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Review Paper on Educational Technology Research and Development

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Review Paper

Educational Technology Research and Development

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Introduction

This paper aims to introduce the reader to the current landscape of educational technology research and development. It:

- Reviews the recent history of research related to educational technology
- Describes the current key research themes and methods of the field
- Looks forward to some of the most promising future directions for the field.

Our emphasis is on outlining these issues and illustrating them through descriptions of exemplary work in relevant areas. In the appendices, we list sources of further information for the interested reader.

Lessons Learned from Research

Researchers, developers, and practitioners have been seeking to define the best roles and functions for electronic technologies in educational settings since computers first began appearing in schools, in the mid-1960s (Cuban, 1986). This interest has accelerated since microcomputers became available in the late 1970s. Early studies emphasized the distribution and emerging uses of the then-new tools in schools, as well as learning outcomes of individual students working directly with machines (Papert, 1980). At that time, there was relatively little learning-appropriate software—innovative or otherwise, in school or laboratory—to be studied. The studies did, however, establish a body of evidence suggesting that technology could have a positive impact on several dimensions of students' educational experiences, and researchers began to identify some of the important mediating factors affecting the student-computer interaction. For example, meta-analyses of student learning studies suggested that computer-based instructional materials have a positive effect on student performance (Kulik & Kulik, 1991). At the same time, other studies demonstrated that the nature of the impact of the technology on students was greatly influenced by the specific student population being studied, the design of the software, the teacher's practices, student grouping, and the nature of students' access to the technology (Software Publishers' Association, 1996). A number of comprehensive reviews and syntheses of the research conducted during this period are available (Kulik & Kulik, 1991; Software Publishers' Association, 1997; U.S. Department of Education, 1996).

By the mid-1980s, the situation was changing rapidly as more innovative electronic material became available. In addition, people began to understand that technologies' effects on teaching and learning could be fully understood only as part of multiple interacting factors in the complex life of schools (Hawkins & Honey,

1990; Hawkins & Pea, 1987; Newman, 1990; Pea, 1987; Pea & Sheingold, 1987). The broad shift in the research focus was due to simultaneous, steady growth and change on several fronts, especially in the nature of the technological objects involved in the research, the research questions being asked, and the research methods used. We review each of these developments below.

Technological change

Throughout the 1970s and 1980s, technical innovation was bringing increasingly diverse and more powerful technological tools into schools. Early studies sought to demonstrate the impact of technologies or software on student learning; necessarily, they were tied very specifically to the particular technologies used by the subjects of the study. These technologies were typically text-based, locally networked, or stand-alone computer-assisted instruction applications. As these technologies have become outdated, replaced by graphics-rich and networked environments, the studies that looked at impact have lost their original usefulness (President's Committee of Advisors on Science and Technology, Panel on Educational Technology, 1997). Additionally, because these studies looked so specifically at particular technologies and their impact, they contributed little to the larger, more challenging project of learning about the generalizable roles that technologies can play in addressing the key challenges of teaching and learning, as well as learning about optimal designs for such technologies.

The pace of technological development, and of the introduction of new technologies into educational settings, has accelerated dramatically during the 1990s. The combination of computation, connectivity, visual and multimedia capacities, miniaturization, and speed has radically changed the potential for technologies in schooling; these developments are making possible the production of powerful, linked technologies that can substantially help address some of the as-yet-intractable problems of education (Glennan, 1998; Hawkins, 1996; Koschmann, 1996; Pea, Tinker, Linn, Means, Bransford, Roschelle, Hsi, Brophy, & Songer, in press).

Changes in the questions being asked

As the technologies themselves have changed, our research questions have changed as well. We began, in the 1970s, by asking questions about whether certain kinds of computer-based activities improve student learning. Studies did find improvements in student scores on tests closely related to material covered in computer-assisted instructional packages (Kulik & Kulik, 1991). Yet these studies did not acknowledge that effective technology use needs to be embedded in a larger process of school change, and instead tended to treat technology as a discrete, isolated, yet—it was hoped—overwhelmingly powerful input.

Implicit in these initial strands of research was an assumption that schooling is a "black box." Research attempting to answer the question, Does technology improve student learning?, had to eliminate from consideration everything other than the computer itself and evidence of student learning (which in this type of study was usually standardized test scores). Teacher practices, student experiences, pedagogical contexts, and even what was actually being done with the computers—all these factors were bracketed out. This was done so that the researcher could make powerful, definitive statements about effects—statements unqualified by the complicated details of actual schooling.

The problem was that all the studies conducted in this way—and there were hundreds—told educators clearly that specific kinds of technology applications, such as integrated learning systems, could improve students' scores on tests of discrete information and skills, such as spelling, basic mathematics, geographic place-names, and so on. But these studies were not able to tell educators much about addressing the larger challenge of using technology to help students develop capacities to think creatively and critically, and to learn to use their minds well and deeply in and across the disciplines, inside school and out.

Past research has make it clear that technologies by themselves have little scalable or sustained impact on learning in schools. To be effective, innovative and robust technological resources must be used to support systematic changes in educational environments that take into account simultaneous changes in administrative procedures, curricula, time and space constraints, school-community relationships, and a range of other logistical and social factors (Chang, Honey, Light, Moeller, & Ross, 1998; Fisher, Dwyer, & Yocam, 1996; Hawkins, Spielvogel, & Panush, 1996; Means, 1994; Sabelli & Dede, in press; Sandholtz, Ringstaff, & Dwyer, 1997).

While pressure builds to learn more about how technologies contribute to student learning, there has been increasing recognition that technology is a crucial player in a complex process of change that cannot be accomplished by technological fixes alone. Researchers are increasingly asking questions about 1) how technology is integrated into educational settings; 2) how new electronic resources are interpreted and adapted by their users; 3) how best to match technological capacities with students' learning needs; and 4) how technological change can interact with and support changes in other aspects of the educational process, such as assessment, administration, communication, and curriculum development.

Changes in methods

Answering such questions requires examining a range of interconnected resources–including technologies, teachers, and social services–that cannot be isolated

for study in the way a single software program can be. Further, the kinds of outcomes associated with changing and improving the circumstances of teaching and learning are much more holistic than those measured by standardized tests of specific content areas, and they require more sophisticated strategies of the researcher attempting to capture and analyze them. To explore how best to use technology in the service of these goals requires looking at technology use in context and gaining an understanding of how technology use is mediated by factors such as the organization of the classroom, the pedagogical methods of the teacher, and the sociocultural setting of the school.

A handful of classic research methods have been commonly used to explore these questions and should continue to be drawn on in future research. These include:

- **Design research.** Design work can begin with existing or emerging technological functionalities that are then adapted or transferred into the educational context, or it can begin with key educational challenges and create new technologies that speak directly to those needs.
- **Formative research.** Well-executed formative research provides crucial feedback on the ongoing development of new educational technologies. Formative researchers observe how the intended audience for a new intervention interprets the intervention, makes sense of it and begins to use it. These researchers seek out hurdles to effective use and clues for improving the innovation that its developers might not have considered. Findings can be fed back to developers, programmers, or writers so that they can improve their work.
- **Studies of student learning.** Caution is necessary when investigating student learning effects. Both the intervention itself and the nature of the "learning" that the technology is meant to improve are always difficult to define. Findings from highly constrained or artificial research (such as out-of-school laboratory studies) can seldom be generalized to other settings or applications of the intervention, while more naturalistic studies generate findings that are typically too nuanced or conditional to support the kinds of absolute judgments audiences may find useful.

  Any study needs to be sensitive to more factors than the simple presence of a technological object or technology-mediated process. A good study of student learning in a technology-rich context needs to focus less on establishing that technology-rich situations are "better" than non-technological situations than on establishing two ideas: first, that the technology rich situation makes possible something *different* from what would be possible without technology, and second, that students can and do succeed

in learning the concepts the technology-rich situation is designed to help them learn (Honey, McMillan, Tsikalas, & Grimaldi, 1995; Honey, McMillan, Tsikalas, & Light, 1996).

Broadly applicable student learning research requires long-term longitudinal studies of students who move through a range of technology-rich learning experiences. Further, more methodological research is needed to better identify best practices and to develop innovative approaches to research around this complex problem.

- **Evaluation.** There are two kinds of evaluation studies. *Formative* evaluation studies use the formative research techniques described above and are becoming increasing important in the work of many researchers and program developers. *Summative* evaluations judge the overall effectiveness or success of a particular intervention. Matching the goals of the evaluation to the goals of the program is crucial to effective evaluation research. Good evaluators need to understand the obstacles faced by project implementors that may have significantly facilitated or hindered the success of the program.
- **Policy research.** Policy research increases understanding of how to create effective institutional change. Policy research allows us not only to understand the success or failure of individual initiatives, but also to learn, across multiple studies, what factors most persistently complicate the delivery of effective educational resources, what chronic challenges of systemic educational change exist, and how educational systems are, in fact, gradually changing over time and across the country.

The following section discusses several emerging models created to capture and examine more adequately these multifaceted, complex environments and the ways that they simultaneously mediate and are pushed forward by newly introduced technologies.

Review of Current Research

Researchers are now exploring roles that technologies can play in realizing complex changes in real educational settings and in identifying the contextual conditions necessary to realize those changes. They are focusing on the intersections of design, learning, school culture and practices, and other factors that shape the impact that technologies can have in schools (Collins, 1990; Dede, 1998; Means & Olson, 1995). In addition, there have been increasing calls for large-scale longitudinal studies examining the consequences of technology use in schools settings in concert

with a broad range of factors, analogous to epidemiological studies (President's Committee of Advisors on Science and Technology, Panel on Educational Technology, 1997). The president's report further recommends a substantial increase in available research funds, as research on technology and education has been chronically underfunded.

Research on tool design and learning

Another major domain of educational technology research–one closely tied to technology development efforts–has been under way for two decades. This thriving body of work focuses on identifying particular ways that the distinctive functionalities of technology can support learning in a different or better way than other resources. This type of research seeks to answer questions such as these: What is technology particularly good at? What are the most promising intersections between what is hard to teach and what technology can do? This line of work begins with a set of teaching and learning questions, generally framed in the terminology of cognitive science, and charges researchers and developers with working together to design specific tools or pieces of software that can be effectively integrated into the classroom to improve student learning around specific tasks. Typically, the emphasis is on creating new materials in a lab setting and then transferring the innovation to practitioners in a separate implementation phase.

A number of promising projects have worked extensively in this area (Bell, Davis, & Linn, 1995; Brunner, Honey, McMillan, Ross, & Tsikalas, 1997; Frederiksen & White, 1997; Gomez, Gordin, & Carlson, 1995; Guzdial, 1997; Hawkins, 1990; Krajcik, Soloway, Blumenfeld, & Marx, 1998; Pea, 1993; Pea, Edelson, & Gomez, 1994; Scardamalia & Bereiter, 1996; Soloway, Jackson, Klein, Quintana, Reed, Spitulnik, Stratford, & Studer, 1996). Given adequate technical expertise and sufficient time for formative research, researchers and developers have come up with tools that help teachers and students achieve a wide range of work that they could not otherwise do in the classroom. For example, the Climate Visualizer, developed as a part of the Collaborative Visualization project at the Institute for the Learning Sciences at Northwestern University, allows students to manipulate real weather data and investigate how various shifts in data change the character of the weather maps produced by the visualization tools. Students can move back and forth between visualizations and data sets, exploring the interactions between these different representations of underlying phenomena (Gordin, Polman, & Pea, 1994). Projects like this use technology *creatively*, exploiting and adapting existing functionalities to support good learning and teaching, rather than imposing them as-is onto the classroom.

The problem with many projects such as the Climate Visualizer, however, is that

innovations developed this way are very rarely adopted and owned by in-school educators in any sustained way. They remain "islands of innovation" or "proof of concept" demonstrations, used in the classrooms of individual enthusiasts; they don't begin to touch the core of school practice in a significant way. This situation is referred to as the problem of *scalability*—of bridging the chasm between prototypes and widespread practice. Though the reasons for the persistence of scalability challenges are many, one significant factor is that in this model of research, schools are implicitly treated as "black boxes," in that the research and development processes have bracketed out the institutional complexities and constraints that shape how teachers and students actually work in schools. Research and development teams often base their models of "good learning and teaching" largely or entirely on theory, paying little attention, at least initially, to the ways those theories are translated into practice in real schools. Consequently, they "deliver" solutions, developed in labs, to teachers, and do not consider the way teachers—or students, or community members—define what is important in schooling or how schooling should or must occur. Research and design teams are, however, increasingly using more rapid cycles of prototyping, testing in practical circumstances, and revision, working iteratively to build tools, test them in classrooms, and modify their designs in response to lessons learned from the realities of classroom practice and from learning outcomes associated with use of the tool.

Even as this model of tool development evolves, it faces other important challenges of scalability, ownership, and what Nora Sabelli of the National Science Foundation calls "localization." How will individual teachers in particular schools make sense of these new tools, and how will they fit them into their curriculum? How do the learning goals embedded in the tool design mesh or conflict with local priorities and visions of quality education? How can the initial excitement of new resources and new ideas translate into sustained commitments to new forms of teaching and learning? Creating promising strategies for building the kinds of local ownership of technological resources, curricula, and infrastructures necessary for sustained and substantive change is at the core of an emerging model of collaborative, practitioner-focused research.

Emerging models for innovative research practices

Research needs to focus on improving circumstances of learning and on determining how technology can help make that happen. This requires viewing technology not as a solution in isolation, but as a key component in enabling schools to address core educational challenges. A consensus has emerged (Dede, 1998; Means, 1994; President's Committee of Advisors on Science and Technology, Panel on Educational Technology, 1997; Sabelli & Dede, in press) that the larger issue to be addressed across a wide range of iterative, collaborative research projects is gaining

an understanding of the qualities of successful technological innovations as they begin to have an impact within local, district, regional, and national contexts.

Several common characteristics have emerged in the design and methods involved in this type of research. Key *assumptions* include:

- Conceding that technologies in and of themselves rarely bring about substantial change in teaching and learning.
- Understanding that the impact of technology on specific aspects of teaching and learning can be usefully understood only in context. That is, technologies matter only when harnessed for particular ends in the social contexts of schools, and consequently they must in major part be studied in that context. This does not eliminate the need for careful formative research with users in experimental or laboratory settings but does mean that the research agenda is not completed when a robust application has been developed for use in learning settings.

Methodological features of this kind of research include the following:

- It is largely process-oriented. The researchers' goal is to understand *how* innovation occurs in schools, not just what outcomes are correlated with the innovation.
- It is oriented toward change rather than toward doing better within the old framework (that is, student learning as narrowly defined by test scores). Tools and programs that are promising to study are the ones that support or act as catalysts for change in the *organization* of teaching and learning.
- Teachers and researchers play an active role in interpreting technologies as tools for reforming schools and in supporting and sometimes guiding the change process.
- It is multidisciplinary, combining elements of different fields, including: 1) anthropological lenses on the culture of schools and classrooms and kids' lives inside and outside them, 2) developmental and cognitive psychology lenses on learning, and 3) sociological lenses on school institutions and school change.

Important *design* elements in this type of research include:

- Long-term collaborations with educators. Teachers are likely to be partners and co-constructors of the innovations and of the research process, rather than viewed as subjects or passive recipients of the innovation.
- Systemic examinations of the impact of innovations across multiple levels

of the school system. Isolated classroom experiments are being replaced with broad examinations of the roles that technological innovations can play in the whole system of schooling, or at the classroom, individual school, district, state, and national levels. This type of research includes "test bed" studies that track technology-enhanced, long-term school changes (Chang, Honey, Light, Moeller, & Ross, 1998; the Center for Learning Technologies in Urban Schools, Louis Gomez & Ron Marx, Principal Investigators).

What we have learned so far

Several broadly supported conclusions have emerged from this type of research. We have begun to learn about how specific technologies can help reorganize the education workplace. We have become accustomed to defining our strategies and research questions from the point of view of education problems or challenges, rather than beginning from the technologies' capabilities. And we have come to appreciate the powerful role technology can play in creating new links between schools and the world outside the schools, connecting individuals, providing resources, and broadening the cultural and political contexts available to students and teachers for exploration and examination.

Promising Directions for Future Research and Development Work

The following section outlines 14 thematic areas much in need of further research and development work. Within each area, multiple types of research questions need to be asked, and research methods that have traditionally been used independently of one another may need to be combined in various ways, or hybridized, to create new research approaches.

Thematic areas for future research

Making real-world connections. One of the most powerful and talked-about aspects of Internet access is the opportunity it provides for students and teachers to work with up-to-date information, real-time events, and experts from outside the school community. Many projects are currently connecting kids in classrooms to motivating real-world problems and experiences or are involving them in ongoing research projects and adventures that require engagement in real-time data collection and dissemination. The World Wide Web also allows students to act as producers and publishers of knowledge in these projects, not just as recipients. Our understanding of how such projects can best be designed to help students learn, however, or how the social and academic connections made possible by the Internet can be leveraged

to diminish the long-standing political and social isolation of schools, is still in its early stages.

MODEL PROGRAMS:

- *The Adventures of Jasper Woodbury* series at Peabody College/Vanderbilt University (http://peabody.vanderbilt.edu/projects/funded/jasper/Jasperhome.html)
- The *Quest* series sponsored by Classroom Connect (http://www.classroom.com/)
- The Geoffrey Haines-Stiles *Passport to Knowledge* series (http://learn.ivv.nasa.gov/products/sp/)
- *Archeotype*, an archaeology simulation developed by the Dalton School and Columbia University

Engaging in complex analysis. The combination of more powerful desktop computers and the Internet brings rich authentic data sets into the classroom, enabling teachers and students to explore resources such as scientific visualizations and primary source materials. Such resources help create contexts in which learning can be more student-centered and inquiry-based; children can "do" science, or history, in more active and complex ways. Research and development work in this area needs to focus on investigating 1) how best to engage students with the complexity of the scientific and social systems represented in these materials, and 2) how to teach students to engage critically with resources representative of the past and of the present. Questions that are only beginning to be investigated include, How do new tools of investigation (such as simulations and visualizations) and the increased exposure to "raw" resources and documents (such as historical documents and contemporary media) change the circumstances of teaching and learning? How can collections of these resources best be scaffolded and presented for in-school use, and what kinds of new tools and environments (for instance, portable devices and supports for the analysis of visualized data) need to be designed and developed to support student exploration?

MODEL PROGRAMS:

- The Learning through Collaborative Visualization project at Northwestern University's Institute for the Learning Sciences (http://www.covis.nwu.edu)
- The Center for Highly Interactive Computing in Education at the University of Michigan (http://hi-ce.eecs.umich.edu/)
- The University of Michigan's Digital Library Teaching and Learning Project (http://umdl.soe.umich.edu/)

- The WISE collection at SRI (http://wise.sri.com/)
- The Library of Congress American Memory resources for educators (http://lcweb2.loc.gov/ammem/ndlpedu/educator.html)
- The Institute for Learning Technologies at Teachers College, Columbia University (http://www.tc.columbia.edu/~academic/ccte/)

Literacies: A key challenge faced by developers interested in broadening the scope and diversity of the visual resources students are using in school is how to help students develop their critical abilities to select, interpret, and evaluate source materials of different kinds, as well as synthesize or create visual resources of their own. These skills are sometimes called "media" or "information" literacy. These are obviously critical skills in the anarchic and commercialized environment of the Internet. Increasingly, similar literacy skills are becoming necessary for helping students make sense of simulated or virtual environments. Developing these literacies is not trivial, even for students exposed to powerful computational tools and environments. It doesn't happen simply by immersing kids in thoughtfully designed materials. It requires careful adult human scaffolding of critical reflection and expression—in this case, provided by the teacher.

MODEL PROGRAMS:

- Young Children's Literacy Program, at the Learning Technology Center at the Peabody School/Vanderbilt University, in collaboration with Little Planet and Scholastic (http://peabody.vanderbilt.edu/ctrs/ltc/general/)
- ALMA, the Adult Literacy Media Alliance at Education Development Center, Inc. (EDC) (http://www.edc.org/ALMA/)
- The Center for Media Literacy (http://www.medialit.org/)
- The Media Workshop New York, sponsored by the Bertelsmann Foundation (http://mediaworkshop.org/)

Home/school/community connections. This involves an expanded view of learning as occurring not merely in specific classroom tasks but across the multiple contexts of kids' lives—in homes, communities, museums, libraries, and so on. Researchers have barely begun to explore how technology might help schools establish stronger connections with students' homes and with the local community, how community organizations can make use of technology to support their goals and serve their constituents, or other related questions about technology's potential to increase communication and alignment among the major social institutions that influence children's overall development.

MODEL PROGRAMS:

- The Buddy Project (http://www.buddy.k12.in.us/, http://rockman.com/projectmain.htm#buddy)
- Science Linkages in the Community, sponsored by the American Association for the Advancement of Science (http://www.aaas.org/ehr/slic/)
- Several projects under way in the Union City, New Jersey, school district, including Project Explore, Project Hiller, and the Libraries Initiative (http://www.union-city.k12.nj.us/)
- The Science Learning Network (www.sln.org)

Teacher learning and professional community. How can technology change work practices, work circumstances, and professional communities for educators and educational systems? Teachers' chronic isolation and their need for continuing education are recognized as important hurdles to improving education, and technology can potentially play an important role in meeting teachers' needs. Some promising work has been done on using technology to support more flexible, more authentic, and more sustained professional development programs for teachers. Several higher education institutions have been making use of distance-learning technologies to support their teacher training programs, but broader applications of technology to teacher preservice have largely been neglected thus far. Much work remains to be done in investigating the potential of online peer-to-peer learning situations for teachers, and of sustained online teacher communities. An array of other technologies also needs to be explored further as potentially important media for delivering richer and more complex material to teachers in training, such as case studies presented in multimedia or video formats.

MODEL PROGRAMS:

- INTEC, the International Netcourse Teacher Enhancement Coalition at the Concord Consortium (http://intec.concord.org/)
- The CoreModels project sponsored by Maryland Virtual High School (mvhs1.mbhs.edu)
- The Mathematics Learning Forums at Bank Street College (http://www.bnkst.edu/)
- The Swarthmore Math Forums (http://forum.swarthmore.edu/)

Reorganizing the education workplace. While much research has focused on the impact of technology on students or on classroom-level teaching and learning processes, much less attention has been paid to the role of technology in enhancing, or potentially further problematizing, teachers' and administrators' work lives.

Researchers and developers need to investigate uses of technology that alter how teachers, administrators, and students spend their time, to help them be more efficient, to improve administrative and coordination functions, and to increase their focus on the complex learning relationships among people that are central to the learning process. Promising applications that are beginning to be investigated include data mining for administrators and counselors to track student progress and social factors; administrative systems that give teachers flexible, up-to-date access to appropriate information; the use of intranets to improve intra-faculty information exchange and work processes; and use of the Web to increase parent and community access to school "report cards" summarizing relevant school data.

MODEL PROGRAMS:

- IBM's Reinventing Education program (http://www.ibm.com/education)
- GreatSchools.net: The Comprehensive Guide to Bay Area Public Schools (http://www.greatschools.net)

Equity and access/gender/special education. Gaining an understanding of the current and evolving differential impact of technology on diverse student audiences is crucial to any vision of a future for education in which technology access and use are equitable. Though important policy-level research has been done, more on-the-ground study of the integration of technology into the education of different populations is needed. Key questions include: How can we ensure equitable access to and use of technology to all students? How do different populations' needs differ, and how can special needs be addressed with technological solutions? What can we learn about applications for the general population from the experiences or needs of specific populations?

MODEL PROGRAMS:

- Telementoring Young Women in Mathematics, Science, and Engineering, sponsored by the Center for Children and Technology/Education Development Center, Inc. (http://www.edc.org/CCT/telementoring/)
- NCIP, the National Center to Improve Practice in Special Education through Technology, Media, and Materials, at Education Development Center, Inc. (http://www.edc.org/FSC/NCIP/)
- CTCNet (the Community Technology Centers' Network) (http://www.ctcnet.org/)
- Access by Design, at Education Development Center, Inc.

Research and development on emerging technologies and challenging/difficult content. As technologies rapidly evolve, it is critical to

increase investment in the exploration of new technologies for key education challenges. Currently, relatively more research and development investment has been devoted to mathematics and science, and considerably less to the humanities. Critical decisions about investment should be based in part on matches between disciplines, content areas, or education workplace challenges, and the appropriate emerging technologies. Making such matches requires anticipatory design research that is deeply informed by both the course of technology development and the needs of the educational community.

MODEL PROGRAMS:

- The Center for Innovative Learning Technologies, a collaboration of SRI International, the Concord Consortium, Vanderbilt University, and the University of California at Berkeley (http://www.cilt.org/)
- The Learning through Collaborative Visualization project at Northwestern University's Institute for the Learning Sciences (http://www.covis.nwu.edu)
- The Center for Learning Technologies in Urban Schools, at the Institute for the Learning Sciences at Northwestern University (http:// www.ls.sesp.nwu.edu/ projects.html)
- Robert Tinker's SmartProbes work at the Concord Consortium (www.concord.org)
- The Thomas J. Watson Research Laboratory (http://www.watson.ibm.com)
- Advanced Technology projects at the National Science Foundation

International studies of technology in education; global context of teaching and learning with technologies. Substantial information has accumulated in both developed and developing countries about strategies and consequences for integrating technologies. Rapidly developing global connections also provide new opportunities for improving teaching and learning. Researchers are beginning to explore issues such as how cross-cultural exchanges among teachers can stimulate reflection on deeply ingrained practices and how technology integration unfolds in widely varying educational contexts around the world. Technology can play an important role in supporting international development and collaboration around educational technology issues in many ways, including facilitating conversation across multiple languages and time zones and supporting the distribution of complex work products among distant collaborators.

MODEL PROGRAMS:

- The work of Michael Potashnik and others at the World Bank on international education issues and technology (http://wbln0018.worldbank.org/

HDNet/ HD.nsf/SectorPages/Education. Open document, click on "education technology")

- Dr. Elad Peled and Dr. Zimra Peled's work in information technology development plans for schools
- Bob Kozma, of SRI International, and Ron Anderson, of the University of Minnesota
- Ziaodong Lin and John Bransford of Vanderbilt, with Jan Hawkins of Harvard University and The Center for Children and Technology at Education Development Center, Inc.
- Some of the countries tackling educational technology issues most ambitiously, including Barbados, Brazil, Costa Rica, Denmark, Jamaica, Singapore, Turkey, and the United Kingdom

Using technology to support lifelong learning. Researchers have consistently demonstrated that adults engage in substantive learning activities well beyond the confines of traditionally-defined schooling. Non-institutional, learner-initiated, and learner-driven education plays a chronically under-emphasized role in the landscape of formal and informal education. In addition to informal, learner-driven education, corporations, not-for-profits, and governmental agencies consistently invest heavily in training for their employees and clients across an enormous range of skills and content domains.

The needs of the informally, usually adult learner–a population that is highly dispersed, diverse in its background and needs, and entirely self-selected–are well matched to the strengths of many of the technologies that are being used to support distance- and self-paced education. Lifelong learning institutions are using technology to connect people in disparate locations with similar needs or interests, to provide opportunities for asynchronous but sustained discussion, and, in more localized contexts, to tailor instruction to individual needs and interests.

Few clear best practices have yet emerged in this domain, and much research remains to be done. Further, little systematic exploration has centered on how best to combine face-to-face and technology-mediated experiences, or on how best practices vary in relation to the kind of education or training being offered.

MODEL PROGRAMS:

- Adult Literacy Media Alliance (http://www.edc.org/ALMA/)
- California Distance Learning Project (http://www.otan.dni.us/cdlp/cdlp.html)

- CTCNet (the Community Technology Centers' Network) (http://www.ctcnet.org/)

Supercomputing. In the past, high-performance computers, graphic workstations, and high speed networks seemed to far exceed the needs of students and teachers. But educators' interests in using technology, particularly in science and mathematics courses, is becoming more sophisticated, and powerful computers and broadband, high-speed networks are beginning to become much more available at the school and district levels. Therefore, learning experiences afforded by these kinds of technologies are beginning to become more common parts of students' educations. These experiences include the exploration and construction of complex simulations, exploration of virtual environments and communities, and the creation of animations and models of complex systems. Such applications can support students in their exploration of complicated phenomena like automobile crash testing, human genetics, pharmaceutical development, and epidemiology.

MODEL PROGRAMS:

- MaxwellWorld, virtual reality programs created by researchers at George Mason University, the University of Houston, and the National Aeronautics and Space Administration's Johnson Space Center
- The ScienceSpace project, at George Mason University simulates an environment true to the laws of physics (http://www.virtual.gmu.edu)
- Imaging Lab, South Burlington High School, where students produce their own computer-animated presentations, and public service announcements.

Assessment. Educators have become increasingly aware that what students learn is heavily influenced by what is valued in the tests they are given (that is, that teachers "teach to the test"). Consequently, there has been much reconsideration of how students are assessed, and recent years have seen a strong trend toward performance-based assessments of student learning (Herman, 1999).

In contrast to norm-referenced testing, performance assessments are thought to measure complex thinking and problem solving more effectively, as well as to reflect more accurately the world in which students will need to apply their skills and knowledge. Key characteristics of performance assessments are that students create products that both represent their learning and are meaningful to them; and assessment tasks and contexts are authentic—relevant to and consistent with real-world problems and situations.

Computer technology has contributed to performance assessment techniques and outcomes in interesting and provocative ways. Most important, it has changed

the nature of products that students construct to represent and demonstrate their knowledge, and it is changing how teachers score and interpret student work. Increasingly, students are not only documenting their academic progress on the computer (through electronic portfolios, websites, and so on) but are designing computer-based artifacts to demonstrate their understanding and skills. In the U.S. Department of Energy's Adventures in Supercomputing program, students construct computer simulations to explain the scientific phenomena they have studied. Examples of students' work include a simulation of coral reef growth in which users may alter variables such as water temperature and salinity and see the effects of the changes on the type and rate of coral propagation (Honey, McMillan, Tsikalas, & Light, 1995).

Web-based applications are also being developed to support the crucial process of teacher-to-teacher discussion of the assessment process. Web-based platforms allow teachers to share student work easily, as well as scoring rubrics and records of teachers' interpretations of various artifacts of student learning. These environments offer teachers opportunities for ongoing professional development as well as a mechanism for supporting innovative assessment practices.

Promising areas of research within the domains of student learning products and teacher interpretive processes include:

- How can novel, student-determined representations of knowledge influence how educators support a diverse body of learners in a wide range of learning environments?
- How can technology facilitate high-quality assessment of rich student learning products?
- What impact does technology-enhanced assessment have on teachers' beliefs about their students' abilities, and on their pedagogical and professional development practices?

MODEL PROGRAMS:

- The Design of Student Assessment Tools for the GLOBE Program (Global Learning and Observations to Benefit the Environment) (http://www.sri.com/ policy/ctl/html/globe.htm#tools)
- Center for Research on Evaluation, Standards, and Student Testing (CRESST) (http://www.cse.ucla.edu)

Telementoring. With the widespread use of electronic mail, online mentoring via the Internet has proliferated across the country, supporting formal and informal online exchanges between students of all ages and practicing professionals in the

real world of work. Internet access has popularized such relationships, apparently because the technology allows participants to choose when to communicate, breaking down barriers of time and distance and enriching the everyday educational experiences of students and educators alike.

As a broad range of telementoring projects has developed, researchers, teachers, and participants are learning more about some of the design challenges associated with creating successful online mentoring programs. Principal challenges include facilitating the initial "getting to know you" and goal-setting processes so that mentors and students share common goals and intentions, sustaining regular online communication so that all parties involved feel responded to and included in the activity, providing resources to turn to when mentoring pairs encounter personal or logistical roadblocks to continuing their partnerships, and creating ways for online relationships to conclude their work together effectively, so that mentors have a tangible understanding of their impact on student work and students can reflect on how their communication skills may have evolved in the course of the mentoring relationship (Bennett, Tsikalas, Hupert, Meade, & Honey, 1998).

In addition to making these kinds of mentoring relationships possible, computer technologies are also being used to support several online databases for matching students with mentors across a range of projects. See the model programs listed below for examples of such databases.

Model programs:

- CoVis Telementoring: Scientists work online with students on inquiry-based science projects. (http://www.covis.nwu.edu/mentors/welcom.html)
- University of Texas' Electronic Emissary project: Offers a broad range of subject matter experts to teams of teachers and students in schools. (http://www.tapr.org/emissary)
- Telementoring for Young Women in Mathematics, Science, and Engineering. Facilitated one-on-one and group discussions about paths to science and engineering professions for women and girls. (http://www.edc.org/CCT/ telementoring)
- Hewlett-Packard, Inc. Mentoring program for science students, sponsored by the Hewlett-Packard corporation. (http://mentor.external.hp.com)

Computer-assisted instruction. Computer-assisted instruction (CAI) can be defined loosely as the use of a computer and other associated technology with the intention of improving academic performance. Technology utilized in this manner is generally used to supplement regular classroom instruction, replace a portion of classroom instruction, or replace classroom instruction altogether. CAI systems

generally bring students into highly structured feedback loops that guide them through progressively more difficult material, while providing some form of consistent feedback about success or failure to provide correct answers.

Many of the integrated learning systems commonly used in schools provide only simple, routinized forms of feedback and adaptation to student needs. Some researchers, however, are developing more sophisticated systems intended to diagnose and respond to the particular cognitive strengths and weaknesses expressed by students in relation to specific content areas. Such tutoring systems use complex models of cognition and learning to determine the student's course through the presented material. Much development work remains to be done in this area, and consequent research will need to focus on the impact of this type of tutoring on transfer knowledge, and on sustained knowledge over time, as well as on identifying optimal combinations of this type of computer-based tutoring with other forms of instruction.

MODEL PROGRAMS:

- Andes: An Intelligent Tutoring System for Physics, a project of the Learning Research and Development Center at the University of Pittsburgh: Draws on expertise in cognitive science, physics content, and artificial intelligence to create a physics tutoring system. (http://www.lrdc.pitt.edu/research/lat99.htm)

Appendix A: Key Papers Addressing the Central Issues

RESEARCH PAPERS

- Becker, H.J., & Ravitz, J.L. (1997). *The equity threat of promising innovations: The Internet in schools.* Paper presented at the annual meeting of the Society for the Psychological Study of Social Issues, Chicago (http://nsn.bbn.com/dissemination /docs/equity.html).
  This paper examines potential sources of inequality in the use of the Internet with students in the U.S. The concerns raised involve not only inequality across communities and schools, but also inequality among students within schools.

- Chang, H., Honey, M., Light, D., Moeller, B., & Ross, N. (1998). *The Union City Story. Education reform and technology: Students' performance on standardized tests.* New York: Education Development Center, Center for Children and Technology.
  This paper reviews Project Explore, a set of technology and education reform initiatives of the Union City, New Jersey, School District. It also examines the impact of technology access on student standardized test scores and discusses the usefulness and limitations of examining such measures of student learning as a means of judging the impact of technology-rich programs on students and on district-wide change processes.

- Cognition and Technology Group at Vanderbilt (1997). *The Jasper project: Lessons in curriculum, instruction, assessment, and professional development.* Hillsdale, N.J.: Erlbaum.
  This text reviews the development of the influential *Adventures of Jasper Woodbury* series, a set of multimedia curriculum materials focused on innovative science learning for middle school students. It reviews findings from years of formative assessment work and the ongoing development of the materials, findings from teacher development experiences, and plans for future development and expansion of the series.

- Coley, R.J., Cradler, J., & Engel, P.K. (1997). *Computers and classrooms: The status of technology in U.S. schools.* Princeton, N.J.: Educational Testing Service (http://www.ets.org/research/pic/compclass.html).
  This report from the ETS Policy Information Center provides a snapshot of the use and effectiveness of technology in American schools. Its questions include: How much technology is in our schools, and is it allocated fairly? How are computers used in schools? Is access equitable? How can teachers and technology be better connected? What do we know about the educational impact of technology? What is the quality of current courseware? Is

it related to current educational standards? And what are the costs of deploying technology in our schools?

- Dede, C. (Ed.). (1998). *ASCD Yearbook: Learning with Technology.* Alexandria, VA: ASCD.
  This yearbook discusses a vision of education in the twenty-first century, including ways to use technology to empower and extend learning communities. In addition to an overview article by the editor, it includes articles envisioning future technology use for education as well as summaries of several influential educational technology projects.

- Edelson, D., Pea, R., & Gomez, L. (1996). Constructivism in the Collaboratory. In B. G. Wilson, ed., *Constructivist learning environments: Case studies in instructional design* (pp. 151-164). Englewood Cliffs, N.J.: Educational Technology Publications.
  This paper reviews the Collaboratory, a software tool for science inquiry originally developed as part of the CoVis project. It outlines the pedagogical philosophy underlying the design of the tool, the research and design process involved in its development, and findings from formative research in classrooms.

- Fulton, K., Wasser, J.D., Rubin, A., Grant, C.M., McConachie, M., Feldman, A., Spitzer, W., McNamara, E., & Porter, B. (1996). *Technology Infusion and School Change: Perspectives and practices.* Model Schools Partnership research monograph. Cambridge, Mass: TERC (http://ra.terc.edu/alliance/TEMPLATE/alliance_resources /reform/tech-infusion/index.html).
  This paper reviews the work of a TERC research team with U.S. Department of Defense Education Agency schools (funded by the National Science Foundation). TERC was charged with developing, in collaboration with DoDEA schools in Hanau, Germany, a vision of change through technology and an implementation plan for moving toward that vision. In the context of this project, it discusses how technologies can be infused throughout the curriculum and practice of elementary, middle, and secondary schools.

- Hawkins, J., Spielvogel, R., & Panush, E. (1997). *National study tour of district technology integration: Summary report.* New York: Education Development Center, Center for Children and Technology.
  This report draws on case studies of twelve school districts across the country that have made significant investments in instructional technology for at least ten years. Based on these districts' experiences, the report

outlines common themes across the sites and explains how they may be informative to districts attempting to make systemic investments in technology to support education reform.

- Means, B. (Ed). (1994). *Technology and education reform.* San Francisco: Jossey-Bass.
  This book demonstrates how the introduction of new instructional technologies can support and further the efforts of school reform. It provides concrete illustrations from successful programs around the country and looks at the technologies holding the most promise for increasing student learning.

- Pea R.D. (1994). Seeing what we build together: Distributed multimedia learning environments for transformative communications. *Journal of the Learning Sciences, 3*(3), 283–298.
  This article discusses two concepts of communication—transmission and ritual views—and the roles they have played in educational practice. The author then proposes a third model, transformative communication, in which learners are able to build on and extend their knowledge, and it discusses the implications of this kind of communication for the design of collaborative technologies.

- Sabelli, N., & Dede, C. (1998). *Integrating educational research and practice: Reconceptualizing the goals and process of research to improve educational practice.*
  In this paper the authors reflect on what they learned from their experiences as senior Program officers in the Directorate for Education and Human Resources at the National Science Foundation. The authors argue for a taxonomy of research endeavors that highlights crucial education issues currently not studied in a sustained fashion.

- Schofield, J.W. (1995). *Computers and classroom culture.* New York: Cambridge University Press.
  This book seeks to increase our understanding of how the social organization of school and classroom influences the use of computers, and how computer use in turn affects the functioning of classrooms. Through intensive study of a single urban high school, the author explores the implications of computer technology for our schools and examines ways that computer use is shaped by the social context in which it occurs and how attitudinal and organizational barriers obstruct it.

POLICY RESEARCH PAPERS

- Hawkins, J. (1996). *Technology in education: Transitions.* New York: Education Development Center/Center for Children and Technology.
  This paper proposes that important changes are occurring in three dimensions of technology implementation in relation to education: the move from purchasing stand-alone hardware to networked computers for schools; the move from isolated skills practice to tool use as the primary mode of technology application in schools; and the move from inadequate to increased support for teachers learning to use technologies.
- President's Committee of Advisors on Science and Technology, Panel on Educational Technology (1997). *Report to the president on the use of technology to strengthen K–12 education in the United States.* Washington, DC: USGPO.
  This report makes a set of strategic recommendations for shaping research about and investment in educational technology, and reviews past research, current applications of technology, and economic issues related to expanding the technological infrastructure of K-12 schools.
- U.S. Department of Education (1996). *Getting America's students ready for the 21st century: Meeting the technology literacy challenge.* A report to the nation on technology and education. Washington, DC: US. Department of Education (http://www.ed.gov/Technology/Plan/NatTechPlan/).
  This report outlines the rationale for the federal Technology Literacy Challenge, announced in 1996. It reviews past research, outlines the benefits of educational technology use, and discusses strategies for expanding and improving the resources available to schools interesting in making more use of technology.
- McKinsey & Company, Inc. (1995). *Connecting K-12 schools to the information superhighway.* Report to the National Information Infrastructure Advisory Council. Palo Alto, CA: McKinsey & Company, Inc.
  This report outlines the challenges and opportunities involved in connecting all K-12 schools nationwide to the national information infrastructure (NII). It provides in-depth estimates of the costs involved in this effort, as well as emphasizing the importance of sustaining effective leadership and providing substantive professional development to teachers.
- Conte, C. (1997). *The learning connection: Schools in the information age. Report from the Communications Policy and Practice Program.* Washington, DC: Benton Foundation.
  The U.S. investment in wiring schools is at risk unless the human elements

of education keep pace with twenty-first-century technology. This report emphasizes that educators are grappling with the difficult interplay of technological change and educational values. It also identifies key factors that make the connection work and reviews major players in the education technology arena.

- Glennan, T.K., & Melmed, A. (1996). *Fostering the use of educational technology: Elements of a national strategy.* RAND Technical report, document #MR-682-OSTP/ED. Santa Monica, CA: RAND Corporation. The premise of this report is that enlarging the presence of technology in schools offers an important opportunity to a nation seeking improved performance from its schools. The authors draw on previous research done at RAND and elsewhere to identify key elements of national strategy and federal policy that will contribute to effective use of technology by the nation's schools.

Appendix B: Key Academic, Research, and Policy Institutions

Bank Street College of Education

http://www.bnkst.edu/default.html

For more than 80 years, the Bank Street College of Education has been a nationally recognized resource and leader in child-centered education. Bank Street is comprised of a graduate school of education, an elementary school for children, an on-site child care center, a continuing education division, and a publications and media group. Bank Street College develops projects that meet the emerging needs of children and families including: serving homeless families, addressing the issues of substance abuse and HIV/AIDS, and introducing new technologies into the classroom.

Bank Street has formed several major partnerships with schools, school systems, colleges and universities, community-based organizations, publishing companies, corporations, foundations, and television and cable networks. These partnerships have engendered family support and parent education programs; early childhood curriculum and staff development projects; leadership development initiatives; school structure reform; and direct services to children, youth, and families.

BBN: Bolt, Beranek, and Newman, Inc.

www.bbn.com

In the field of education technology, BBN Technologies offers a variety of research, development, and consulting services, primarily to government organizations such as the National Institute of Health and the National Science Foundation, as well as to public and private educational institutions. BBN coordinates and conducts research around several major research and development initiatives related to technology and education. Two examples are described below.

- Co-NECT
  http://co-nect.bbn.com

  Developed by BBN, the Co-NECT school design (Cooperative Networked Educational Community for Tomorrow) is a model for innovative schooling that provides schools with a framework for restructuring their educational environment. In support of these efforts, the Co-NECT organization helps K–12 educators use technology for whole-school change and improved academic results. The project works with schools and districts prepared to make serious investments in technology and professional development for the sake of improved teacher and student performance. This approach also emphasizes the school as the key level of organization for reform and accountability. The Co-NECT project has worked with

schools in Juneau, Alaska; Dade County, Florida; Memphis, Tennessee; Hammond, Indiana; and Worcester, Massachusetts.

- National School Network
  http://nsn.bbn.com/

  The National School Network (NSN) is a broad partnership of educators coming together to address the challenge of Vice President Al Gore "to connect all of our classrooms, all of our libraries, and all of our hospitals and clinics [to the National Information Infrastructure (NII)] by the year 2000." Organized in 1992 by the Educational Technologies Group at BBN Corporation, NSN seeks to develop and implement tools, information services, technology, and support for a national network of local learning communities.

Benton Foundation
http://www.benton.org

The Benton Foundation works to realize the social benefits made possible by the public-interest use of communications. Bridging the worlds of philanthropy, public policy, and community action, Benton seeks to shape the emerging communications environment and to demonstrate the value of communications for solving social problems. Through demonstration projects, media production and publishing, research, conferences, and grantmaking, Benton probes relationships between the public, corporate, and nonprofit sectors to address critical questions for democracy in the information age.

The Center for Highly Interactive Computing in Education
http://hi-ce.eecs.umich.edu/

The Center for Highly Interactive Computing in Education (Hi-CE) is an interdisciplinary group of faculty, staff, and students at the University of Michigan, assembled to develop learner-centered software tools and curricula founded on the pedagogy of inquiry, or project-based science. Hi-CE collaborates with teachers and administrators to integrate technology into K–12 classrooms throughout the Detroit and Ann Arbor Public Schools.

Center for Technology Innovations in Education
http://www.ctie.missouri.edu/

The Center for Technology Innovations in Education (CTIE) conducts research to improve teaching and learning through innovations in technology. Established in 1995 at the University of Missouri–Columbia, CTIE focuses on the integration of technology with mathematics and science education.

The Computer as Learning Partner
http://clp.berkeley.edu/CLP/

The Computer as Learning Partner (CLP) project is an ongoing educational research effort at the School of Education at the University of California at Berkeley. The project is dedicated to informing and improving middle school science instruction.

The Concord Consortium
http://www.concord.org/

The Concord Consortium is a nonprofit, educational research and development organization launched in 1994 by educators in Concord, Massachusetts. The heart of the consortium is the Educational Technology Lab, a state-of-the-art facility created to develop an intellectually rich lab environment that fosters creativity and experimentation, as well as innovative, responsive, and cost-effective solutions to pressing educational problems.

Education Development Center/Center for Children and Technology
http://www.edc.org/CCT/

The EDC Center for Children and Technology was founded at Bank Street College of Education in 1981 and changed its affiliation in 1993 to become a division of Education Development Center, Inc. The Center's aims is to improve education by altering the circumstances of teaching and learning; it conducts basic, applied, and formative research as well as technology development. Much of CCT's work is done in collaboration with schools, universities, libraries, community programs, museums, and other institutions concerned with learning, teaching, and technology design.

The Exploratorium
www.exploratorium.edu

The Exploratorium is a science museum and one of the first museums in the nation to bring children into hands-on contact with the world of science. The Exploratorium contributes to improving science education by acting as a center for exhibit-based public education, assuming a leading role for science learning and teacher training, and becoming a center for interactions between science and the media. To accomplish these goals, the Exploratorium supports three centers within the museum: the Center for Public Exhibition, the Center for Teaching and Learning, and the Center for Media and Communication.

Georgia Institute of Technology College of Computing
http://www.cc.gatech.edu/index.html

The GIT College of Computing is a graduate school dedicated to advancing the state of the art of computer science and related disciplines as well as to working actively with researchers and practitioners in a variety of fields to help advance their areas. Several GIT/COC projects are specifically concerned with advancing the design and implementation of innovative educational technologies.

- "Classroom 2000"
  http://www.cc.gatech.edu/fce/c2000/

  Classroom 2000, a project created by the Future Computing Environments group at the Georgia Institute of Technology aims to study the impact of technology on improving education, as well as the design and impact of ubiquitous computing–an attempt to replace the traditional desktop model with a computer-based environment.

- EduTech Institute
  http://www.cc.gatech.edu/edutech/

  The EduTech Institute is a multidisciplinary research organization committed to enhancing science, math, and design education through innovative uses of technology. Based at the Georgia Institute of Technology, it intends to create rich environments for learning, both embodied and virtual, for middle school science and math students.

- Graphics, Visualization and Usability Center
  http://www.cc.gatech.edu/gvu/

  Housed in the College of Computing at the Georgia Institute of Technology, the Graphics, Visualization and Usability Center (GVU) is an interdisciplinary project focused on inventing and teaching principles and technologies that, by making computers ubiquitous, more useful, and easy to use, make individuals and organizations more effective in many important professional, scholastic, and private activities.

IBM International Foundation
http://www.ibm.com/IBM/IBMGives/IIF/ibmfndtn.htm

The IBM International Foundation has become an integral part of the IBM Corporation's contributions effort, both in the United States and worldwide. The foundation's charter, once limited to South Africa, was expanded in 1992 and now encompasses major worldwide initiatives.

In the United States, these include the foundation's cash Matching Grants Program and annual general support grants to nonprofit organizations addressing societal needs in the areas of education, health, human services, arts and culture, and public policy research, as well as support of the under-represented. Worldwide contributions include grants in Africa, Europe, and Asia, as well as global initiatives in environmental research, total quality management, job training, and management development.

The foundation plans to continue to support these programs while focusing on education as its primary issue. The use of leading-edge technology will be incorporated, wherever possible, in all foundation strategies and initiatives.

Institute for Learning Technologies

http://www.ilt.columbia.edu/ilt/

Founded in 1986 at Teachers College, Columbia University, the Institute for Learning Technologies (ILT) works to advance the role of computers and other information technologies in education and society. In particular, the institute seeks to implement constructivist-based multimedia and network technologies to create sophisticated learning environments, to sponsor exploratory development and participatory design efforts in order to discover the academic potentials of emerging technologies, and to sustain public policy initiatives that mobilize broad coalitions of interested parties from academe, government, and industry in order to transform education.

Institute for Research on Learning

http://www.irl.org/

The Institute for Research on Learning (IRL) was founded in 1987 as a response to the escalating learning crisis in the United States. IRL's mandate to "rethink learning" addresses the root cause of this crisis—a limited understanding of successful everyday learning. IRL's research-in-action approach moves beyond thinking to doing—to a set of tools, methods, and technologies that help bring about effective change.

IRL's ultimate goal is to create environments in which people can realize their full potential for learning. The center builds its work on a set of "core capabilities" that are based on the knowledge and skills of its multidisciplinary research team.

Learning Research and Development Center

http://alan.lrdc.pitt.edu:80/lrdc/

Founded in 1963 at the University of Pittsburgh, the Learning Research and Development Center (LRDC) probes the nature of thinking, knowing, and understanding in and beyond school. In particular, LRDC is interested in the ways in which multimedia and artificial intelligence technologies can produce powerful tools both for learning and for further investigations of learning.

Learning Technology Center
http://peabody.vanderbilt.edu/ltc/general/

The Learning Technology Center (LTC) at Vanderbilt University is a collaborative, multidisciplinary group working on technology in education. Members of the LTC are currently working on a variety of projects in the areas of mathematics, science, social studies, and literacy.

MIT Media Lab
http://www.media.mit.edu/

MIT's Media Laboratory, founded in 1985, conducts advanced research into a broad range of information technologies, including digital television, holographic imaging, computer music, computer vision, electronic publishing, artificial intelligence, human-machine interface design, and education-related technologies. The Media Lab's charter is to invent and creatively exploit new media for human well-being and individual satisfaction without regard to present-day constraints. The lab employs supercomputers and a range of input/output devices to experiment today with notions that will be commonplace tomorrow. The not-so-hidden agenda is to drive technological inventions and break engineering deadlocks with new perspectives and demanding applications.

National Center for Supercomputing Applications
www.ncsa.uiuc.edu/Edu/

The Education Division of NCSA expects to shape the way people of all ages benefit from education by transforming current practices–using imagination, scientific inquiry, and emerging computational technology–to enable them to participate in and contribute to emerging education technology applications.

Northwestern University
www.nwu.edu

Two graduate programs at Northwestern University work to design cutting-edge educational technologies and to study the social and educational issues related to the implementation of technologies in schools.

- Learning Sciences at the School of Education and Social Policy
  http://www.ls.sesp.nwu.edu/projects.html

  The Learning Sciences program is dedicated to advancing the scientific understanding and the practice of teaching and learning. The program is interdisciplinary and focuses on understanding and improving learning environments—not only in schools and classrooms but also in homes,

neighborhoods, and work environments. Research projects focus on developing and studying pedagogical, technological, and social policy innovations aimed at improving education. The design of technology plays a special role in the program, exploring ways that technological innovations can facilitate new cognitive and social roles for students and teachers.

- Institute for the Learning Sciences
  http://www.ils.nwu.edu/

  Established in 1989 and based at Northwestern University, the Institute for the Learning Sciences (ILS) is an interdisciplinary research and development center dedicated to developing innovative educational technology that enables children and adults to develop relevant, real-world skills as they learn by doing.

Ontario Institute for Studies in Education (OISE) at the University of Toronto
http://www.oise.utoronto.ca/

OISE is Canada's leading educational institution dedicated to the establishment of a learning society, through immersing itself in the world of applied problem solving and expanding the knowledge and capacities of individuals to lead productive lives. OISE/UT is committed to the study of education and matters related to education in a societal context in which learning is a lifelong activity. Its mission emphasizes equity and access and the improvement of the educational experiences of people of all age levels and backgrounds. The CSILE project is one of OISE's best-known research and development projects related to educational technology.

- CSILE Computer Supported Intentional Learning Environments
  http://csile.oise.on.ca/default.html

  After more than two decades, cognitive science (the study of how people think, learn, and remember) has reached a point where it generates approaches to teaching and learning that are both practical and effective. One basic finding confirmed in countless studies is that learning results from thinking. When students actively try to make sense of what they are learning, they understand it better, remember it better, and can even use it to solve new problems. And so, whatever the subject, research tells us that the goal is to encourage students to reach a genuine understanding that goes well beyond rote memorization. CSILE is a program designed to help students achieve extraordinary learning by providing supports for thinking and understanding.

The Regional Educational Laboratories
http://www.nwrel.org/national/

There are ten Regional Educational Laboratories, not-for-profit educational research and development organizations supported by contracts with the U.S. Department of Education, Office of Educational Research and Improvement (OERI). The laboratories are dedicated to helping schools—and the students they serve—reach their full potential. The regional laboratory network includes the following organizations, among others:

- North Central Regional Educational Laboratory
  http://www.ncrel.org/

  NCREL provides research-based resources and assistance to educators, policymakers, and communities in Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio, and Wisconsin. Its Midwest region is home to more than 20 percent of the nation's schools, teachers, and students. NCREL's ultimate goal is to help its clients apply proven practices to create productive schools where all students can develop their skills and abilities. It draws on the latest research and best practices to strengthen and support schools and communities in order to make this goal a reality.

- Northwest Regional Educational Laboratory
  http://www.nwrel.org/

  The mission of NWREL is to improve educational results for children, youth, and adults by providing research and development assistance in delivering equitable, high-quality educational programs. NWREL provides research and development assistance to education, government, community agencies, business, and labor, serving primarily the northwestern region of Alaska, Idaho, Montana, Oregon, and Washington.

- WestEd
  http://www.wested.org/

  WestEd is a research, development, and service agency dedicated to improving education and other opportunities for children, youth, and adults. Drawing on the best from research and practice, it works with practitioners and policymakers to address critical issues in education and other related areas: from early childhood intervention to school-to-work transition, and from curriculum, instruction, and assessment to safe schools and communities. WestEd was created in 1995 to unite and enhance the capacity of the Far West Laboratory and Southwest Regional Laboratory, two of the nation's original educational laboratories created by Congress in 1966. In addition to its work across the nation, WestEd serves as the regional

education laboratory for Arizona, California, Nevada, and Utah. Its headquarters are in San Francisco, with additional offices in Arizona, Massachusetts, Washington, DC, and elsewhere in California.

Rockman ET AL
http://www.rockman.com/

Rockman ET AL is an independent research and consulting firm, specializing in the application of technology to meet educational and business learning needs. The company provides research, evaluation, and policy development consulting for clients including corporations, educational organizations, and state and federal agencies. Saul Rockman, the company's president, has focused his career on studying the appropriate, effective uses of technology for learning in educational settings, businesses, and homes.

Stanford Research International, Center for Learning Technologies
http://www.sri.com/policy/teched/

From its earliest days, education research has been an integral part of SRI International's mission. After an early start in the 1980s, it became very clear that technology was to play an increasingly significant role in the education of children, youth, and adults. In recognition of this trend, SRI broadened its research to include the use of technologies in education. By the early 1990s, the issues of how to effectively use technologies to support learning were considered to be so important that the Center for Technology in Learning (CTL) was established at SRI. The Center was established within SRI's Policy Division, where it is closely allied with ongoing education and health research programs.

Technical Education Research Center
http://www.terc.edu/

TERC is a nonprofit research and development organization committed to improving mathematics and science learning and teaching. Founded in 1965, TERC is internationally recognized for creating innovative curricula, fostering teachers' professional development, pioneering creative uses of technology in education, contributing to educators' understanding of learning and teaching, and developing equitable opportunities for underserved learners.

University of Illinois College of Education

http://www.ed.uiuc.edu/ or
http://www.ed.uiuc.edu/tlp/

The College of Education at the University of Illinois has pursued a number of research and implementation projects related to the creation of a technology-rich teacher-training program. The Technologies for Learning program is a graduate specialization focusing on new technologies for learning, cross-cutting the many departments and disciplines represented across the university. Current projects include a collaboration with other Illinois universities called Preparing Illinois Educators for the 21st Century, intended to demonstrate approaches within Illinois institutions for preparing teachers and administrators to be the leaders and visionaries for the education of future generations.

University of Indiana School of Education

http://education.indiana.edu/~disted/

The Distance Education Program at the University of Indiana is a leading example of a large university using distance-learning technologies to support pre-service teacher education. Fully accredited coursework is delivered via the Internet and two-way interactive video on topics ranging across the elementary and secondary curricula. Distance-learning courses can be credited toward master's degrees at the University of Indiana or at other institutions.

University of Michigan School of Education

http://soe.umich.edu/ or
http://www.soe.umich.edu/research/index.html

The School of Education's primary mission is to improve learning and teaching at all levels of education by preparing highly talented individuals for the education professions, by advancing knowledge about education, and by improving educational practice. Because it is situated in a premier research university, one of the central ways the school performs its mission is by maintaining an active program of research and scholarship.

Faculty are currently working in many areas of educational inquiry. They are pioneering research on alternative forms of educational assessment; developing new approaches to teaching in the content areas, including approaches that rely heavily on new education technologies; conducting important research on the organization and restructuring of schools and colleges to promote higher academic achievement and better social development for students; and designing and analyzing education policies at the local, state, and federal levels.

University of Northern Iowa
http://www.uni.edu/teachctr/

The Center for the Enhancement of Teaching at the University of Northern Iowa is investing significant resources in documenting and exploring how the Iowa Communications Network—a statewide fiber-optic system linking universities and K–12 schools—can be used to support distance-learning opportunities for pre-service teachers.

University of Virginia Curry School of Education
http://curry.edschool.virginia.edu/

The Curry School has integrated educational technologies into almost every discipline within the school. The school has been particularly recognized for its efforts to integrate technology into its teacher education program. The Curry School also offers a graduate degree in instructional technology.

Appendix C: Key Individuals

- John Bransford
  Co-Director, Learning Technology Center, Vanderbilt University
- Allan Collins
  Professor of Education and Social Policy, Northwestern University
- Chris Dede
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- Barbara Means
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- Roy Pea
  Director, Center for Technology in Learning at SRI International
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- Margaret Riel
  Associate Director, Center for Collaborative Research in Education (CCRE), University of California at Irvine
- Nora Sabelli
  Senior Program Officer, Directorate for Education and Human Resources, Division of Research, Evaluation, and Communication
- Marlene Scardamalia
  Professor, Centre for Applied Cognitive Science and Department of Curriculum, Teaching, and Learning, University of Toronto
- Elliot Soloway
  Professor of Electrical Engineering and Computer Science, University of Michigan
- Robert Tinker
  Chairman, The Concord Consortium

Appendix D: Other Organizations to Contact for More Information

American Institutes for Research
http://www.air.org/

Founded in 1946 by John C. Flanagan, the American Institutes for Research (AIR) is an independent, not-for-profit corporation that performs basic and applied research, provides technical support, and conducts analyses in the behavioral and social sciences. Its clients include federal and state government agencies, not-for-profit organizations, and private corporations, both in the United States and abroad.

AIR's research program currently encompasses these subject areas: human performance, education (education reform and assessment, education finance, adult education, international and comparative education, postsecondary education, special education, education statistics, and special education finance), child development, program planning and implementation, program evaluation, statistical methods, usability engineering, community research, and employment equity.

American Library Association
http://www.ala.org/

The American Library Association provides leadership for the development, promotion, and improvement of library and information services and the profession of librarianship in order to enhance learning and ensure access to information for all. Core values of the ALA include diversity, education, and continuous learning, equity of access, intellectual freedom, and 21st-century literacy. The ALA works in areas including advocacy for libraries, provision of awards, grants, and scholarships to libraries and librarians, technology, censorship, copyright and intellectual property, and community outreach.

Center for Media Education
http://www.cme.org/cme/

The Center for Media Education (CME) is a national nonprofit organization dedicated to improving the quality of the electronic media. CME fosters telecommunications policy making in the public interest through its research, advocacy, public education, and press activities.

Founded in 1991 to carry on the work of Action for Children's Television, CME's primary focus is on children. At the national and state levels, CME is working with education, library, and child advocacy organizations to expand the access of poor and minority children to new educational technologies in school and at home. CME is partnering with several state child-advocacy groups in campaigns to promote

telecommunications policies on behalf of children and disadvantaged families.

Council of Chief State School Officers
http://www.ccsso.org/index5.htm

The Council of Chief State School Officers (CCSSO) is a nationwide, nonprofit organization composed of the public officials who head departments of elementary and secondary education in the states, the District of Columbia, the U.S. Department of Defense Education Activity, and five extra-state jurisdictions. CCSSO seeks its members' consensus on major educational issues and expresses their view to civic and professional organizations, federal agencies, Congress, and the public. Through its task forces and committees, the council advances major education initiatives and addresses a range of concerns about education.

In representing the chief education administrators, CCSSO has access to the educational and governmental leaders in each state and organizes national influence on education issues. CCSSO forms coalitions with many other education organizations and is able to provide leadership for a variety of policy concerns that affect elementary and secondary education. CCSSO members act cooperatively on matters vital to the education of all students in the United States.

Education Commission of the States
http://www.ecs.org

The mission of the Education Commission of the States is to help state leaders identify, develop, and implement public policy for education that addresses current and future needs of a learning society. For 33 years, ECS has been the only major education organization that does not serve a particular special-interest group, reaching out to thousands of people in literally every state, role group, level of education, and major education organization. A combination of direct person-to-person contact, program and project work, group assistance through meetings, and public visibility through communications work enables ECS to stay on the cutting edge of education issues and provide continuing assistance to constituents. It also makes ECS uniquely qualified to help policymakers change their K–12 and postsecondary education systems to better serve the needs of all students.

National Center for Education Statistics (NCES)
http://nces.ed.gov/

The National Center for Education Statistics (NCES) is the primary federal entity for collecting and analyzing data related to education in the United States and other nations. NCES fulfills a congressional mandate to collect, collate, analyze, and report complete statistics on the condition of American education; conduct and publish reports; and review and report on education activities internationally.

National Education Association
http://www.afj.org/mem/nea.html

The National Education Association was founded in 1857 to elevate the character and advance the interests of the profession of teaching and to promote the cause of education in the United States. Members include elementary and secondary teachers, higher education faculty, educational support personnel, retired educators, and students preparing to become teachers.

National Foundation for the Improvement of Education (part of the National Education Association)
http://www.nfie.org/

NFIE's mission is to promote excellence in teaching and learning. NFIE carries out this mission by providing teachers, other school employees, and higher education faculty and staff with opportunities to develop and test solutions to the challenges facing American public education. These opportunities include grants, technical assistance, professional collaboration, conferences, institutes, electronic networking, and support for developing leadership roles.

Participants in NFIE's programs have produced substantial results in hundreds of schools and many higher education institutions all over the United States. Through briefings, reports, outreach, and the media, NFIE informs educators, education policymakers, and the public about the effective projects and practices it has supported.

National School Boards Association
http://www.nsba.org/

The National School Boards Foundation, a division of the NSBA, encourages and prepares local school board members to become catalysts for educational change and agents for systemic reform in the public schools so that all students will be prepared to meet the challenges of tomorrow. Its innovative projects are designed to help school boards meet today's challenges while strengthening the uniquely American tradition of local representative governance of the public schools.

The foundation has three long-term goals:

- To design and implement innovative programs that give school boards the tools to change and improve their school districts.
- To forge new partnerships with other organizations in order to involve school boards in discussing and implementing changes that will improve student achievement.
- To help school boards learn from the successes and failures of other school boards across the country.

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