve a rethinking of the very nature of schools and the educational experience for children. Resulting changes may be structural in nature, such as a revision of the school day or the school year, or they may be more fundamental in nature, resulting in a very new curriculum that asks students to learn and perform in ways much different than before.

A driving force of these restructuring efforts is the belief that a school system built on a Nineteenth Century industrial efficiency model is inadequate to meet the needs of the society of the Twentieth-First Century that has been transformed by technology. Because technology has transformed businesses and many other components of daily life, many are relying on technology to help transform the nature of the school experience. As the new millennium begins that transformation is still incomplete.

In October 1999, at the National Education Summit states were asked to fully implement the final stage of their reform efforts by adopting policies that held schools and educators accountable for their successes and for their failures. Results matter, and therefore determining what best produces desirable results is an important part of the accountability efforts.

There is evidence that computers and the related technologies[1] have made major inroads into the schools. There are now an estimated 10 million computers in the schools with annual school expenditures for technology of about 6 billion dollars. There is one instructional computer for every 5.7 students and more than half of the nation's classrooms have been connected to the Internet. A 1999 national survey conducted by *Education Week* in collaboration with the Milken Exchange found that 97% of all teachers surveyed use a computer for educational purposes, either at home or at school, and 53% use software for classroom instruction. Virtually every state reform plan includes technology as an integral component, and student school access to technology is higher than ever before.

[1] In educational practice computers have become the predominate "new" technology, but they are often used in concert with other forms of technology, such as the internet and video capabilities, making it difficult, if not impossible, to talk in terms of just computer use. In this paper I use the terms computers and technology interchangeably.

At the same time, the views surrounding technology in the schools are diverse. Some advocate the expansion of technology use to enhance student technological literacy, while others believe its primary purpose should be as a learning tool. "The romanticized view of technology is that its mere presence in schools will enhance student learning and achievement. In contrast is the view that money spent on technology, and time spent by students using technology, are money and time wasted" (National Research Council, 1999, p. 194). Yet, many proponents of increasing the role of educational technology in the schools admit that our current knowledge about the educational affects of that technology is rudimentary at best. This is due to the fact that much of the evaluation that has taken place has been in classrooms with mixed or partial deployments of technology with varying levels of training and limited content. Full implementation has been hampered by a lack of capital budgets and insufficient research and development funds necessary to create fully integrated learning environments.

There is perhaps no other profession that is so subject to "the new and innovative" as is education. The tendency for educators to tout first one innovation and then another and the failure of these innovations to make any marked improvement in student learning has been well documented. And, rightly or wrongly, there are many today who are skeptical of the educational value of the new technologies, or at least skeptical of the schools' abilities to use them effectively or to deploy them sufficiently to transform the learning environments.

Educational policy-makers are responsible for determining the direction, nature, and scope of educational programs, and for determining how scarce resources are to be allocated. Ideally, educational policy will reflect the "best practices" of the profession. By best practices, we mean the educational approaches, programs, materials, etc., that have proven to be of the most educational benefit and value to the greatest number of children. But where exactly do computers and related technologies fit into this realm of "best practice?"

Determining "best practices" is not a simple matter. In fact, there is no shortage of differing opinions about what the schools should be doing and how teachers should be teaching. Advocates of the various views are sincere in their beliefs that what they are advocating for is "best" for the children.

It is important to note that the beliefs that influence policy are often times only that—beliefs. It may be that they are all true (although that seems unlikely), or at least true to some limited degree (which seems more probable). Empirical evidence that these claims are true is many times lacking. As Carl Sagan once said, "We sometimes pretend something is true not because there's evidence for it, but because we want it to be true."

"Making Research Serve the Profession."

In an article in the *American Educator* Bonnie Grossen (1996), a researcher at the National Center to Improve the Tools of Educators, wrote: "Unlike other research-based professions, our mechanisms for distinguishing fads that will probably fail from effective innovations are weak and ineffective. In fact, there may be more incentives for faddism than for the dissemination of proven practices" (p. 7). Her point was that many of the educational practices that are widely touted lack any empirical evidence as to their effectiveness. These practices often lack supporting research evidence, or if it does exist it is often ignored in favor of strongly held opinions. Part of the problem within the profession is that there is no agreement on a definition of "research," and no agreed upon understanding of "at what level of evidence will new research be incorporated into the professional canon"(p. 8)?

Grossen suggested using a three-level category system proposed by Ellis & Fouts (1993; 1994; 1997), one that is helpful for understanding the large quantities of research on educational technology. Level I research is basic research and theory building. It is research that is exploratory or descriptive in nature and leads to hypotheses about cause and effects. The theories and hypotheses may evolve out of empirical studies, for example using correlations, out of individual case studies or qualitative methods, or out of medical studies, such as research on the brain. They may also go hand-in-hand with certain philosophical views, such as behaviorism. Level I or basic research in education mostly involves the work of psychologists, learning theorists, linguists, and more recently neuroscientists. Their findings, either in isolation or combined, have implications for how people should best be taught.

Once the theories and hypotheses have been proposed, it is the role of Level II research to test the hypotheses by formal experiments in controlled varied situations to determine their truth. These are usually small-scale studies and must be replicated in a variety of settings to ensure the generalizability of the findings. Level III research is evaluation research to determine if the program can be implemented on a large scale, and if so, under what conditions. It can also be used for accountability purposes for the programs.

Educators often seize on the Level I research and resulting theories and develop educational techniques or programs and present them as "research based." Grossen states that "One huge problem with our current professional knowledge base is that many experimental practices have been allowed to jump from Level I research straight into the professional canon (p. 22)." This is a sentiment with which the President's Committee of Advisors on Science and Technology is in agreement:

> It is well to remember, however, that the history of science (and more specifically, of educational research and practice) is replete with examples of compelling application-specific hypotheses that seem to arise "naturally" from well-founded theory, but which are ultimately refuted by either rigorous empirical testing or manifest practical failure. Knowledge of the nature of learning and thought is closely related to, but nonetheless distinct from, knowledge of the best ways to cause such learning to take place (Shaw & PCAST, 1998, p.118.).

To what degree does educational technology fit this pattern? To what degree are our current practices “research based” and grounded in sound evidence as to their effectiveness? In the following pages the research evidence is reviewed and an agenda is suggested for “making research serve the profession.”

Past and Present Research Findings on Computers and Related Technology in Education

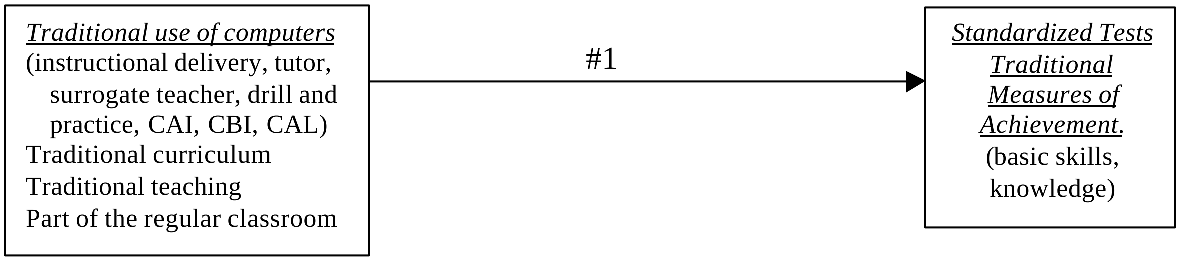
Over the past several decades technology has been used in a variety of ways for a variety of purposes. Researchers have employed varying research methods in an attempt to understand the role that technology can and does play in the education of children. Consequently, there are a number of differing lines of research that have been conducted, and many of the lines of inquiry may overlap with others. This has resulted in a large amount of research, but so varied in method and treatment that at times is difficult to categorize. There are areas for which there is little, if any, information available, meaning that there is much that we do not yet know about the effect of this technology on student learning. Because there are a variety of ways in which technology has been used in the past and a variety of ways it is being used today in education it is important to consider each line of research individually in an attempt to sort out the status of what is known and what research is yet to teach us.

As new technologies have emerged they have often times replaced or have been used concurrently with earlier technologies, thus dramatically changing the nature of the way the technology has been used in the classrooms. Computers and related technologies have been used as tutors, surrogates and supplemental teachers of the regular curriculum, as tools for the purpose of transforming the classroom, as delivery modes for distance education, and for educational management applications, including improved planning, data analysis, communication and personal productivity.

The Computer as Tutor and Surrogate Teacher

One of the earliest uses of computers in classrooms was to teach the traditional curriculum and basic skills, often operating as a means to deliver instruction, sometimes as a supplement to the teachers' classroom instruction, and sometimes in lieu of the teachers' instruction. Much of the software focused on basic skills and knowledge in the various content areas, used programmed instruction and drill and practice, and was often based on behaviorism and reductionism for its instructional design. As time progressed, the software and usage changed and the line between the computer as a tutorial and the computer as a tool became blurred. For example, as word processors became more sophisticated and available, the computer was often used to produce student writing. Other types of programs, such as Logo, soon further blurred the line between tutor and tool. With the change of usage came questions about how best to evaluate the effect of the technology on student learning, but in most instances, the researchers relied on standardized test scores or other traditional measures of achievement. Line #1 in Figure 1 represents the relationship between the traditional use of computers for instruction and student achievement.

Figure 1



The instructional design used in much of the computer assisted instruction, particularly in the early years and either by design or because of the limitations of the technology and software capabilities, was based on behavior theory and the basic or Level I research of behaviorist psychologists and combined with reductionism (see Burton, Moore & Magliaro, 1996). In practice, the behaviorist and reductionist view of learning was implemented as the successive mastery of properly sequenced small pieces of knowledge and skills derived from broad educational objectives. These component parts were believed best learned through direct instruction, proper sequence, immediate feedback, and immediate reward. This view of learning had direct implications for the function the computer served.

An extensive body of Level II/experimental research developed over the years to evaluate the accuracy of these beliefs about learning and the resulting instructional design and computer usage. This line of research produced hundreds of studies over the past several decades. Research from the 1960s, 70s, 80s, and 90s has been reviewed and summarized many times, resulting in published reports in professional journals, papers presented at professional conferences, institutional or organizational reports, book chapters and ERIC documents. The reviewers generally used terms such as computer assisted instruction (CAI), computer based education (CBE), computer based instruction (CBI), computer managed instruction (CMI), or computer based learning (CBL) to describe the nature of the treatment. Although these terms have their own precise definitions and computer usage differed to some degree in the original studies, they all tended to either supplement or replace traditional instruction while focusing on the knowledge and skills of the regular curriculum. In reviewing the studies the reviewers often used differing methods for summarizing the findings, including narrative review, meta-analysis and best evidence synthesis. They also used differing criteria for the inclusion of a research study in the review, depending on the quality, purpose, or nature of the research. Finally, some of the reviews included other technologies with the computer, such as interactive video.

There are broad, general reviews, summaries, meta-analyses, and reviews of reviews that include a variety of educational outcomes and subjects (Bangert-Drowns,1985; Bangert-Drowns, Kulik, & Kulik, 1985, 1987; Bialo & Sivin, 1990; Bracey, 1982, 1987; Christman, Badgett, & Lucking, 1997; Cotton, 1991; Cronin & Cronin, 1992; Education Turnkey Systems, 1985; Edwards, Norton, Taylor, Weiss, &

Van Dusseldorp, 1975; Ely, 1984; Fletcher-Flinn & Gravatt, 1995; Hasselbring, 1984, 1986; Khalili & Shashaani, 1994; Kozma, 1991; Krendl, 1988; Kulik, Bangert & Williams, 1983; Kulik & Kulik, 1987a, 1987b, 1991; Kulik, Kulik & Bangert-Drowns, 1985; Liao, 1992; Liao & Bright, 1991; McNeil & Nelson, 1991; Niemiec, Weinstein & Walberg, 1987; Ploeger, 1983; Rapaport & Savard, 1980; Roblyer, 1988, 1989; Roblyer, Castine, & King, 1988; Ryan, 1991; Sivin-Kachala & Bialo, 1994; Software Publishers Association, 1998; Statham & Torell, 1996; Szabo & Montgomerie, 1992; Umbach, 1998; Vinsonhaler & Bass, 1972; Wang & Sleeman, 1993; Wilkinson, 1980), and more specialized reviews of research on computers and word processing and writing (Bangert-Drowns, 1989; 1993; Dahl & Farnan, 1998), math (Burns & Bozeman, 1981; Hughes & Maccini, 1997), language learning (Inoue, 1999; Miech & Mosteller, 1997), cognitive effects (Liao & Bright, 1991; Mandinach, 1983), learning disabled and special education children (Hasselbring & Goin, 1988; Hughes & Maccini, 1997; Roblyer, 1989; Woodward & Rieth, 1997), young children (Clements, 1987a; Clements, Nastasi & Swaminathan, 1993), higher education and adults (Emerson & Mosteller, 1998; Ehrmann, 1995; Kulik & Kulik, 1985; Kulik, Kulik & Shwalb, 1986), and gender differences (Kirkparick & Cuban, 1998).

It is important to note that not all of the computer usage in schools during these decades was focused on the teaching of basic skills and content based on behavior theory. Those educators who envisioned a more student centered curriculum and learning environment did attempt to employ the computers in different ways. For example, there were efforts in some science classrooms to use the computers to provide simulations and modeling of problems to aid instruction and to foster a deeper understanding of method and content (Stratford, 1997). Attempts were made to eliminate the preprogrammed nature of the instruction and to incorporate "intelligent tutoring systems" (ITS) (Goodyear, 1991; Shute & Psotka, 1996; Wegner, 1987) that used diagnostic procedures based on the knowledge of the learner at any given point.

Other efforts, based on the work of Seymour Papert (1980), focused on teaching of computer programming with the belief that it could foster cognitive development. One of the most common programs was Logo for young children. It was the focus of a number of research studies for several years (e.g. Clements, 1987b; Clements & Gullo, 1984; Clements & Nastasi, 1988, Keller, 1990; see DeCorte, 1996), with evidence that a Logo programming environment fosters higher order thinking skills, develops creativity, and produces other desirable outcomes. Sometimes these studies were included in the reviews of research (e.g. Khalili & Shashaani, 1994; Liao & Bright, 1991), and sometimes they were omitted because the use of the computer and the educational outcomes being sought did not fit the scope or criteria of the review.

While not all of these reviews show outcomes in favor of computer usage, the vast majority of them reach positive conclusions about the efficacy of the use of computers in these ways. There is general concurrence that:

- When combined with traditional instruction, the use of computers can increase student learning in the traditional curriculum and basic skills area.

- The integration of computers with traditional instruction produces higher academic achievement in a variety of subject areas than does traditional instruction alone.
- Students learn more quickly and with greater retention when learning with the aid of computers.
- Students like learning with computers, and their attitudes toward learning and school are positively affected by computer use.
- The use of computers appears most promising for low achieving and at-risk students.
- Effective and adequate teacher training is an integral element of successful learning programs based on or assisted by technology.

However, these results are not guaranteed by the simple introduction of computers and related technology into the classrooms, suggesting that there are many other factors involved, such as instructional design and software sophistication, that play important roles in the process.

The research in this area has been heavily criticized for its low quality, such as the lack of control for other variables, short-term duration and the Hawthorn effect, inconsistent treatments and researcher bias. (Bracey, 1987, 1988; Brown, 1991; Clark, 1983, 1985a, 1985b, 1991, 1992, 1994, 1995; Clark & Clark, 1984; Clark & Stuart, 1985; Colorado, 1988; Miech & Mosteller, 1997; Reeves, 1995; Williams & Becker, 1987; 1986; 1992; Williams & Brown, 1991). Most of the reviewers acknowledged these weaknesses but accepted the findings with varying degrees of confidence. However, it is because of the low quality of this research and the lack of Level II and Level III research on other computer uses that a number of educators and writers maintain that there is insufficient evidence as to the effectiveness of computers and technology to warrant expanded use. This idea has been clearly articulated in articles, such as *The Computer Delusion* (Oppenheimer, 1997).

The use of computers in the teaching of foreign languages is an example of changing usage due to changing ideas within the profession about how people learn. Miech & Mosteller (1997) reviewed the research on computer-assisted language learning (CALL) and found a pattern of usage reflecting changing underlying educator beliefs about learning. “Computers themselves do not possess theories of learning; computer programmers and educators, consciously or unconsciously, bring those theories to the task”(p. 61). Early use of the computer to teach foreign language was drill and practice and “placed the teachers in a largely peripheral role, as students interacted with the machine and could progress through the sequence of lessons alone”(p. 66). During the 1990’s the theories of the behaviorists were superceded by the theories of the cognitive psychologists that focused on how the mind works and makes meaning in learning. Concurrently, language teachers began focusing on the “natural approach,” and on linguistic theories that posited language learning is an innate capability. These changing ideas about learning coupled with new technological capabilities resulted in changes in computer usage. The technology was used to create

> multidimensional networks where teachers use CALL to promote person-to-person interactions in the target language, often with 'distant others' beyond the walls of the classroom, that transcend obstacles of distance and time. . . . educators can use computers as vehicles both to support new and different interaction among students and teachers in the target language and to create opportunities for students to converse with native speakers and others outside of the classroom and the university (p. 66-67).

This is an excellent example of how our changing ideas about how people learn has changed the way in which technology has been used in the classroom. But it also points out that the current relevancy of much of the earlier research is questionable, not just because patterns of usage have changed, but also because the technology itself has changed dramatically in just the last few years alone, as has the ways in which it is being deployed. While this research should not be ignored completely, it does not involve new technological developments such as the Internet and enhanced networking capabilities. It must be the role of a new generation of research to provide directions for best practices for technology in the schools.

Technology as a Transformational Agent and Learning Tool

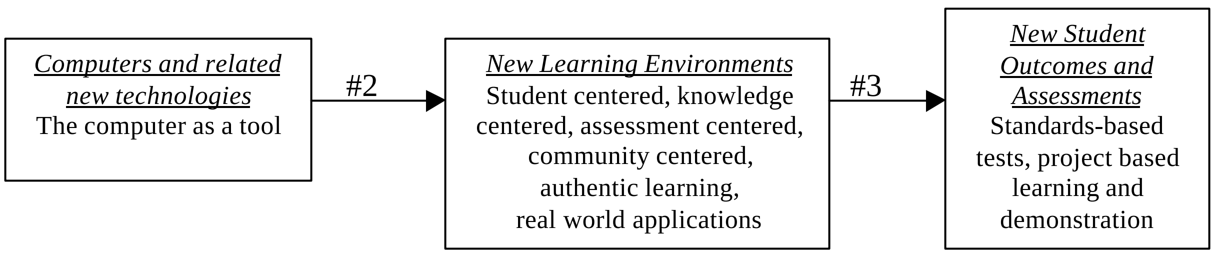
In the past decade the use of the computer and related technologies has expanded from use primarily as an instructional delivery medium to technology as a transformational tool and integral part of the learning environment. In fact, many proponents of the current reform efforts see technology as a vital component of a new educational paradigm in which the curriculum, teaching methods, and student outcomes are reconceptualized (see Means, 1994). This view was adopted by the U.S. Department of Education at least as early as 1993. In U*sing Technology to Support Education Reform"* (United States Department of Education, 1993) it was stated: "technology supports exactly the kinds of changes in content, roles, organizational climate, and affect that are at the heart of the reform movement."[2]

In these settings the computer and related technologies are serving at least four distinct purposes: (1) they are used as previously to teach, drill and practice using increasingly sophisticated digital content; (2) they are used to provide simulations and real world experiences to develop cognitive thinking and to extend learning; (3) they are used to provide access to a wealth of information and enhanced communications through the internet and other related information technologies; and (4) they are used as productivity tools employing application software such as spreadsheets, data bases, and word processors, to manage information, to solve problems and to produce sophisticated products. Line #2 in Figure 2 represents the relationship between the new uses of technology and the transformed classrooms and new learning environments.

[2] Many documents found online in non-PDF format do not have page numbers. In this paper page number citations are provided for all hard copy documents in the normal manner. Quotes used without page number citations are from on-line documents with no page numbers.

One of the central components of school reform is the desire for higher academic standards and a stronger focus on higher order thinking, problem solving skills, and learning associated with "real world" applications. To accomplish these ends a new learning environment for schools is necessary. Proponents of school technology assert that it is just that type of environment and those types of learning that are facilitated by the new technology. At the same time there is a predominant belief that the traditional standardized tests are inadequate to measure the types of learning teachers are now being asked to teach. This has resulted in a demand for new assessment procedures for the new learning outcomes. Those new assessments are taking the forms of projects, portfolios, demonstrations, and new standards-based tests. From this perspective technology cannot be viewed or evaluated apart from the other major changes that should take place within the school setting, and is seen as an enabling factor for these other changes. Line #3 in Figure 2 represents the relationship between the new learning environments and the new student outcomes and assessments.

Figure 2



Basic/Level I Research on Learning and Teaching

The changing use of technology reflects the changes in understanding over the last two decades about how the mind works and how children actually learn. There is a strong Level I or basic research base that supports these ideas, and the research has direct implications for how children should best be taught. Collectively, the research has been called the new "science of learning" (Bransford, Brown & Cocking, 1999), and the research is truly basic research in nature. The new science of learning is derived from the findings of researchers in developmental psychology, cognitive psychology, linguistics, and neuroscience, and coupled with the philosophical ideas of constructivism (Duffy & Cunningham, 1996). Taken together they serve as the basis for many of the current beliefs about what and how children should learn in school. "Our understanding of human learning has . . . evolved (based on a wealth of evidence collected over a wide range of different domains and media) from a process based on the passive assimilation of isolated facts to one in which the learner actively formulates and tests hypotheses about the world, adapting, elaborating and refining internal models that are often highly procedural in nature"(Shaw & President's Committee of Advisors on Science and Technology, 1998). These ideas have been tried by creating technology rich learning environments in basic research settings, not only in the United States, but also in a number of other countries (Vosniadou, DeCorte, Glaser, Mandl, 1996).

The National Research Council's Committee on Developments in the Science of Learning articulated an idea central to this new understanding of human learning: "A fundamental tenet of modern learning theory is that different kinds of learning goals require different approaches to instruction; new goals for education require changes in opportunities to learn" (Bransford, et al., p. xvi). *These new learning opportunities should take place in learning environments that are student centered, knowledge centered, assessment centered and community centered, and the new technologies are seen as consistent with the principles of a new science of learning.*[3]

Key conclusions:

- Because many new technologies are interactive, it is now easier to create environments in which students can learn by doing, receive feedback, and continually refine their understanding and build new knowledge.
- Technologies can help people visualize difficult-to-understand concepts, such as differentiating heat from temperature. Students are able to work with visualization and modeling software similar to the tools used in nonschool environments to increase their conceptual understanding and the likelihood of transfer from school to nonschool settings.
- New technologies provide access to a vast array of information, including digital libraries, real-world data for analysis, and connections to other people who provide information, feedback, and inspiration, all of which can enhance the learning of teachers and administrators as well as students (Bransford, et al., p. xviii-xix).

For several years the National Science Foundation has "supported work [that] focuses on 'learning about learning' by emphasizing the integration of theory with experiments that ground, test, and advance basic understanding of learning and intelligent behavior"(Sabelli & Kelly, 1998, p. 42). The Learning and Intelligent Systems (LIS) initiative of the Foundation continues work in this basic research area. Sample descriptions of the projects provide an insight into the nature of the research being conducted.

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[3] The National Research Council's usage of certain terms in describing these learning environments differs somewhat from the more common usage in education. Learner centered refers "to environments that pay careful attention to the knowledge, skills, attitudes, and beliefs that learners bring to the educational setting." It implies "building on the conceptual and cultural knowledge that students bring with them to the classroom"—a basic constructivist perspective. Knowledge centered environments "take seriously the need to help students become knowledgeable by learning in ways that lead to understanding and subsequent transfer." In these environments it is important to identify clearly the domains and knowledge to be learned, including automaticity of skills, but also to help students to develop true understanding. Assessment centered environments provide students with the opportunity "for feedback and revision and that what is assessed must be congruent with one's learning goals." While both formative and summative assessments are important, formative assessments are the assessments vital for enhancing student learning. Community centered environments are where "Students, teachers, and other interested participants share norms that value learning and high standards." The term community includes "the classroom as a community, the school as a community, and the degree to which students, teachers, and administers feel connected to the larger community of homes, businesses, states, the nation, and even the world." A thorough explication of these ideas is provided by Bransford, et al (1999), pages 119-142.

> A new generation of computer tutoring systems that adds advanced planning and natural language components to existing intelligent tutoring systems will be the focus of a collaboration between two major universities (p. 43).
>
> Researchers will begin building systems-level neural theories of incremental learning through a set of LIS projects. Such a neural theory of incremental learning would build on computer simulations of animal brain activity during learning, magnetic resonance imaging in humans under similar tasks, and robotics implementation to test the models (p. 43).
>
> Researchers will explore spatial competence and its emergence over time at the cognitive, computational, and neural levels. Such research into spatial learning has consequences for how we teach in the classroom, particularly in the use of educational software and in designing information searchers—navigating the Internet or learning cognitive maps (p. 45).

The President's Committee of Advisors on Science and Technology (Shaw & PCAST, 1998) concluded that "much of the research literature dealing with constructivist applications of technology consists of theoretical and critical analysis, reports of informal observations, and well-articulated but high-inference reasoning" based on research in a variety of areas. They used the term "progenitive research" and "formative in nature" to describe much of what has been done, and that it is "often quite sound," but "intended more as a preliminary exploration of new intellectual territory" (p. 118). So, the Level I research is extensive, but it does not qualify as, in the words of the President's Committee, "*rigorous empirical testing*."

Research on Classroom Transformations and New Learning Environments

Are the assertions of the technology proponents in this line of thinking correct? Does the introduction of extensive technology into the classrooms facilitate the transformation of the learning experience as envisioned by the advocates, and does the use of the technology enhance the creation of the new learning environments and the attainment of the new outcomes?

Some of the earliest research on the role of technology as a transformational agent was conducted during the 1980s and 1990s on the Apple Classrooms of Tomorrow (ACOT). This project, which involved over 100 schools in a variety of settings, resulted in numerous evaluation reports (e.g. Apple Computers, Inc. 1995; Baker, Gearhart & Herman, 1989; David, 1992; Dwyer, 1992; 1994; Fisher, 1989; Herman, 1988; Kitabchi, 1987; Knapp, 1989a, 1989b; Tierney, 1988, 1989; Tierney, Kieffer, Whalin, Stowell, Desai & Gale, 1992). The overall guiding question for the project was "What happens when teachers and students have constant access to technology?" Much of the research was formative or qualitative in nature; however, there were a few studies conducted on traditional student outcomes, such as test scores, that sometimes showed mixed and sometimes positive results.

Taken as a whole, the evaluation reports document the important role that the computers and related technology played in changing the classrooms over time. David Dwyer (1992) summed up the classroom transformations this way:

> We came to understand that personal computers, printers, laserdisc players, VCRs scanners, MacRecorders, and general purpose tool software could play a far more powerful role in learning. These technologies provided an excellent platform—a conceptual environment—where children could collect information in multiple formats and then organize, play, visualize, link, and eventually construct new ideas about relationships among facts and events. The same technology could then be used powerfully by students to communicate their ideas to others, to argue and critique their beliefs, to persuade and teach others, to add greater levels of understanding to their own growing knowledge (p.5-6).

Other ACOT research reports contain phases such as, "a more dynamic learning experience" and "greater focus on problem solving." For example, Baker, Gearheart, Herman, (1989) noted, "more importantly, informal observation suggests the experience of ACOT itself appears to be resulting in significant new learning experiences for students and greater attention to complex higher level processing." However, hard data were lacking and the researchers from UCLA concluded that new evaluation tools capable of measuring the complexities of ACOT effects are needed.

Means and Olson (1995) conducted research for the OERI on nine schools from around the country that had high degrees of technology. They reported changes in the roles of both the students and teachers, increased motivation and self-esteem, increased technical skills, the accomplishment of more complex tasks, increased use of more external resources, increased collaboration among peers, and increased communication skills during presentations. They concluded: "technology can support fundamental changes in classrooms and schools with resulting benefits in terms of student motivation, self direction, and accomplishment" (Means, 1998, p. 1).

Glennan & Melmed (1996) examined 5 "technology-rich schools" in which "curriculum and instruction have been changed, and the school day is reorganized to make effective use of technology." These schools were considered to be "representative of the best practices across the nation," and they demonstrated that technology could be used to restructure the learning experience for students and improve learning outcomes. Glennan & Melmed were cautious in their conclusions however and stated: "research has not yet identified a sufficient number of examples of technology-supported whole school reforms to allow us to fully gauge the contributions that educational technology can be reliably expected to make to reform objectives."

Sivin-Kachala and Bialo (1994) reviewed 133 research reviews and reports on original research projects from between 1990 and 1994, and the process was then repeated by Sivin-Kachala, Bialo and Langford (1997) who reviewed 219 educational technology research reviews and reports from 1990 to 1997. Through this process they concluded that introducing technology into the classroom results in more student-centered learning, cooperative learning, and teacher/student interaction.

An emerging body of evaluation research in the last three years gives support for the contention that computers and technology can be important for reforming education and that it has the potential to alter or transform classrooms, changing what and how teachers teach and the types of activities in which students engage. Most, if not all, of this research is qualitative in nature, usually program evaluations conducted in technologically rich environments and in a variety of educational settings.

Evaluators of international projects (Means, et al., 1996; Means, et al, 1997; Means, et al., 1998; Torney-Purta, 1996), national projects (Rockman, Et Al, 1997, 1998c), multi-district projects, (Fouts & Stuen, 1997, 1999) and single district projects (Boyd, 1997 Metis Associates, Inc., 1997; Rockman, Et Al, 1998a; Stevenson, 1998) concur that a ready access to computers and related technology can be an instrumental factor in altering the nature of the schooling experience. For example, one pair of evaluators concluded:

> In these classrooms, a student-centered environment is replacing what was, in many cases, teacher-centered instruction, and the role of the teacher is shifting from one of "director of learning" to that of "facilitator of learning." Interdisciplinary projects requiring students to perform and coordinate multiple tasks have become the primary means of teaching and learning, typically undertaken by small groups. Students are more actively engaged in their work, which teachers believe will result in authentic and long-term learning. Probably the most frequently shared observation, however, is the extent to which technology has influenced student motivation and enthusiasm. . . . These findings suggest that, technology seems to have the potential to help create classrooms where students experience education rather than schooling, where they understand rather than memorize, where they are active rather than passive, and where the learning is connected to the "real-world" rather than isolated and artificial. However, it is important to note that these changes were not necessarily equally evident in all classrooms but were a matter of degree. The technology alone cannot create these changes, and other factors, such as overall teacher ability play an important role. (Fouts & Stuen, 1999, p. ii).

A more narrow focus for reviewing research in this line was used by Bracewell, Breuleux, Laferriere, Benoit, & Abdous (1998). They limited their review to studies of *online* technology in the classrooms and adopted the position of Hannafin, Hannafin, Hooper, Rieber, and Kini (1996) that it is important to change our perspectives from "learning from media to learning with media." They believe we should be concerned with "how human processing changes in distinct, qualitative ways when an individual is engaged in an intellectual activity using the computer as a tool"(p.392). The reviewers found that most research concerned learning context and process rather than focusing on content or learning outcomes. They did cite several descriptive studies and concluded that "Learning situations become more realistic and authentic as classrooms are getting online," and that "Online resources boost student interest and motivation in the classroom through a greater diversity of learning goals, projects and outcomes."

It is important to note that not everywhere high levels of computers and related technologies have been introduced or that everywhere there have been large expenditures on the technology have these results been obtained. However, from these evaluation studies emerge two salient factors: (1) the classroom transformations are gradual and take place over a period of time, generally several years; and most importantly, (2) these changes are not assured by simply giving teachers computers. Certain factors greatly increase the likelihood of classroom changes, including:

- Lower student to computer ratio;
- Teacher ownership of the reform efforts;
- *Extensive* teacher training and planning time;
- High levels of technological support; and
- High levels of administrative support.

The importance of teacher training has been widely acknowledged, but unfortunately, a national study conducted by the National Center for Education Statistics (1999) concluded:

> Although many educators and policy analysts consider educational technology a vehicle for transforming education, relatively few teachers reported feeling very well prepared to integrate educational technology into classroom instruction (20 percent). In the previous 12 months 78 percent of the teachers participated in professional development activities designed to integrate educational technology into the grade or subject taught, but only 23 % of these teachers felt well prepared to do so.

Research on the New Learning Environments and Student Achievement

Perhaps the most pressing research question focuses on how students in the high technology new learning environments perform on the new assessments of student learning when compared to students in the more traditional or non-high technology classrooms. There is a wide belief among technology proponents that the transformation of the classrooms facilitated by the use of technology will produce positive learning results not assessed fully by traditional standardized tests. Consequently, there is reluctance to use the traditional standardized tests to evaluate the impact of the technology on student learning. This is the line of inquiry is represented by line#3 in Figure 2.

It is the role of sound experimental (Level II) and evaluation research (Level III) to determine if student learning is superior in the technology rich new learning environments. At this point in time there is only a limited amount of such research. As the President's Committee stated: "the specific pedagogical applications to which such theory has given rise in the field of educational technology have thus far been subjected to only limited (though by no means negligible) rigorous experimental testing"(p.118).

There have been a few attempts to conduct research in this new and difficult area. A case in point is the research conducted by Stevenson (1998) in Beaufort, South Carolina. His evaluation of the Anytime, Anywhere Learning program in the Beaufort County School District showed a positive relationship between laptop computer usage and academic achievement using standardized test scores, and this relationship was strongest among free and reduced lunch children. These are encouraging findings, but, as Stevenson points out, the findings must be accepted with caution because of the non-experimental nature of the program. While these and other such findings are encouraging, they generally do not meet the standard of "*rigorous empirical testing*." Instead, the evaluation reflects the real world in which educational researchers attempt to conduct their research, rather than the controlled atmosphere of a laboratory setting.

Researchers often attempt to examine the effects of the new environments, of which technology is a part, with no attempt to isolate the technology variable. Hutinger, Bell, Beard, Bond, Johanson, and Clare (1998) evaluated the use of the Interactive Technology Literacy Curriculum with preschool children and noted positive results. McGilly (1995) has collected the findings from several studies that show promising results for student learning in these types of environments. In some of the studies the technology is seen as enhancing the broader effort at student cognitive development and learning through classroom applications of certain principles (Spoehr, 1995; Scardmalia, Bereiter, & Lamon, 1995). The Cognition and Technology Group at Vanderbilt (CTGV) (1991, 1994a, 1994b, 1997) has conducted a series of developmental and experimental studies over a period of years that have also shown promising results in support of these types of environments. Their work in MOST (Multimedia environments that Organize and Support learning through Teaching) looks particularly promising with at risk students.

Bracewell & Laferriere (1996) reviewed the research using the New Information and Communication Technologies (NICT) of the 1990's. In many of the studies they reviewed, the purpose and usage of the computers and technology closely resemble the usage represented by lines #2 and #3 in Figure 2. They draw 14 conclusions [generalizations] from the research, including:

> New technologies have the power to stimulate the development of intellectual skills such as reasoning and problem solving ability, learning how to learn, and creativity (p. 8.).
>
> The new technologies have the power to stimulate the search for more extensive information on a subject, a more satisfying solution to a problem, and more generally, a greater number of relationships among various pieces of knowledge or data (p. 14).
>
> The potential for simulation, virtual manipulation, rapid merging of a wide variety of data, graphic representation and other functions provided by the new technologies contributes to a linkage of knowledge with various aspects of the

> person, thereby ensuring more thorough assimilation of the many things learned (18).

In support for the first generalizations the reviewers cite research conducted by Newman (1994), Scardmalia, Bereiter, and Lamon (1994), Padron and Waxman (1996), the Cognition and Technology Group at Vanderbilt (1991; 1994), and a few others. In support of the second generalization they cite Lafer and Markert (1994), Heidmann, Waldman and Moretti (1996) and McKinnon, Nolan and Sinclair (1996). In support of the third generalization they cite only Dwyer (1994) and Barron and Goldman (1994).

This review and resulting generalizations is an example of the difficulty educators have in attempting to use research to guide practice or policy when there is a limited quantity of applicable Level II/experimental research available. The studies and observations used in this review are interesting and early works into the question of the potential effects of the information technologies on learning and other outcomes. Particularly interesting is the work of the Cognition and Technology Group at Vanderbilt. But are the studies cited in this review adequate in number and quality to draw broad conclusions useful for educational or policy decisions? This is no way a criticism of the work these reviewers have done or a criticism of the original research studies. Rather, the point is simply that there is no current agreement among the profession about how much research is enough before definitive statements can be made. *However, most agree that at the present time the quantity and quality of the research in this line is insufficient to draw firm conclusions.*

In a later review of research of online technologies, Bracewell, Breuleux, Laferriere, Benoit, & Abdous (1998) attempted to find studies that examined learning outcomes, but met with minimal success. They found only a “few small scale studies” and agreed with the 1998 UNESCO World Report that there were few studies that showed that school online usage demonstrated clear learning gains over conventional classroom processes. In similar fashion, Ayersman (1996) reviewed the research on hypermedia learning and concluded that “There is clearly not enough research on hypermedia-based learning to merit a meta-analysis.” What he did find was “research originating from action-research, classroom-based samples that many would argue do not constitute generalizable data because of the small sample sizes and uncontrolled extraneous variables”(p.500). McKnight, Dillon, & Richardson (1996) also concluded that “there is little reliable evidence (yet) to support the claims that hypertext systems can really support alternative and super modes of learning . . .”(p. 632).

The best that can be said at this point in time is that there are some strong *perceptions* that students are learning more or achieving different learning outcomes in these transformed learning environments. These perceptions are the result of qualitative research, program evaluations, anecdotal information and only a very few quantitative studies providing any evidence. The program evaluation studies mentioned earlier in this section provide reports from teachers, students, and their parents about the learning increases resulting from the technology. They also noted that the technology seemed to have the greatest affect on at-risk or normally low achieving students. Similarly, a national survey of 21 states (Solmon, 1998) reported that a large percentage of teachers believed that technology is “a powerful tool for helping them improve student learning”(p. 2). One of the few quantitative studies examined the role of online communications in schools (Center for Applied Special Technology, 1996) and found that “students with online access perform better. . . . The results show significantly higher scores on measurements of information management, communication, and presentation of ideas for experimental groups with online access than for control groups with no access.” These are the types of learning outcomes that reform proponents are seeking, but that are not readily apparent in the traditional standardized tests, nor have the results been replicated in a variety of settings.

Currently, the efforts to conduct research on the effects of the new learning environments is handicapped because at the present there are few satisfactory assessment tools that meet traditional research standards, or where they are in use they have not been used long enough to allow for meaningful research. The CEO Forum on Education and Technology (1999), half way through its four year plan, has stated: “In its final year [2001], the CEO Forum will address the important question of how to measure the impact of technology on student achievement . . .”(p. 32). The change in desired learning outcomes has not yet produced valid and reliable measures of those learnings. Until this happens, solid evidence one way or the other will not be forthcoming.

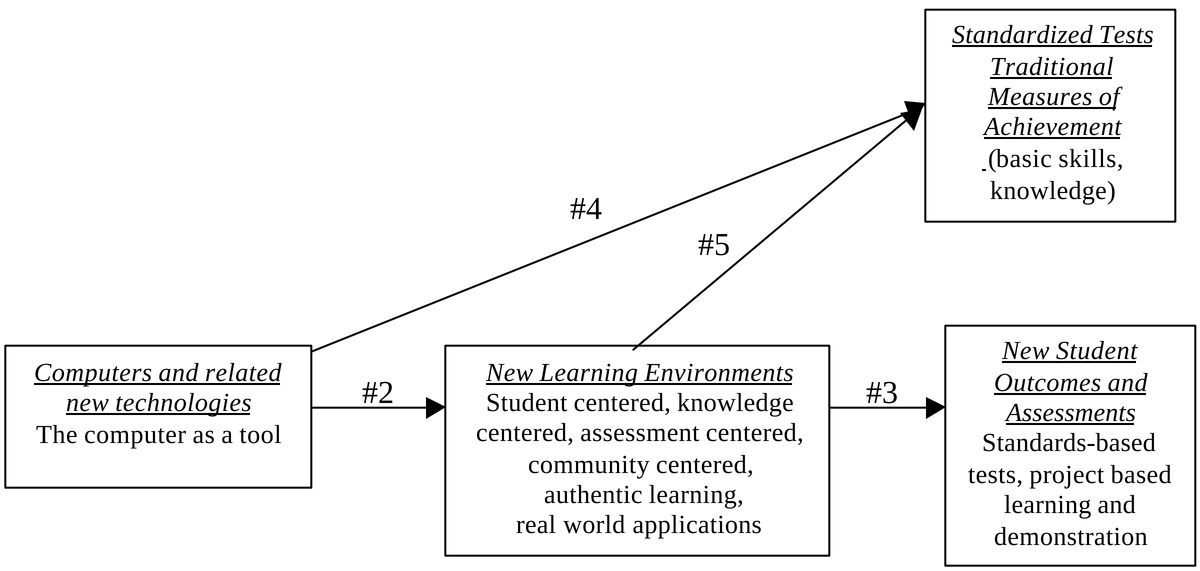
Finally, it is important to include a separate research finding at this point even though it is not a direct finding on creating new learning environments or student achievement. Research over at least two decades (e.g. Busch, 1995; Colley, Gale & Harris, 1994; Comber, Colley, Hargreaves, & Dorn, 1997; D’Amico, Baron & Sissons, 1995; Fetler, 1985; Jones & Clarke, 1995; Kirkpatrick & Cuban, 1998; Levin & Gordon, 1989; Levine & Donitsa-Schmidt, 1995; Nelson & Cooper, 1997; Shashaani, 1994; Sutton, 1991) has shown that student attitudes toward computers can differ dramatically depending on a number of student characteristics, particularly gender and socio-economic status. Generally, more efficacious attitudes toward computers were found among boys and among students with regular access at home. This is thought to affect their use patterns and confidence. These are important considerations for educators who are planning on creating learning environments highly dependent on technology use. Failure to consider these student characteristics may actually exacerbate achievement differences between groups. Efforts must be made to insure that all students have the technological skills and confidence needed in the new learning environments.

Large Scale Studies with Policy Implications

In recent years researchers have attempted to examine the relationship between increased technology access and student achievement. These studies are generally non-experimental, ex post facto in design, and rely on various multivariate statistical analyses in an attempt to control for confounding variables to isolate the technology variable, and usually use traditional measures of achievement. They have generally been large national, state, or regional studies that have policy implications for educational planning or funding. Line #4 in Figure 3 represents the relationship between increases in access to technology and achievement as measured by the standardized tests.

In many schools the increase of computers and related technology is also coupled with a wide range of other school reforms that makes it very difficult, if not impossible, to isolate the technology component to imply any type of cause and effect relationship. In this line of research, the restructured classroom or school, which technology is seen as enhancing, is the focus. Line #5 in Figure 3 represents the relationship between the new learning environments and achievement as measured by the standardized tests.

Figure 3



The relationship between increased technology usage and increased learning as measured by standardized tests has been studied on numerous occasions. Sometimes a positive relationship has been found, and sometimes no relationship has been found. Few, if any, studies have ever reported that technology usage is related to *decreases* in standardized test scores. For example, the Apple Classrooms of Tomorrow (ACOT) researchers found that ACOT students in general did just as well on standardized tests. When those specific skills became the focus of the program, ACOT students scored higher on the tests. These and other findings suggest that the purposeful use of the computer is a strong confounding variable.

In a study in West Virginia (Mann, Shakeshaft, Becker & Kottkamp, 1999) researchers examined the effects of the West Virginia Basic Skills/Computer Education program, which had been in place for ten years. In West Virginia the researchers found the "program had a powerfully positive effect . . . especially in those schools that used it most intensively." They found significant gains in reading, writing and math, and that the program was "especially successful with low income and rural students as well as with girls." This particular research study is strong support for the conclusions of earlier reviews (Figure 1, line #1) and for the conclusions of the ACOT study that found that computers are effective for basic skills instruction when that is their designed purpose. However, the researchers point out that the instructional design of the program was ten years old and "makes little use of project-based learning and other constructivist curricular approaches that are the leading edge of learning technology today." Therefore, those who point to this research as supporting the increased availability and use of technology in the classrooms in general or for transformational purposes are using the findings inappropriately.

The Idaho Council for Technology in Learning (1999) conducted research on the effect of the technology initiative in Idaho. Researchers examined the test score gains, technology usage patterns, and technology literacy along with five other elements of the initiative. The sample consisted of over 35,000 8^{h} and 11^{th} grade students, and the researchers concluded "There is a positive relationship between academic performance in core studies, language, math, and reading and the integration of technology in Idaho's K-12 schools (p. vii)." They also concluded that the gains were greater for 8^{th} graders than for 11^{th} graders and that the differences between the academic gains of Idaho students with high exposure to computers over a four year period and the academics gains of those students who had little interaction with computers over that same time were practical and educationally meaningful. The technology factors that were the strongest predictors of achievement gains were the ability to choose the appropriate software tool, the amount of computer use at school, exposure to Internet and email use, and the amount of computer use at home.

In a seven year study of "underserved inner-city children" in New York researchers in Project Tell (Stanton/Heiskell Center, 1998) attempted to examine the effects of in-home computers and online access on school achievement. They found noticeable gains in reading, higher grades and higher graduation rates. They cautiously concluded that, "computer mediated learning communities can play a positive role in helping teachers, students and families find the educational resources that will help them cope with the new demands." Others considered the findings to be less conclusive, but the research is an example of the difficulty in isolating the technology variable.

In a national study sponsored by Educational Testing Service, *Does it compute? The Relationship Between Educational Technology and Student Achievement in Mathematics* (Wenglinsky, 1998), the researcher "found that technology could matter, but that this depended upon how it was used"(p. 3). Teachers' professional development in technology and using the technology to teach higher order thinking skills were both related to academic achievement, but the overall frequency of school computer use was negatively related to academic achievement. These and other equivocal findings suggest that there are a number of other factors that interact with the technology. Wenglinsky concluded:

> All of this suggests that computers are neither cure-alls for the problems facing schools, nor mere fads that have no impact on student learning. Rather, when they are properly used, computers may serve as important tools for improving

student proficiency in mathematics, as well as the overall learning environment in the school. (p. 4)

Research on school restructuring in Washington State (Fouts, 1999) found that between 1993 and 1997 an increase in the use of technology was the most common classroom change reported by elementary teachers. However, there was no relationship found between the reported increases in technology use and achievement gains on standardized tests of basic skills. However, unlike in the ACOT studies, there were no indications that the technology was used for that specific purpose.

A study in New Jersey that examined larger reform efforts, of which computers and technology were an important part (Figure 3, line #5), produced much less positive results. Fenster (1998) examined the effect of the New Jersey Statewide Systemic Initiative on student learning, a $15 million four and a half year effort. The program followed many of the current reform design components and sought to increase academic standards, to provide a hands-on approach to instruction, to place an emphasis on higher-order thinking skills, to use new assessments, and to incorporate technology into the classrooms. No achievement gains of any type were found, and there were evidently significant problems with the way the program was implemented. "The SSI's 1994-1997 strategy—pay for everything and hope for the best was, at the same time E & L (expensive and limited)"(p. 28). Fenster reported a "fundamental tension" in the SSI program—"depth vs. breadth of reach." The program evolved to the point of working "with as many schools as possible, even if it meant that each school was only getting a very small benefit from affiliating with an SSI." The $3 million per year budget was spread over several hundred schools, and in 44 percent of those schools professional development with 1 or 2 teachers was the extent of the activities.

> With a $3 million year budget, NJSSI tried to influence k-12 education in New Jersey, a $12-13 billion dollar a year business. Put another way, for every $4000 spent on k-12 public school in education in New Jersey, NJSSI spends $1. What is realistic to expect for that $1?

These findings clearly point out that such broad efforts accomplish little, and that if schools are to be reformed and if technology is to help in that transformation, *in-depth* and focused programs are more likely to produce desirable results.

Once again it is important to note that proponents of educational technology argue that the purpose of the technology is not to produce higher test scores, but rather to increase "other" types of learning, which are the focus of current school reform efforts. For example, a recent ERIC Digest report (Kosakowski, 1998) stated: "Most available tests do not reliably measure the outcomes being sought. . . . Assessments of the impact of technology are really assessments of the instructional processes enabled by technology, and the outcomes are highly dependent on the quality of the implementation of the entire instructional process." Consequently, many technology proponents are not overly concerned about the relationship between the technology and the standardized test scores.

This theme has been picked up by several states. For example, the Washington State Technology Plan for K-12 Common Schools (1995)—states: “The intent of the integration of technology under the Reform Act is to add a catalyst and technological factor, which combined with other reform efforts will help schools become learning environments which empower students to successfully attain the new state learning goals.” This same idea is reflected in the Computer Network Study Project by the Texas Education Agency (1999). This agency recommends that educators need to “Identify, develop, and disseminate assessment methodologies and tools to determine the impact of technology and its contribution to student performance” and to “Explore through methdologically sound pilot projects, the impact of technology use on instruction, student performance and behaviors, and campus and district administration.”

What might be concluded from these large relationship studies? The findings reinforce that computers and technology *can be* an important component of educational reform and related to student learning, as in the cases of the ACOT, West Virginia, Idaho, New York, and ETS studies. However, the ETS and New Jersey results clearly support the findings from other categories of research that indicate that computers and technology *alone* will accomplish little, and that how it is used and how a particular program is planned and implemented is equally, if not more, important.

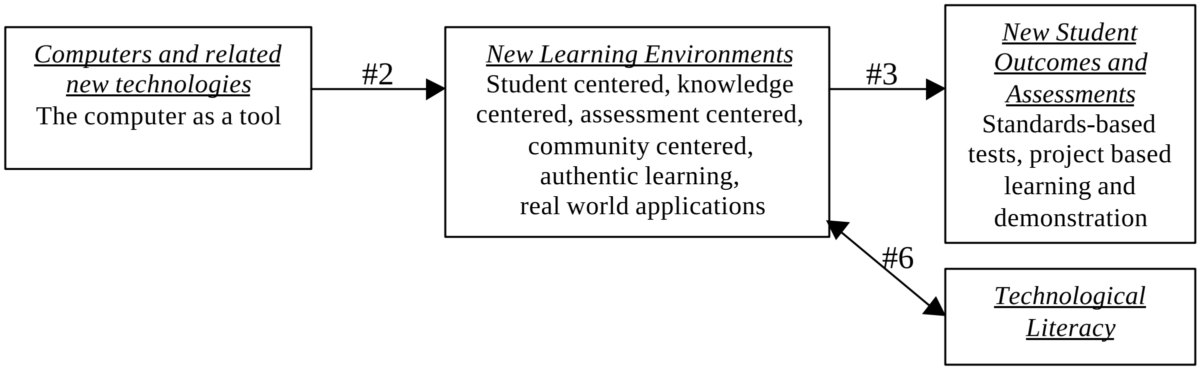
Computers, New Learning Environments, and Technological Literacy

There are many people who advocate increasing technology in the schools because of the need for our children to be technologically literate for success in the Twenty-First Century, and that this literacy is best achieved in classrooms where the technology is an integral part of the environment and where it is used as a daily tool for learning and solving real-world problems. Much of the general public supports increasing technology in the schools for this reason. An interesting finding emerged from a program evaluation in Washington State (Fouts & Stuen, 1999). When 50 parents were interviewed,

> the reasons given for believing in the importance of increased technology in the schools focused almost exclusive on the ideas that “technology is the wave of the future” and that “these kids will need technological skills to get good jobs when they get out into the real world.” *Even when pressed on the topic, only two of the fifty parents (a medical doctor and a mother who was herself an elementary teacher who used technology in her classroom) could articulate the importance of computers and technology for helping to reform education and change the nature of classroom activities, teaching and learning* (p. 48).

Line #6 in Figure 4 represents the relationship between the new learning environments and technological literacy.

Figure 4



The arrow on Line #6 in Figure 3 points in both directions. This signifies the symbiotic relationship between the means and the outcome in this instance. The development of the new learning environments is dependent to some degree on having students with technology literacy skills (such as word processing and on-line capabilities) sufficient to function in the environments. Functioning in the environments over time should further develop the technology skills. In current practice this has led to the tendency to teach the technology skills "just in time," that is, just preceding the need for the skill within the environment or integrated with the learning activity.

Surprisingly, there has been little research conducted in this entire area. Results from a variety of program evaluation studies (e.g. Rockman Et Al, 1998b) show that students at a variety of ages are quite capable of learning a wide range of technology skills, but the research has not yet focused on technology as a basic skill with standards set for specific ages. A few states have adopted technology standards for various grade levels. The International Technology Education Association (1996) has produced *Technology for All Americans: A Rationale and Structure for the Study of Technology*, and the International Society for Technology in Education has released the product from the National Educational Standards Project (NETS), *National Educational Technology Standards for Students—Connecting Curriculum and Technology* (2000). However, at this point in time there is little evidence that researchers have focused on the relationship between the new learning environments and technological skills. The new standards in this area should provide clear outcomes suitable for research and evaluation purposes.

Computers, Technology and Distance Learning

Distance education has been part of the educational landscape for generations. From the earliest days of correspondence courses, to the days of electronic course delivery through radio, television, and satellite, to the more recent developments of electronic course delivery via the Internet, educators have asked if students who take courses away from the teacher and the traditional classroom setting learn as much or as well as do students who are face to face with the teacher and/or part of a larger learning group. Line #7 in Figure 5 represents the relationship between distance learning (which now often employs some form of computers or related technology) and traditional measures of student learning.

Figure 5

The research on the effectiveness of electronic delivery of courses is entwined with the research on the effectiveness of distance learning in general, although much of the research on distance education in recent years involves electronic media. The distance learning research has been compiled for a number of years by Tom L. Russell (1999) at North Carolina State University. The publication is now in its 5th edition and available in book format. The essence of the research findings on the effectiveness of distance education is captured in the title of the work, *The No Significant Difference Phenomenon.* There is also a bibliography available on the Internet that is updated regularly with new studies.

Russell has catalogued and summarized 355 research reports from 1928 to the present that show a consistent pattern throughout the years—students in distance learning, irrespective of the delivery system, perform equally as well as do students receiving traditional classroom instruction. Time and time again through his catalogue of studies the statistical phrase "no significant difference," or its equivalent is highlighted in bold print. Three recent examples of the findings are typical:

> There were '**no significant differences'** in the test scores for the classes measured . . . same class, same instructor, same audience, same exam—just different format (Clark, 1999).
>
> The findings appear to provide evidence that cyberlearning can be **as effective** as traditional classroom learning . . . Results from t-tests indicated **no significant differences** on six of the eight academic variables. (Navarro & Shoemaker, 1999).
>
> The results of this paper have shown that when virtual lectures are used in place of traditional delivery methods there is **no significant difference** in the attainment level as measured by end of year examination marks (Smeaton & Keogh, 1999).

It must be pointed out that many of these studies were conducted on college students, but a sufficient number have been conducted using high school students with identical findings to provide a broad generalization about the efficacy of distance education and electronic media delivery formats. The research suggests that student can learn equally well when instruction or learning activities take place apart from the traditional classroom setting.

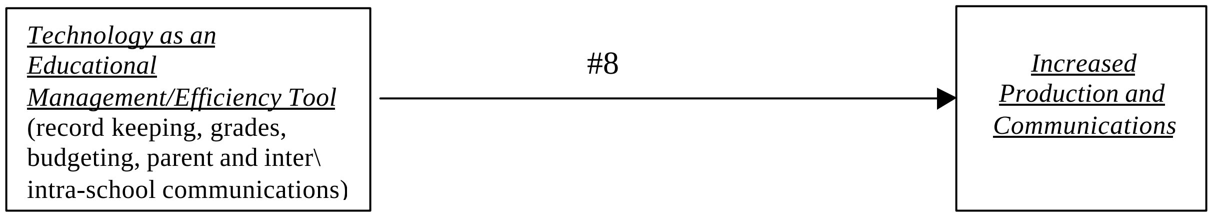
As often seems to be the case in the educational research area, the research and these conclusions are not without its critics. The Institute for Higher Education Policy (1999) was commissioned by the National Education Association and the American Federation of Teachers to conduct a review of the research. In that review, *What's the Difference: A Review of Contemporary Research on the Effectiveness of Distance Learning in Higher Education*, the reviewers were less accepting of the findings, and urged "a more cautious view of the effectiveness of distance education"(p. 1) than the one adopted by Russell. They concluded: "A closer look at the research, however, reveals that it may not be prudent to accept these findings at face value. . . . The most significant problem is that **the overall quality of the original research is questionable and thereby renders many of the findings inconclusive"** (p. 3). In a critique that sounds much like the critique of the research in the computer assisted instruction research (line #1 above), the weaknesses cited include the failure to control for extraneous variables resulting in an inability to establish cause and effect, and non-randomization—in essence, not good experimental research.

Another salient point worth mentioning is that they noted a higher degree of course student dropout among the distance learning students. This suggests that the efficacy of distance learning may be limited to certain types of students. McIsaac and Gunawardena (1996) looked at a number of research reports on this topic and suggest that "some combination of cognitive style, personality characteristics and self-expectations can be predictors of success in distance education programs. It appears that those students who are most successful in distance learning situations tend to be independent, autonomous learners who prefer to control their own learning situations"(pp. 424-425). However, these findings were not conclusive and McIssac and Gunawardena suggest that much further research in this area is needed.

Technology as an Educational Management/Efficiency Tool

Finally, school district technology funding programs often include various types of technology designated specifically for administrative and/or teacher use. Similar to American businesses, these expenditures are designed to increase efficiency and productivity of the users in a variety of administrative and communication areas. The relationship between computers and technology for administrative purposes and increased production and efficiency is represented in Figure 6 by the line labeled #8. To date, there has been little, if any, research that has examined the effect of technology on the administrative, productivity and communication patterns in schools because of the technology.

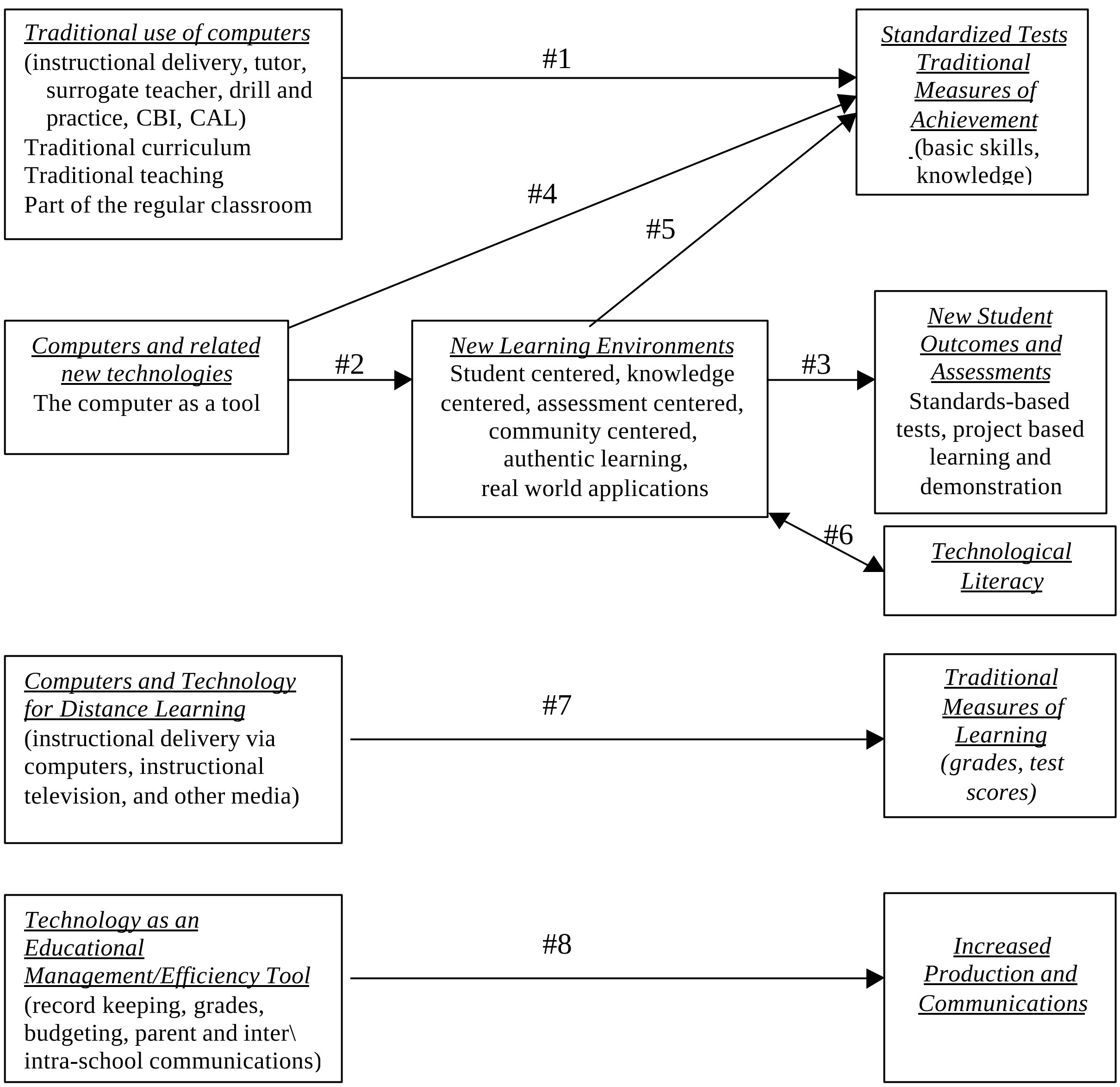
Figure 6


Technology as an Educational Management/Efficiency Tool (record keeping, grades, budgeting, parent and inter\ intra-school communications)
#8
Increased Production and Communications

Conclusions

Policy makers and educators who ask the broad question, "What does the research say about the effectiveness of computers in schools?" are faced with the problem of asking a question that has many potential answers. The answer depends, in part, on whether or not a particular line of research has been addressed by researchers over a period of time long enough to produce a substantial body of findings. Given the wide range of uses of the computers and technology in the schools and the different purposes to which they are employed, when combined, these lines of research have presented a substantial challenge to researchers. The complex nature of the overall lines of research is shown in Figure 7. Below is a summary of the status and research findings in each of the areas.

Figure 7



Line #1 -- The Computer as Tutor and Surrogate Teacher

- This line of research has produced hundreds of Level II studies over the past several decades. While there are methodological problems with much of the research, there is some degree of general concurrence that

  - when combined with traditional instruction, the use of computers can increase student learning in the traditional curriculum and basic skills area.
  - the integration of computers with traditional instruction produces higher academic achievement in a number of subject areas than does traditional instruction alone.
  - students learn more quickly and with greater retention when learning with the aid of computers.
  - students like learning with computers, and their attitudes toward learning and school are positively affected by computer use.
  - effective and adequate teacher training is an integral element of successful learning programs based on or assisted by technology.

- The simple introduction of computers and related technology into the classrooms does not guarantee these results, however. There are many other factors involved, such as instructional design and software sophistication, that play important roles in the process.

- Because of the methodological flaws in the studies, as Cuban and Kirkpatrick (1998) point out, the profession "can accept, conditionally accept, or reject the positive research findings"(p. 29). However, whether one accepts these conclusions or rejects them to some degree is a moot point because much of the computer usage, technological capabilities, and methods of deployment today differ to such a degree that it is a mistake to justify increases in technology by generalizing from these findings.

Line #2 & Line #3-- Technology as a Transformational Agent and Learning Tool

- There is a strong Level I or basic research base that supports these ideas, and the research has direct implications for how children should best be taught. Collectively, the research has been called the new "science of learning". It is derived from the findings of researchers in developmental psychology, cognitive psychology, linguistics, and neuroscience, and coupled with the philosophical ideas of constructivism. The Level I research is extensive, but it does not qualify as, in the words of the President's Committee, *rigorous empirical testing*.

- Basic research in this new science of learning continues at a fast pace. There is a growing body of research that indicates that the computer and related technologies, when combined with teacher training and support, can be a transformational agent and help create new learning environments as suggested by the basic research and as envisioned by educational reformers.

- Level II and Level III research has not kept pace with the basic research and formative studies in educational reform. There is general concurrence that, apart from qualitative data, observations and student, teacher, and researcher *perceptions,* there is not an adequate amount of experimental or program evaluation data to provide evidence of increased student learning in the new environments.

Line #4 & Line #5--Large Scale Studies with Policy Implications

- These studies are generally non-experimental, ex post facto in design, and rely on various multivariate statistical analyses in an attempt to control for confounding variables to isolate the technology variable, and usually use traditional measures of achievement. In some studies the increase of computers and related technology is also coupled with a wide range of other school reforms that makes it very difficult, if not impossible, to isolate the technology component to imply any type of cause and effect relationship.

- The relationship between increased technology usage and increased learning as measured by standardized tests has been studied on numerous occasions. Sometimes a positive relationship has been found, and sometimes no relationship has been found. Few, if any, studies have ever reported that technology use is related to *decreases* in standardized test scores.

- The findings from these studies show that computers and technology *can be* an important component of educational reform and related to student learning. The results clearly support the findings from other categories of research that indicate that computers and technology *alone* will accomplish little, and that how it is used and how a particular program is planned and implemented is equally, if not more, important.

Line #6—Computers, New Learning Environments and Technological Literacy

- There has been little research conducted in this entire area. New technology standards produced by the professional associations and others adopted by various states should provide clear outcomes suitable for research and evaluation purposes.

Line #7--Computers, Technology and Distance Learning

- The research on the effectiveness of electronic delivery of courses is entwined with the research on the effectiveness of distance learning in general, although most of the research on distance education in recent years involves electronic media.

- There is a large body of research that suggests that students can learn equally well when instruction or learning activities take place apart from the traditional classroom setting.

- The research has been criticized for lacking the qualities of good experimental research.

- A higher drop-out rate among students in distance learning has been noted, suggesting that the experience may be more appropriate for certain types of people.

Line # 8--Technology as an Educational Management/Efficiency Tool

To date, there has been little, if any, research that has examined the effect of technology on the administrative, productivity and communication patterns in schools because of the technology.

"Research Serving the Profession:" A Research Agenda for Technology and the Schools

In recent years there have been numerous calls for extended research activities in the area of technology, learning, and schools. These calls have come from a variety of organizations, including the President Committee of Advisors on Science and Technology (Shaw & PCAST, 1998), the National Science Foundation (Guzdial & Weingarten, 1995), the National Research Council (Bransford, Brown, & Cocking, 1999), private charitable foundations, (Milken Exchange on Educational Technology, 1998a, 1998b), and research institutes such as the RAND Corporation (Glennan & Melmed, 1996). There is a general concurrence among professional educators and others that there is insufficient empirical evidence on the value of computers and related technologies to student learning. While the Level I or basic research base is substantial, and increasing at a very fast rate, there is not an adequate amount of quality experimental and program evaluation evidence "desirable from a public policy viewpoint"(Shaw & PCAST, p. 117).

Critical Issues in Educational Technology Research

From the preceding review of the research on educational technology several critical issues have emerged that should be considered when setting research priorities.

- **The need for a planned agenda with specified priorities**

Although many people in education and government have called for an organized research agenda with substantial federal and private funding, this has not yet happened. While there is good research being conducted (particularly at the basic research level), much of it is being conducted in an uncoordinated manner. In the minds of many people, educational reform and technology are so closely tied together as to be inseparable. A carefully planned agenda with funded research priorities can produce valuable information for educators to further the reform efforts.

- **The need for *rigorous empirical testing*.**

The basic research comprising the new "science of learning" is substantial and increasing rapidly. However, it is appropriate here to mention again the sentiment expressed in the early pages of this paper. The history of education is replete with examples of pedagogical methods derived from basic research findings being implemented in the classrooms, only to discover later that they accomplished little. The implications of the new science of learning must be tested through sound empirical research, and there is evidence that little of this type of research is being conducted. Jones and Paolucci (1998) reviewed 834 articles from the leading research journals in educational technology from 1991 through 1996. They found that "only 12% . . . of work is of an empirical and objective nature." Further analysis of those articles led them to conclude that “approximately 5% of total research is conducted using formal methods such as control groups with *comparative* learning outcomes”(p. 12). There is a consensus that the experimental/Level II research has not kept pace with the basic research on human learning.

This rigorous empirical testing should consist of experimental studies and program evaluations that attempt to isolate the effect of technology on student learning, along with experimental studies and program evaluations that examine the effects of the new learning environments on student learning.

- **The need for new assessment instruments**

The rigorous empirical testing so needed in this area has been greatly handicapped by the lack of valid and reliable instruments that assess the new standards that have become the focus of the reform efforts. Results from a national survey of 21 states (Solmon, 1998) found that only 21% of the districts “frequently use technology in student assessment efforts”(p. 3). Researchers are handicapped by the lack of acceptable instruments for outcome assessments. There is a critical need for researchers to work with educators to develop assessment methodologies that are formative in nature for the purpose of improving instruction and learning in the classroom, and to develop assessment procedures that are satisfactory for research purposes and for high-stakes summative assessments tied to online capabilities.

- **The need for new digital content tied to new standards**

Recent research has shown that teachers have difficulty finding appropriate software for their classes (Education Week & the Milken Exchange on Education Technology, 1999). For example:

- 59% of the teachers say it is somewhat or very difficult to find appropriate software.
- As the grade level increases, the difficulty of finding software increases.
- Only 12% of the teachers say they have lists of titles that match curriculum standards.

The full potential of the technology is, at times, limited because of these problems. Extensive research and development is needed to develop digital content appropriate for the various age levels and tied closely to the state standards, learning outcomes, and assessments that are such an important part of the reform efforts.

- **The need for clear program goals for technology.**

Research on and evaluation of the role of technology in the schools has been and will continue to be handicapped by a lack of consensus on clear goals or stated purposes of the programs.

> The blurry picture stems mainly from a muddling of the aims for technology in schools. Three distinct purposes compete for resources. Policy makers and administrators seldom distinguish between calls for computers in the classroom for the sake of ensuring that students are computer literate, calls for computers in the classroom for more and better learning via computers (that is, acquiring academic content and basic skills, including higher-order thinking skills such as analysis and problem solving), and calls for computers to alter the classroom's social organization so as to make it more student-centered (Cuban & Kirkpatrick, 1998, p. 26).

Practitioners, researchers, and evaluators must clarify what is expected of the technology before meaningful research and evaluation can take place.

Basic Assumptions for a Research Agenda

The fact that virtually all segments of society have changed dramatically by information technologies and will continue to change in the future cannot be ignored. Schools must be a part of these changes and research should proceed with the assumption that technology *is and will continue to be* a growing element within the schools. As the President's Committee stated,

> the principal goal of such empirical work should *not* be to answer the question of whether computers can be effectively used within the school. The probability that elementary and secondary education will prove to be the one information-based industry in which computer technology does not have a natural role would at this point appear to be so low as to render unconscionably wasteful any research that might be designed to answer this question alone (Shaw & PCAST, 1998, p. 121).

Therefore, any research agenda must be seen as a concerted effort to answer the broadest research question--"How are the new technologies *best* used in education?"-- rather than "*Should* the new technologies be used in education?"

The basic or Level I research (the new science of learning) is extensive and growing. This basic research should continue through the work of the National Science Foundation's LIS program, various universities, and other appropriate organizations. However, there is a strong consensus that the Level II and III research has not kept pace, and that is where the most immediate need for research is to be found. As Bonnie Grossen (1996) pointed out, "One huge problem with our current professional knowledge base is that many experimental practices have been allowed to jump from Level I research straight into the professional cannon" (p. 22). This is a current criticism of technology use. Therefore, the immediate priority is for Level II and Level III research.

In the sections below are suggested guidelines for further research and development, and guidelines for further Level II and Level III research in the area of technology and education. The sections are organized along the lines of research identified earlier, with modifications and expanded where appropriate. No list of questions could be complete because research questions are often developed from the findings of the most recent research, which is not static, but is rather an on-going process. The research questions listed below are not meant to be all inclusive, but are *sample* questions representing the areas of focus that need further attention.

The Computer as Tutor and Surrogate Teacher—Directions for Further Research

It seems doubtful that technology will be used exclusively in this manner in the future. This type of usage is only one of several tasks that technology is being asked to perform in the new learning environments. However, as the basic research on the science of learning continues our understanding of human learning will change even more from behaviorism to reflect the findings of cognitive science. Inevitably then, the focus and instructional design of the educational software should change. The ability of technology to perform this function will depend, in part, on the nature of the content standards adopted by states and local districts. Glennan & Melmed (1996) have stated, "Such software, keyed to the content standards of states and local districts, is important for realizing the full potential of computers."

Dickey and Roblyer (1997) have proposed an interesting line of inquiry regarding the nation's use of the NAEP and TIMSS [traditional type] assessments to evaluate the health of American education. Given the emphasis on technology for reform they state: ". . . there is no evidence on NAEP or TIMSS of 'technology-active' questions—that is, questions that can be answered correctly only if students have a strong background in technology use. As of now, little research has explored the hypothesized relationships presented here between technology use and test skills"(p. 57).

- **Research and development general focus--**Linking new digital content based on science of learning principles to the new state and local content standards.

Sample Questions:

- Are the content standards adopted by states and local districts appropriate for teaching through technology applications alone?
- Is it cost efficient to teach certain content standards or basic skills through technology?
- Is technology instruction for basic skills an appropriate use of the technology in the new learning environments?
- Is computer based learning with sophisticated digital content compatible with the new learning environments?
- Does the use of the technology in this manner have differential effects on various groups of students (such as age and at-risk groups)?

- Does new digital content with instructional design based on the science of learning principles produce greater learning in students than does software with instructional design based on behaviorism and reductionist assumptions?
- Does technology enhanced instruction provide the types of learning measured by the NAEP and TIMSS assessments?
- Does technology enhanced instruction effect student performance on the NAEP and TIMSS assessments?

Technology as Transformational Agent, Learning Tool, and Student Learning—Directions for Further Research

This is the broadest area for further research. Considerable work has been done in this area, but there is still much left to do.

Technology and the new learning environments

Research over the last several years has shown that technology can be a valuable force for creating a new learning environment. We have learned some of what it takes for the technology to be used in a way to help transform the classroom. Certain factors greatly increase the likelihood of classroom changes, including lower student to computer ratio, teacher ownership of the reform efforts, *extensive* teacher training and planning time, and high levels of technological and administrative support. However, there is still much we do not know. Continuing research is needed to answer questions in a number of areas.

<u>*Teachers*</u>

- What kinds of training are most effective for helping teachers use high-quality instructional programs?
- Are there general integration skills that can be taught to all teachers, or are the integration skills dependent on subject matter?
- What do teachers need to know about the learning processes to be able to use technology to its full potential?
- What do teachers need to know about the technology itself?
- How much time is needed for teachers to learn, to reflect, to absorb discoveries, and adapt practices?
- How much time is needed for teachers to design integrated, engaging and personalized learning experiences?
- What is the best way to use technology to facilitate teacher learning?

Students

There is evidence from earlier research on computer assisted instruction and from qualitative evaluation studies on the new learning environments that the technology seems to be particularly beneficial to low achieving or at-risk students. Kirkpatrick and

Cuban (1998) synthesized the research on gender differences and computer use and found that "the inequalities are alarming"(p. 58). There is also a strong need for researchers to identify the most appropriate technology activities and types of learning that can be enhanced with technology. The recent brain research findings strongly suggest that different intellectual skills are developmental, with learning windows at various age levels. All of these student characteristics provide areas for further research.

- How much time and access to technology does a student need to affect learning?
- What computer and related technology skills are most appropriate for the different age groups of children?
- What types of learning enhanced by technology are most appropriate for the different age groups of children?
- What is the effect of technology rich classrooms and teaching on at-risk students?
- What is the effect of technology rich classrooms and teaching on students from lower-socio-economic backgrounds?
- What is the effect of technology rich classrooms and teaching on low achieving students?
- What is the effect of technology rich classrooms and teaching on gifted students?
- Do boys and girls respond differently to or function differently in the new learning environments?
- Does creating a technologically rich learning environment handicap some learners?

Subject Matter

Research findings from the cognitive sciences and the study of experts in various fields have shown that the different content areas, such as science, mathematics, and history, have different organizing properties (Shaw & PCAST, 1999). This implies that the ideal nature of a learning environment may differ depending on what subject is being taught or that some subjects may lend themselves more readily to learning certain types of cognitive skills.

- Are there certain characteristics of transformed classrooms that are more appropriate or desirable depending on the subject matter of the class?
- Are the potential benefits of technology-enhanced learning greater in certain subject areas than in others?
- At what grade or age level is it appropriate to integrate subjects in the curriculum and does technology aid in doing this?

The new learning environments and student learning.

This is the single most pressing issue demanding researcher attention. The remarkable advances in brain research and the cognitive sciences have greatly advanced our understanding of how people think and how they learn. However, educators have not been able to show through "rigorous empirical testing" that students have learned more in the new learning environments suggested by the Level I research and the new science of learning.

Barbara Means (1998) from SRI has stated that, "if positive impact of technology cannot be decisively demonstrated within the next few years, the public will castigate the perpetrators of this latest, and most expensive, educational 'fad'." The President's Committee (Shaw & PCAST, 1998) concluded that "considerably less empirical research has been done on the effectiveness of constructivist applications of technology than on traditional, tutorial-based applications" (p. 119), but that in these new environments "attempts to isolate the effects of technology as a distinct independent variable may be both difficult and unproductive"(p. 121).

This places researchers in a very difficult situation. On the one hand they must attempt to demonstrate the value that technology has to learning, while on the other hand, it is generally recognized that it is very difficult, perhaps even unproductive, to isolate the technology variable from the overall learning environment and resulting instructional strategies.

Nonetheless, it is appropriate that researchers examine further the role that technology can play in the new environments and how it can best interact with the environment and aid learning, while a separate line of research should examine the learning that takes place in the new environments without attempting to isolate the technology variable.

Sample Questions for Student Learning:

- In what ways can technology serve as an extension of human capabilities and cognitive functioning?
- How can technology provide 'scaffolding' support to augment what learners can do and reason about on their path to understanding.
- What specific cognitive skills are most likely to be enhanced by the use of technology for learning?
- What effect does the use of technology have on the acquisition of content and subject matter knowledge?
- Do the new learning environments result in greater learning depending on the subject matter?
- Does the use of technology aid in the development or acquisition of the "basic skills" such as writing, and if so, how is this best achieved?
- Do the new learning environments result in greater learning independent of student characteristics?
- Do the new learning environments result in greater learning as measured by the new state standards and high-stakes assessments?

Assessment, the transformed classroom, and student learning.

Ultimately, the ability of researchers to address the questions regarding student learning is dependent on the development of valid and reliable new measures that accurately assess the learning that is believed to take place in the new environments. The fact is, at the present time there is not a satisfactory way to measure what or how technology enhances learning, even though many believe that it does.

This is an area in which there will need to be considerable research and development coordinated with the identification of the types of learning that go hand in hand with technology integration in the classroom. It is helpful to think of the assessment component as both formative and summative within the classroom, and summative for external accountability purposes (Bransford, et al., 1999). Within the classroom formative assessments are assessments that give feedback for the purposes of improving teaching and learning, and summative assessments are used at the end of a learning activity. External summative evaluations are usually national, state or district assessments used for accountability and other high stakes purposes. Both the classroom and the external assessments must be developed further through research.

An additional area worthy of further research is the *mode* of assessment. Russell & Haney (1997) found in their research that multiple choice tests results did not differ due to mode of administration, but for students who were accustomed to using a computer their hand written papers were substantially lower than those written by computer. They concluded:

> Validity of assessment needs to be considered not simply with respect to the content of instruction, but also with respect to the medium of instruction. As more and more students in schools and colleges do their work with spreadsheets and word processors, the traditional paper-and-pencil modes of assessment may fail to measure what they have learned. . . . we should be extremely cautious about drawing inferences about student abilities when the media of assessment do not parallel those of instruction and learning (p. 17).

Sample Questions for Classroom Assessments.

- What is the domain of cognitive tasks or other skills expected within the new learning environments?
- Do the cognitive tasks and skills differ by subject or content area?
- How do these cognitive skills and tasks interact with subject matter knowledge?
- What are appropriate cognitive tasks and skills for each age level?
- How can these cognitive tasks and skills best be measured within the classroom?
- How can technology be best used to provide immediate feedback on student learning?
- How can technology be best used to publish and aggregate student work and to communicate the results?
- How does the use of technology in the assessment situation affect the results?

- How do these cognitive tasks and skills align with high stakes assessments such as NAEP, TIMSS, and the new standards-based tests?
- What assessment skills do teachers need to conduct the type of assessments needed to improve student learning?
- What is the best training and professional development for teachers to obtain these skills?

Sample Questions for External Summative Assessments

- What is the domain of cognitive tasks and other skills expected of all students?
- Do the cognitive tasks and skills differ by subject or content area?
- What are appropriate cognitive tasks and skills for each age level?
- How can these cognitive tasks and skills best be measured on a large scale?
- How can technology be best used to assess these skills?
- How can on-line assessments be best used to enhance student learning and for accountability purposes?
- Are high stakes assessment results affected by student use of technology to take the test?
- What is the most cost-efficient way to conduct large-scale high-stakes assessments that incorporate the types of learning enhanced by technology?

School reform and technology.

The degree to which technology will be successfully integrated into the nation's classrooms is tied to the much larger job of restructuring the schools and classrooms in the more general sense. For example, research from the New American Schools project (Bodilly, 1998; Glennan, 1998) has shown that school and classroom changes are dependent on many factors including strong leadership and trust between the school and central office. It may be that where true school reform is or has taken place, it is much more likely that technology will be used as an integral part of learning and the overall schooling experience. Therefore, it may be that focusing exclusively on technology research is too narrow of a focus. It may be most advantageous to examine the technology in the broader context of overall school reform.

Sample questions:

- How do the different school reform models best make use of technology?
- What institutional factors prevent technology from being part of the overall school reform efforts?
- How can teachers best be made to feel a sense of ownership of the school reform efforts?
- How can technology be used to facilitate overall school reforms?

Computers, New Learning Environments, and Technological Literacy—Directions for Further Research

The development of the new learning environments is dependent to some degree on having students with technology literacy skills (such as word processing and on-line capabilities) sufficient to function in the environments. In current practice, this has led to the tendency to teach the technology skills "just in time," that is, just preceding the need for the skill within the environment or integrated with the learning activity. The new standards in this area should provide clear outcomes suitable for research and evaluation purposes.

Sample Questions:

- What is the developmental appropriateness of suggested technological skills for various age groups?
- What role do technology literacy skills play in creating the new learning environments?
- What is the best way to teach technology skills—independent of the curriculum, or "just in time"?
- How can technology literacy best be assessed?

Computers, Technology and Distance Learning—Directions for Further Research

There is evidence that traditional distance education delivery modes have produced similar levels of learning, among at least some students. However, technological advancements have provided the opportunity for new forms of distance education through on-line opportunities, and interactive and video conferencing. The challenge will be to develop compelling curricula and to use the technology in such a way as to provide a comparable type of learning experience as that provided in the new learning environments based on constructivist ideas.

Sample questions:

- Do learner/teacher communications through interactive and online technologies provide a comparable learning experience to the new learning environments?
- Are there equal degrees of student satisfaction with and motivation for distance learning primarily by technology?
- Are distance education student learning outcomes comparable to outcomes of students in classes?
- With the new distance learning approaches with technology, do the student drop-out rates remain high, and if so, why?
- Are student characteristics related to success or satisfaction with distance education through technology?
- Is successful distance education through technology content specific?

- What training do teachers need to delivery this type of distance education?

Technology as an Educational Management/Efficiency Tool

Technology has transformed the work and work environment in many other sectors of society. It has, and will continue to have, the potential to redesign and automate business processes, create new business formats, products and services, to reduce costs, to improve quality, and to improve access to information and communication. It has allowed the transformation of organizations from hierarchical command/control to flat/fast learning organizations. Understanding this transformational potential is an important area of "design research" drawing from "best practices" in other sectors.

Sample questions:

- How can technology best be used to improve district and school productivity in areas such as communications, scheduling, and record keeping?
- How can technology best be used to improve teacher personal productivity in the areas of student assessment, record keeping, and communications with students and parents?
- How can technology best be used to enhance accountability?
- How can on-line assessments best be used to enhance student learning and for accountability purposes?

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