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Using Information Technology

To Transform the Way We Learn

February 9, 2001

A report from the

President's Information Technology Advisory Committee

Using Information Technology To Transform the Way We Learn

A Vision of Learning Transformed by Information Technologies

Any individual can participate in online education programs regardless of geographic location, age, physical limitation, or personal schedule. Everyone can access repositories of educational materials, easily recalling past lessons, updating skills, or selecting from among different teaching methods in order to discover the most effective ways of learning. Educational programs can be customized to each individual's needs, so that the information revolution reaches everyone and personal digital libraries provide a mechanism for managing one's accumulated knowledge resources. Learning involves all our senses, to help focus each student's attention and better communicate educational material.

Information Technology Research: Investing in Our Future, PITAC Report, February 1999

Introduction

Lifelong education and training are foundations of the modern democratic state and the 21st century economy. Education and training consistently rank among the top concerns of U.S. industry and citizens at large. While the best U.S. educational and training facilities and processes are among the world's greatest, the variance in access and results over the entire enterprise is too great – median results are too low, the low end is far too low, and too many learners drop out of the K-12 system. There is unremitting pressure to improve U.S. education and training for all citizens, at all ages, in all circumstances. With the additional challenges this pressure places on the educational community come significant opportunities.

Information technology can help significantly. Information technology has been progressing at an awesome pace, with many advances seeded by sustained, long-term, and farsighted Federal government research investments over the past six decades. Increasingly, we can use information technology to organize and deliver information over long distances, in ways that adapt to different learners and contexts, to simulate real-world processes, and to foster distributed communities of learners. These uses evidence the promise that information technology can improve the efficiency and effectiveness of teaching and learning across the U.S. education and training enterprise in revolutionary ways. Information technology can enable a cultural shift in which all citizens will be linked to education throughout our lives. This report proposes that the Federal government – in concert with state and local governments, universities, foundations, and industry – act at once to realize that promise.

Much attention today is focused on providing widespread access to current information technologies, such as personal computers with access to the Internet. Providing access is necessary for progress but not sufficient. As a first step, increased attention needs to be paid to providing adequate software, training, and support for integrating technologies into the practices of learning and education. For the long term, though, a great deal of research into and development of technologies, methods, and measurement methodologies are required to ensure continuous improvements in technology-enhanced learning.

Previous PITAC Efforts That Led to this Study

In *Information Technology Research: Investing in Our Future*, its 1999 report to the President, the President's Information Technology Advisory Committee articulated a vision of the ways information technology will drive progress in the 21st century. The Committee identified 10 vital areas of our national life in which information technology offers the potential to dramatically transform current practices in ways that will greatly benefit all citizens. The report described the promise in these key areas and outlined the technical challenges that must be overcome to realize the desirable societal transformations enabled by information technology and to reap the resulting public benefits.

Among those areas is the way we learn. In its report the Committee said:

> *Information technology is already changing how we teach, learn, and conduct research, but important research challenges in the field of education remain. In addition to research to meet the scalability and reliability requirements for information infrastructure, improvements are needed in the software technologies to enable development of educational materials quickly and easily and to support their modification and maintenance. We know too little about the best ways to use computing and communications technology for effective teaching and learning, in particular, how to effectively use multimedia capabilities to create a richer, and more appealing learning experience. We need to better understand what aspects of learning can be effectively facilitated by technology and which aspects require traditional classroom interactions with the accompanying social and interactive contexts. We also need to determine the best ways to teach our citizens the powers and limitations of the new technologies and how to use these technologies effectively in their personal and professional lives.*

As a follow-up to its report, the PITAC established a group of panels to examine the transformations' challenges in greater depth and make recommendations for addressing them to the President and Congress. This document details the findings and recommendations of the Transforming Learning Panel, co-chaired by PITAC members Susan L. Graham and Andrew J. Viterbi.

Scope, Focus, and Approach

This report covers both education and training – pre-kindergarten, K-12, university, professional, adult, community, military, government, and industrial. While these settings differ in many ways, information technology is adaptable to all of them, and much of the required information technology research is applicable throughout that spectrum. Education and training are both forms of learning; the distinction between education and training is based on differences in the relative importance of certain objectives and the different institutional contexts for pursuing them. Information technology is applicable to both education and training, but the objectives and learning styles of the students in every instance determine the appropriate blend of information technology solutions and the types of further research and development that are needed. One of the most desired outcomes and profound challenges of research in this field is that the resulting education and training applications will be localizable to different settings, cultures, student capabilities, teacher objectives, local standards, etc.

Although the report's scope is broad, it focuses on the technological aspects of education and training and actions needed to make educational and training technology useful. Thus, it does not address research into childhood cognitive development, theories of learning and pedagogy, and the like, even though these are very important in the larger context. The PITAC suspects that, as with most technologies, scientific understanding of why certain information technology education and training technologies and methods do or do not work will be solidified only after the technologies have been developed, used, and evaluated. As with technologies more broadly, the greatest utility and marketplace success will be gained by involving user communities in identifying needs and in the design and improvement of the technologies.

To conduct its study, the Learning Panel met with researchers, visionaries, practitioners, teachers, and commercial deliverers of online education and training. With the help of the San Diego Science and Technology Council and the University of California, San Diego, the Panel held a workshop in San Diego July 17-18, 2000, and there were several Panel meetings from December 1999 through September 2000.

This report assumes the reader is familiar with the need for improvements in learning throughout our education and training systems and with the increasing requirement for lifelong learning to adapt to changing circumstances. It does not attempt to analyze the state of education and training in the U.S., a well-documented topic. The report has a narrower focus than the study conducted by the Web-Based Education Commission chaired by then -Senator Bob Kerrey of Nebraska, which released its findings to the Congress, President, and Nation on December 19, 2000, in "The Power of the Internet for Learning: Moving from Promise to Practice" (http://www.webcommission.org). The Commission, composed of 16 members who were selected by the President, Secretary of Education, and congressional leadership, conducted a detailed study of the critical pedagogical and policy issues affecting the development and use of Web-based content and learning strategies to improve achievement at the K-12 and postsecondary levels.

Findings

Information technology is just part of the solution to the Nation's education and training requirements. The following findings and recommendations do not address the entire span of productive educational reforms that might be envisioned, but they do extend beyond information technology *per se*. That should not be surprising since industrial experience over the last two decades demonstrates that successful information technology-assisted process improvement almost always requires that information technology be coupled with a careful rethinking of the targeted processes and social institutions.

Overarching Finding

Education and training of all citizens throughout their lives is one of our most important national goals. Information technology promises to play a significant role in empowering teachers and learners.

Improving the reach and effectiveness of education and training are critical to the solution of many societal problems. This is what makes addressing education and training issues so vital for the Nation. Although many people have recognized that information technologies can be used to facilitate education and training, there is a huge gap between the potential of using information technologies for that purpose and the accomplishments. Information technology accomplishments in education and training lag those in other areas, whether in research, commerce, or communications. It is hard to find another application area of information technology where the promise-to-performance gap is wider, and some assert the gap is widening. The barriers that continue to prevent the realization of the promise must be addressed by large-scale, aggressively managed methodological and technological research and development as well as increased opportunities for teacher education. The information technologies that emerge from this research and are put into use through deployment vehicles such as teacher education will enable both incremental and revolutionary improvements. Seven specific findings follow.

Finding: Information technology, used both within classroom settings with well-educated and motivated teachers and by individuals, can provide access to world-class facilities and experiences. It has the potential for simultaneously providing many of the benefits of one-on-one tutoring and group interactions.

Information technology provides intellectual advantage much as industrial machines provide mechanical advantage. The Panel envisions environments where students guided by mentoring teachers actively pursue their education. Fully automated learning and the substantial diminution of the need for teachers are not on the horizon, nor should they be. The critical roles of teachers and group learning need to be better understood to maximize the benefits of integrating information technologies into the teaching and learning process. These basic ideas guided the Panel's thinking about the required research agenda and associated initiatives.

One striking advantage of technology-enhanced education and training, already being realized in the research world, is that online students can have access to distant world-class facilities such as telescopes, electron microscopes, undersea laboratories, and university and government libraries. Access can be provided to real devices or simulated ones, as appropriate for cost, flexibility, or safety reasons. Group interactions can be enhanced through cooperative learning with students at distant locales and experts at workplaces to which students otherwise would not have access. Teachers also benefit from enhanced cooperation with others; they can share lesson plans, learn how to implement higher learning standards, develop cooperative projects, and also learn from experts in various fields. Simulations can be used for experimentation that would be unaffordable or unsafe if implemented in the physical setting.

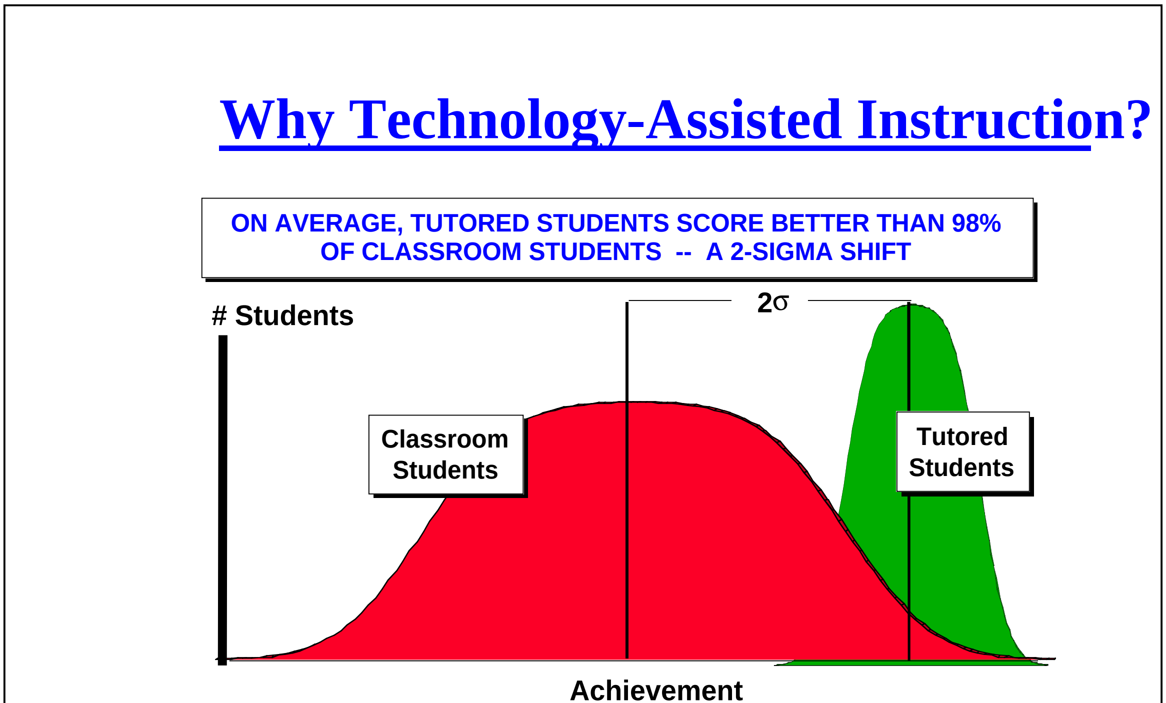

Figure 1 The effect of one-on-one tutoring

In certain circumstances, one-on-one tutoring has been found to benefit instruction, improving the mean of student performance by two standard deviations (2σ) with an accompanying reduction in variance (or spread).[1] (See Figure 1.[2]) This benefit is roughly equivalent to raising the achievement of 50th percentile students to the 98th percentile level. Other research has demonstrated the importance of group interactions in the absorption of knowledge. Gibbons, for example, has found that students who viewed videotaped university-level lectures in an active discussion group performed half a grade-level better than those who attended the lectures in person.[3] Since one-on-one tutoring is unaffordable in most cases, our goal should be to use new methods and technologies to achieve similar results at reasonable cost while at the same time realizing the benefits of group interactions (perhaps over long distances).[4]

In a study of studies covering a wide range of contexts, Fletcher reports:

> We found significant improvements in knowledge and skills gained through the use of technology-based instruction. We are not yet at the 2 standard deviation, or ‘2 sigma’ level, but we have found across 233 assessments that computer-based instruction produced an improvement of 0.39 sigma

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[1] Bloom, B. S. (1984) The 2-sigma problem: The search for methods of group instruction as effective as one-to-one tutoring. *Educational Researcher*, 13 (6), pp. 4-16.

[2] Fletcher, J. D. "Defense Training and the Advanced Distributed Learning (ADL) Initiative," presentation to the PITAC Workshop on Transforming Learning, San Diego, July 17, 2000.

[3] Reported in Brown, J. S., "Growing up Digital," *Change* March/April 2000, p. 13, at http://www.aahe.org/change/digital.pdf .

[4] One-on-one tutoring and evaluation are used where learning performance is deemed critical. For example, in driver and pilot training where societal safety is a concern, one-on-one tutoring and evaluation are required and found affordable. In pilot training, at least for military and commercial pilots, information technology, in the form of flight simulators, has been used for many years as a supplement in order to increase effectiveness and decrease costs. But in no instance is a student allowed a license without one-on-one evaluation by an instructor.

(roughly raising achievement from the 50th percentile level to the 65th percentile), 44 assessments of interactive multimedia instruction produced an improvement of 0.50 sigma (roughly raising achievement from the 50th percentile level to the 69th percentile), and 5 assessments of some recent intelligent tutoring systems that directly mimic one-on-one instruction produced an improvement of 1.05 sigma (roughly raising achievement from the 50th percentile level to the 85th percentile).[5]

Finding: The role of the teacher is changing and will continue to change, but current teacher education and training in the methods of using technology and its potential are insufficient.

Some of the most successful teachers use information technology in concert with a shift in the teacher's role from lecturer to mentor of student learning through inquiry. The main idea is to encourage students to learn by finding information about assigned subjects and to encourage them to piece together the information in some well-structured way that can be reported and discussed with the class. In this way, the student actively constructs an ordered view of the information in his or her mind that tends to be remembered and understood better than information absorbed through passive listening. The teacher's role here is to structure the sequence of assignments, help the student find and understand the information, help the student piece the information together, perhaps establishing a larger context, promote discussion, evaluate results, and redirect as needed. In some cases, teachers have built Web sites for students to explore, often with links to outside materials. Such student inquiries are often conducted in collaborative groups. The learning skills developed by these students form a basis for independent lifelong learning.

Current teacher education is inadequate for the promotion of such methods. The Department of Education reports that in 1999 only one-third of teachers reported feeling well-prepared or very well prepared to use computers and the Internet for classroom instruction.[6] Substantially agreeing with the Department of Education, Market Data Retrieval[7] (MDR) found that more than 60 percent of K-12 teachers are uncomfortable integrating technology into the classroom. One might hope that this is a generational problem being taken care of in the education of new teachers, but the MDR report suggests otherwise. It states that only one-third of new teachers reported that their college experience left them “very well prepared” or “well prepared” to integrate technology into classroom instruction. And, perhaps due to emerging teacher shortages, school districts are not requiring new teachers to be proficient in information technology. Nor do certification authorities generally include information technology competence in their criteria. Even if school districts and teacher certification criteria were to require the ability to use information technology in teaching, adequate performance measures have not been developed for either the technologies themselves or for teachers' use of them.

Even though the nation's schools need more information technology-fluent teachers, it is not clear that the educational system can compete effectively with industry and commerce in attracting them. Statistics on the well-documented shortage of information technology professionals, for example, do not include K-12 teachers since teaching is not classified as an information technology profession. However, many people who might otherwise be qualified to become information technology-fluent teachers can also train to enter the information technology workforce where opportunities are plentiful, salaries are higher, and future career opportunities more plentiful and varied. Other professions also compete with school systems for the brightest college graduates, and it seems that over the past several decades, the other professions have won.

It appears that a shortage of teachers is rapidly approaching.[8,9], with 1.7 million to 2.7 million new public teachers needed by 2008[10]. Even though the PITAC feels that information technology is primarily an

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[5] Fletcher, op. cit.

[6] U.S. Dept. of Education, Office of Educational Research and Improvement, *Teachers' Tools for the 21st Century*, September 2000. http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2000102

[7] Market Data Retrieval, Press Release, at http://www.schooldata.com/pr19.html, September 17, 1999.

[8] Van Moorlehem, T., “Recruiters are wary of a teacher shortage: School districts forced to hire fast and early,” *Detroit Free Press*, May 19, 1999, also at http://www.freep.com/news/education/qshort19.htm .

[9] Yasin, S., “The Supply and Demand of Elementary and Secondary School Teachers in the United States. ERIC Digest”, December 1999, at http://www.ed.gov/databases/ERIC_Digests/ed436529.html .

effective tool for well-trained, supported, and motivated teachers to use, it may turn out that information technology can make teachers more efficient in aggregate. One way in which information technology can do so is by increasing the sharing of materials, approaches, methods, and lessons learned.

In the K-12 context, many observers feel it is important to engage parents more in their children's learning. The combination of increased information technology use in classroom settings and the desire to increase parent involvement suggest that there is a need to train parents better in learning technologies and to provide parents better access to the technologies. Shared use of information technology can also lead to closer and more frequent communication between teacher and parent, for example, by providing a protected Web page summarizing each student's progress and areas for improvement. But the home is also a realm in which the US Department of Commerce has documented a significant “digital divide” in parent and student access to computing and the Internet, as a function of income level, educational level, race and ethnic origins, among other variables, that has become a focus of social policy concern[11].

Finding: Information technology has been applied successfully in industrial and military training contexts: it has been effective and reduced costs. In the military context alone, cost, effectiveness, and productivity improvements due to increased use of information technology in training could save hundreds of millions of dollars per year.

Information technology has been successful in military and industrial training. For example, 65 studies since the 1960's have shown an average of over 30 percent savings – attributable to information technology-assisted training – in the time students take to achieve mastery over various subjects. Achieving 30 percent time savings with 60 percent of military specialized skills students (such as for vehicle mechanics, electronics repair, and radar operation, but not pilot or recruit training) could save about $789 million per year, not counting ancillary savings such as reduced travel and increased use of simulated equipment.[12]

Finding: Current research demonstrates the potential for fundamental transformation in education and training.

Today's Web and computer technologies make possible a good start on exciting new hypermedia-based educational content, but the best may be yet to come. Limitations in technology and our inexperience in taking advantage of what is essentially a new medium have led to content that is largely evolutionary, a revamping of existing materials and traditional means of delivery. Thus we find, for example, streaming video of classroom lectures, perhaps embedded in a Web context of indices and supporting materials, replacing or supplementing live lectures and textbooks, and online chat between learners and instructors replacing or supplementing classroom interaction. While useful and likely to be profitable for the schools, startup companies, and university projects delivering such materials, these are near-term and transitional means for e-learning. Expected improvements in technology hold the promise of dramatic, paradigm-shifting ways of making far more ambitious content available and having new forms of communication and collaboration between learners and instructors that may make today's practices obsolete. The goal is to combine the best of human and machine teaching and mentoring capabilities while providing access to capabilities not available locally, not to eliminate the human element.

Examples of what we may expect in the future include far greater reliance on distributed learning communities, intelligent tutoring systems that model subject matter as well as learners and their preconceptions, families of interoperable, simulation-based “clip models,” collaborative learning-by-design

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[10] HussarW. J., “Predicting the Need for Newly Hired Teachers in the United States,” NCES 1999-026, by U.S. Department of Education, National Center for Education Statistics (1999). http://nces.ed.gov/pubs99/1999026.pdf

[11] “Falling Through the Net: Toward Digital Inclusion,” US Department of Commerce and the National Telecommunications and Information Administration, October 2000, at http://www.ntia.doc.gov/ntiahome/fttn00/contents00.html .

[12] Fletcher, op. cit.

environments, and learning environments for core subject disciplines that have more in common with massive multi-player Internet video games – with their complex immersive worlds and constantly evolving rules – than with textbooks. Content will be available not just on desktops but on wireless devices using many different form factors, including cheap, non-obtrusive virtual reality displays that will provide a revolutionary sense of immersion and presence. But these new, richly expressive forms of content cannot be created without significant, sustained basic and applied research in learning science and technology.

Finding: Grassroots applications of current Web-based technologies are occurring in many educational and training contexts, but there are critical barriers to more rapid dissemination of existing beneficial technologies and materials. These barriers include insufficient teacher preparation for appropriate uses of information technology, absence of adequate educational performance metrics, the expense of developing materials, lack of standard, application-level infrastructures, and lack of knowledge about research-documented effective strategies.

Individuals and research groups have been producing stand-alone, online educational materials for many years. The common approach to industrial training materials is custom-built courseware designed to run on a specific platform for a specific audience. The advent of the World Wide Web has sparked the creation of Web-based materials in the industrial arena and in educational environments. This shows that creative and exploratory desires exist and that leading-edge teachers see the possibilities. However, these efforts remain disconnected, sporadic, custom-built, and largely unevaluated.

Inadequate technology infrastructures cause multiple problems: duplicative content development for multiple platforms, lack of interoperability among learning modules, lack of data sharing among systems, difficulty in locating existing materials, issues of unreliable quality of service, absence of a convenient way to charge for use of materials, and a disincentive to develop and publish materials a small amount at a time. The Panel saw evidence that supplying Web-based templates and basic usage standards accelerated the production of materials by K-12 teachers. A well-thought out, flexible, easy-to-use infrastructure might ignite a huge amount of activity.

Another barrier is the cost of entry for new materials. Education and training content development is hard and expensive. It is not unusual to spend 100-200 hours developing one hour's worth of interactive materials; simulations are even more costly. And any materials that incorporate sophisticated media, such as video, inherit the costs of media production. Tools to decrease these levels of effort are desperately needed.

Even though there is widespread experimentation with existing and emerging educational technologies, there is very little dependable information on what works, in what circumstances, and why. The efficacy of computer-aided and distance learning in a training environment has been studied. But we need far more analytical and empirical explanation for successes and failures, particularly in K-12 and university education, with research methodologies that acknowledge the complexities of such interventions.

Finding: Education and learning R&D are dramatically underfunded both on an absolute basis and compared with other domains.

Given its importance to the Nation, it is hard to understand why R&D in K-12 education is funded at only 0.03 percent of total K-12 expenditures ($100 million out of $300 billion expended).[13] The PITAC recognizes that the total expenditure for education and training R&D is difficult to determine due to the highly distributed nature of the funding and effort, but the numbers we were able to find seem alarmingly low. For example, the 1997 PCAST report[14] on educational technology compared U.S. R&D in pharmaceuticals and K-12 education as follows:

> The magnitude of the problem is illustrated by a (somewhat oversimplified) comparison between the American education system and the American pharmaceutical industry. In 1995, the United States

[13] Fletcher, op. cit.

[14] President's Committee of Advisors on Science and Technology, *Report to the President on the Use of Technology to Strengthen K-12 Education in the United States*, Section 8.4, March 1997, at http://www.ostp.gov/PCAST/k-12ed.html.

spent about $70 billion on prescription and non-prescription medications, and invested about 23 percent of this amount on drug development and testing. By way of contrast, our nation spent about $300 billion on public K-12 education in 1995, but invested less than 0.1 percent of that amount to determine what educational techniques actually work, and to find ways to improve them.

Moreover, while pharmaceutical research expenditures have increased significantly over the past few decades as new technologies opened new avenues for medicinal innovation, research funded through the National Institute of Education dropped by a factor of five (in constant dollars) between 1973 and 1986. Although this situation has improved somewhat over the past decade, the Department of Education continues to allocate a relatively insignificant portion of its $30 billion annual budget to research.

The PCAST went on to argue for a more reasonable level of Federally funded research into improving the efficacy and cost-effectiveness of U.S. K-12 education:

> In view of both the importance of elementary and secondary education to America's future and the enormous investment our nation makes in such education each year, the Panel recommends that after a brief transitional period involving substantial yearly increases, a steady-state allocation of no less than 0.5 percent of our nation's aggregate K-12 educational spending (or approximately $1.5 billion per year at present expenditure levels) [15] be made to federally sponsored research aimed specifically at improving the efficacy and cost-effectiveness of K-12 education in the United States.
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> While this sum may seem quite large in absolute terms, when expressed as a fraction of total educational expenditures, it is some ten to twenty times lower than the comparable ratio in most knowledge-based industries. More importantly, because even a modest improvement in the cost-effectiveness of the educational process would result in an enormous reduction in the public expenditures required to achieve a given level of educational outcomes, the Panel believes that such an investment could result in substantial savings over time. Even these savings, however, would likely pale by comparison with the long-term dollar impact that a significantly improved K-12 educational system could be expected to have on our nation's economic competitiveness throughout the early decades of the twenty-first century.

Finding: The breadth and scale of the needed research effort and the necessity for learning technology innovation and diffusion requires unprecedented partnerships among government, industry, foundations, universities, and schools.

Taking the potential role of information technology in all of education and training, from pre-kindergarten through military, industrial, and lifelong learning as the target, there is a great deal of work to do. The Panel feels that the barriers listed above will yield to well-managed, aggressive efforts and that a community of researchers, industrial participants, educators, and educational institutions is available to carry out the work. Current funding and research management mechanisms are, however, grossly inadequate. To pursue the role of information technology in learning, Federal government expenditure of approximately one tenth of one percent of total K-12 education expenditures should be possible when matched by available industrial and foundation funds and managed aggressively and non-bureaucratically. That would imply a Federal funding level of about $300 million per year plus foundation and industry matching for a total of $600 million per year. An additional Federal investment of at least $100 million per year, again matched from

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[15] More recent figures from the December 2000 Web-Based Commission report indicate that “The current budget for the Office of Educational Research and Improvement, the major research arm of the U.S. Department of Education, is $540 million. Even adding the $60 million spent by the Research, Evaluation, and Communication Division of the National Science Foundation’s Education and Human Resources Directorate, best estimates suggest total spending for education research is in the $600 million range.” (p. 73). At http://interact.hpcnet.org/webcommission/index.htm.

other sources, is needed to include those aspects of the research more associated with adults, pertaining to university, corporate, and lifelong learning technologies.[16]

Recommendations

Overarching Recommendation

Make the effective integration of information technology with education and training a national priority.

More effective – and cost-effective – education and training are key to our well being, as individuals, families, communities, and as a Nation. Information technology, in the hands of well-educated teachers and trainers, has the potential to provide enormous leverage in the pursuit of better and less costly education and training. Pre-kindergarten, K-12, and university education are conducted primarily at the state, local, and private levels, and training is conducted by the military services, thousands of companies, professional schools and societies, and the like. This widely dispersed effort has its merits, but the diffuse operational entities are unable to fund the type of far-reaching research proposed here for a national initiative. The Federal government has to take primary responsibility to fund the research required to improve the processes executed by these many thousands of operational entities.

The PITAC recommends the following four specific actions at the Federal level: (1) establish and coordinate a major research initiative for information technology in education and training; (2) establish focused government-university-industry-foundation partnerships to aggressively pursue the information technology research program required to advance education and training technology in the United States; (3) enable educators and related professionals to use information technology effectively; and (4) develop and promote standards for information infrastructures for education and training.

Recommendation: Establish and coordinate a major research initiative for information technology in education and training.

Having reviewed past studies, proposed technologies, and current programs, the PITAC has concluded that there are critical, long-term technical issues that need to be addressed to realize its vision of transforming the way we learn. The following non-exhaustive list illustrates the many topics encompassed by such an initiative. The list is divided into (1) learning technologies and sciences, (2) information technologies for education and training, and (3) requirements for learning and teaching information technology fluency.

Some of these research areas overlap with existing initiatives such as the Next Generation Internet and Information Technology R&D. That is to be expected and is beneficial. These overlaps, however, place a burden on the Administration to ensure appropriate coordination and on Congress to make sure research funding is sustained so that coordinated plans can be executed.

Learning sciences and technologies:

- Identifying effective information technology-enhanced learning strategies and methods – determining the kinds of methods and materials that engage the learner and groups of learners; develop lasting knowledge, understanding, and skills; assess progress; and identify weaknesses and misunderstandings. This is both a research and a knowledge-diffusion problem. It has critical

[16] Total expenditures for university education and corporate training are believed to be on the order of $400 billion.

implications for the development of curriculum materials and assessments, teacher professional and training programs, and school leadership[17].

- Learning how to learn using information technology – enabling students and teachers to gain maximum advantage from new technologies. The increasing requirement for lifelong just-in-time learning can be supported by a richly populated education and training infrastructure (recommended below). But students need to be taught how to use such an infrastructure for self- and mentored learning. Methods need to be developed to teach students these skills, not as a chore but as an exciting way to progress through life.

- Improving student assessment using information technologies – determining the knowledge and skills of the learner through psychometrically validated performance assessments that align closely with the desired uses of knowledge acquired through learning. A research program could lead to embedded assessments that go far beyond current standardized tests and could be used to help guide instruction continuously. For example, it ought to be possible to develop and evolve an effective English composition evaluator at some useful level, or to assess a student's problem-solving skills by analyzing the sequence of actions taken by the student. Developing a sophisticated, adaptable, IT-based capability for student assessment is essential to the effective implementation of education reforms that place increased emphasis on measurable results and accountability. Such assessment is emphasized in President Bush's initiative, *Transforming the Federal Role in Education So That No Child is Left Behind*.

- Assessing the effectiveness of information technology in education and training – distinguishing the solutions that really work. The recommendations here envision new educational methods and technologies, perhaps radically new. Research into how to measure the effectiveness of those methods and technologies should be integrated with the methodological and technological research projects funded by the programs and initiatives recommended in this report.

  To assess technological effectiveness requires that there be a set of consensus objectives against which results can be measured. Although the PITAC lacks standing to recommend actions in the controversial area of educational content standards, it believes that our education and training establishments must articulate their goals, measure them, and improve performance measured against those goals. Failure to take these steps would result in information technology being applied to educational processes without adequately understanding the underlying objectives of the processes and their critical drivers of effectiveness and efficiency – therefore, without being able to argue persuasively about benefits or deficits of the new methods and technologies. Anecdotal, sometimes astonishing, successes will undoubtedly occur even in the absence of such well-articulated goals, but the longstanding difficulty of diffusing improvements in education and training so that they become systemic will remain.

- Leveraging socioeconomic factors in using information technology in education and training – understanding and exploiting cultural and economic differences that affect learning. Examples include the use of relevant readings and math problems, roles of multilingual content and technologies, accounting for external demands on the student, and socioeconomic factors in perception.

- Searching, discovery, and selection of appropriate content – enabling efficient and effective use of information. We need technologies for tagging materials with information about content, applicability, certification, ownership, royalties, and the like, and ways to look for, screen, and select materials appropriate for individual contexts and users. Materials might self-adapt, for example, to different styles of access devices, cultural contexts of the user, user capabilities or disabilities, and so on. Materials and access processes might respond to a student's personal digital educational record and library if so authorized.

- Learning for cognitively disabled students – using information technology to facilitate learning and training for students with difficulties such as low I.Q., attention-deficit disorder, and dyslexia.

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[17] "How People Learn: Brain, Mind, Experience, and School: Expanded Edition." Washington DC: National Academy Press, 2000.

Information technologies for education and training

- Advanced, complex technologies for education and training – enhancing universal learner understanding of complex subject matter using visualizations, simulations, design environments, multi-player gaming, and other technological strategies. Some of these may require access to high-end computing and many will require access to high-speed communications.
- Content development tools and technologies – addressing the cost-of-entry problem. While responsibility for content development and content selection lies with state and county administration, the tools that facilitate these tasks would benefit from Federally driven R&D and offer a significant opportunity for leverage across the Nation. Online educational materials, ranging from traditional computer-based training courses through real-time simulators and large-scale digital libraries, are essentially software. Material development is an art that shares the attributes of most software development: it is hard, labor intensive, expensive, error prone, and not very well understood. Educational materials that require an hour of student effort to execute might typically take 100-200 hours to develop, assuming no new underlying technology is used. Shortages of well educated, disciplined, and creative workers exacerbate this difficulty, so there are serious personnel-development needs for the learning technologies field. Many of the issues for research in software development carry over into this arena, but focused education- and training-specific efforts are required. We need a wide range of materials and systems that are predictably trustworthy and durable, predictably well-performing, adaptable to various users and contexts, easy to use, evolvable and reusable, maintainable, extensible, interoperable, and scalable. The emergence of component software paradigms may help in this regard[18].
- Collaboration and community tools – enabling sharing of learning problems and projects and access to expertise among mentors, tutors, experts and peers for learning support. Emerging research in this field demonstrates how little we know about how to establish, support, scale, and maintain such communities of learning, and the new problems that arise in such distributed learning environments (e.g., security, safety, knowledge management). Determining appropriate and effective roles for such social computing in learning and education will require long-term, multidisciplinary research in the social and learning sciences.
- Online safety and protection – knowing that we can control our own information. Educational records and processes are very sensitive, like financial records and processes. For example, the envisioned personal digital educational record and library should be private to the owner. A great deal of work is yet to be done to have high-confidence, scalable, secure systems.
- Discernment, archiving, search, and navigation – knowing how to use the vast amount of available information. Many of these most important topics are addressed under the umbrella of digital libraries. The potential is to allow all students and researchers simultaneous, usable, and useful access to the vast stores of information available in collections throughout the world. Discernment, the ability to distinguish usable and valid information among all the available information, is a very difficult problem that will require substantial, long-term research. In education, discernment may interact in unknown ways with learner interests and background knowledge, requiring significant new scientific research to understand.
- Low-cost, scalable, ubiquitous information infrastructure – applying affordable, high-capacity, ubiquitous communications platforms. The education and training environment of the future will enable access to learning materials and systems anywhere, anytime, by any authorized user. Technologies emerging from efforts such as the Next Generation Internet project, and beyond, will be important for education and training. The research on the education and training side should focus on using the new technologies effectively and efficiently, including research on new applications and on the new interactive learning contexts of such ubiquitous use of information technologies outside classrooms. Education and training will require highly reliable, seamless, wireless, access to systems that may run on distant, perhaps very high-end, computers with front-ends that may run on hand-held,

[18] Roschelle, J., DiGiano, C., Koutlis, M., Repenning, A., Phillips, J., Jackiw, N., Suthers, D. (1999). "Developing educational software components." IEEE Computer, 32(9), 50-58.

book-sized devices. Or there may be special places that students go to use multidimensional immersive environments tied to large numbers of computers elsewhere. Transfer of very information-dense media, such as realistic-definition 3-D video with interactive, real-time response to user motion, will be available, perhaps to displays worn as eyeglasses. To accomplish this in a way that scales to the potential population of learners at any given moment requires the Nation to fund research that goes beyond the Next Generation Internet but that will be useful in many domains, not just education and training.

- Access for physically disabled students and teachers – opening the new educational frontier to all citizens. This is a rich area for research with many potential benefits, not only for the disabled but also for all human-computer interactions. It requires integrated hardware and software research.

Requirements for learning and teaching information technology fluency

- Bringing teachers and students up to speed – What do teachers and students need to know in order to take advantage of today and tomorrow's information technologies and infrastructures? How can we promote the necessary learning-how-to-learn skills in this rapidly changing knowledge area? This goes beyond using the information technologies for learning; it includes using systems and networks for various applications in business, science, humanities, the arts, health, and citizenship, to benefit the individual, family, and community[19].

Recommendation: The federal government should collaborate with industry, state governments, and private foundations to aggressively pursue the information technology research program required to advance education and training in the United States.

The Federal government should collaborate with industry and private foundations to co-fund the information technology research required for the national education initiative. Large-scale, sustained efforts are required, each involving multiple disciplines and drawing on expertise from academia, industry, and government laboratories. These research partnerships will need aggressive, activist program managers who can seek out, fund, encourage, assess, and sustain long-term, long-range, pre-competitive research. Huge procurement efforts that draw thousands of small grant proposals should be avoided since the National Science Foundation (NSF) and other agencies already perform that role. Instead, the activist model continuously engages the program manager in the targeting, solicitation, rapid funding, and continuing constructive evaluation of a smaller number of large research efforts that may last five to ten years each. These efforts should focus on non-incremental, high-risk, high-potential research that spans theory, experiment, and application.

Efforts that cost several million dollars per year should not be unusual. The Explorations into the 21st Century described in the PITAC February 1999 report are the appropriate scale here. Research efforts should not be diluted by the requirement for frequent elaborate formal proposals for re-funding nor for voluminous written reporting to the various funding agencies. It will be the partnership's responsibility to balance the wide variety of agendas and vested interests of the funding agencies and industrial participants by drawing them together into productive collaborations.

On the government side, various interested agencies – including the Department of Defense (DoD), the Department of Education (ED), the Department of Energy (DOE), the Department of Labor (DOL), the National Institutes of Health (NIH), and NSF – should be provided insight into the partnerships' activities. They should all be encouraged to provide funds to the partnerships to pursue broad programmatic objectives. State governments[20] should be encouraged to participate as well, since most K-12 educational

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[19] See "Being Fluent with Information Technology," Computer Science and Telecommunications Board, Washington DC: National Academy Press, 1999.

[20] State governments can play a significant role. For example, California is spending $1 billion to establish three California Institutes for Science and Innovation. One major focus of these institutes is how education will be transformed by the technologies they address. See http://www.ucop.edu/california-institutes/.

funding is provided by states, giving them a high stake in the advances outlined in this report. Currently states provide virtually no education or learning technology R&D funding.

The purpose of the research partnerships is not to pursue generic information technology such as improving the bandwidth, quality of service, and security of the Internet or developing higher-resolution displays. For these requirements, partnerships should remain cognizant of and import the results of other information technology R&D efforts and should export requirements to that community through close relationships with Federal funding agencies and industry.

Total Federal funding for such partnerships should ramp up rapidly to $400 million per year with an expectation of equal funding from other sources. Each partnership might be able to manage effectively and efficiently as much as $200 million per year including matching funds.

Our recommended level of funding, while still modest, is based on the 1997 PCAST report on educational technology, which compared U.S. R&D in pharmaceuticals and K-12 education. Our recommendation strikes a balance between the panel's desire to achieve a meaningful investment increase, capable of generating the quantum improvements that our nation needs, and the panel's realistic assessment of the Nation's ability to appropriately identify, qualify, staff, and manage the research projects encompassed in our proposed agenda.

Recommendation: Enable educators and related professionals to use information technology effectively.

Teacher development is lagging development of applicable technology. Teachers and others required for the deployment of new learning technologies need to be better supported in learning how to take advantage of new and emerging technologies. Such professional development is needed for both existing and student teachers and has implications for universities in general, for their schools of education, and for school systems and teacher professional development organizations that provide in-service training. It will require that funding and mechanisms be made available to better reach current teachers. More materials developers and authors need to be trained. Even with the shift from school-centered technology management to an outsourced model for application-service provision (ASP) via the Web, as in corporations, more staff for the management of in-school networks is required.

In addition to the obvious requirement that teachers need to be able to use the new technologies effectively with students, teachers need to be trained in how to engage parents with information technology-enhanced learning. For industrial trainers, the Panel assumes the economic incentives are sufficient for industry to fund the required efforts, but for government and military training, the Federal government will have to accelerate current programs. For industrial retraining of unemployed workers, industry, state, and Federal partnerships such as those promoted by the U.S. Labor Department are appropriate funding mechanisms.

Current grass-roots efforts indicate that some teachers and trainers are able to use technology not only effectively but also creatively. Teachers and trainers, for example, can create online courses and materials, especially if given the appropriate authoring tools. Students can participate, providing valuable learning experiences. These efforts need more fundamental guidance from pre-service training of teachers to in-service support. The $60-million-per-year U.S. Department of Education PT3 program is an important initiative supporting schools of education to prepare tomorrow's teachers to use technology for improved teaching and learning (http://www.pt3.org/).

However, the current lack of a coherent information infrastructure for learning materials tends to make each set of materials monolithic and one-of-a-kind. As the infrastructure described in the following recommendation emerges, teachers need to be trained in how to use the infrastructure to develop materials in cooperation with others.

The Panel cannot know how the emergence and deployment of information-based learning technologies will affect the number of required teachers. Information technology will not reduce the need for teachers, but it may enable them to reach more people. However, the skills needed by tomorrow's teachers will be different and may require more training. In the near term, since shortages are a certainty, incentives must be developed and must quickly be used to attract more teachers, to educate them better in information technology, and to retain them. The Glenn Commission on Mathematics and Science Teaching for the 21st century documented in its September 2000 report many of these challenges and proposed an aggressive partnership of government, industry, and other sectors to tackle the problems (http://www.ed.gov/americacounts/glenn/).

Recommendation: Work with industry and academia to develop technical standards for extendable component-based technologies and infrastructures that can be widely used in online education and training.

The Panel visited research sites and Web sites and has reviewed literature that illustrates that teachers will develop and publish educational materials more readily if they do not have to start from scratch. The result is greater sharing and reuse of materials and methods that teachers believe to be effective, potentially helping to make teachers more efficient. The World Wide Web and other Internet technologies have provided a basis for an education and training infrastructure, but there is a great deal more to be done. It should be possible, for instance, for a teacher to develop an example illustrating some concept and hook it easily into a larger course that includes materials on that concept. In this way, culturally appropriate examples can be substituted in an already existing course. In some contexts, it may be desirable to develop an economy for such small, medium, and large materials such that royalties could be collected and distributed automatically.

Recently, several broad-scale consortia have developed to define and establish technical standards, recommended practices, and guides for software components, tools, and design used in the development, deployment, maintenance, and interoperation of computer implementations of education and training components and systems. These groups include the IEEE Learning Technology Standards Committee (ltsc.ieee.org), the IMS Project (www.imsproject.org), and SCORM (Sharable Courseware Object Reference Model) from the DoD Advanced Distributed Learning initiative (www.adlnet.org). Many Federal agencies that either require education and training (such as DoD) or support it (such as ED, DOL, and NSF) have an interest in these standards. They need to work with all of their relevant programs, and with the private and educational sectors, to define and promote the adoption of common technical standards for the design of online courses, meta-tagging of digital learning content, and universal design standards for access for the disabled. Government should not establish or try to maintain control over a separate set of standards. Industry must be heavily involved, particularly those companies commercially committed to education and training. Once the infrastructure standards have been established, agencies may have to provide grants and contracts to seed and demonstrate various instances of the infrastructure appropriate to their domains.

Conclusions

Education and training are of central importance to national progress. Most people who have investigated the state of U.S. education and training recognize that there is plenty of room for improvement, and many feel that the current situation requires drastic nationwide action. Current grassroots efforts to apply Web-based approaches to education and training are just early stirrings signaling the potential of information technology to assist in the needed improvements. Existing research and development in learning sciences and technologies is seriously underfunded. Improved use of existing and emerging information technologies, research and development of new information technologies and infrastructure standards, development and promulgation of new learning methods and interactive learning environments, and development of metrics, goals, and assessment techniques are all part of the answer to the pressing national need to transform the way we learn.

A Note on Access to Computing and Communications

Widespread access to computing is not sufficient to achieve improved information technology-enhanced learning and education. However, it is a necessary precursor. Society-wide transformation in learning will require a critical mass of networked computers in every classroom, along with well-educated, information technology-knowledgeable teachers, appropriate software, and budgets to cover ongoing costs of ownership. The ability to access computers and the Internet must extend beyond the schoolroom, however, into the communities and homes of the students.

As a basis for future progress, current levels of computer access are inadequate. We must move beyond measuring national progress in educational technology in the unit of students-per-computer. We must start measuring student learning in relation to access time to computer-enhanced learning environments. Computers, software, and high-speed Internet connections are needed in every classroom for every student and must also be accessible from outside the school, preferably from every home or at least in readily accessible community centers that can provide access and appropriate training.

To reach the goals this Panel recommends, a nationwide effort involving governments, industries, and schools at all levels is required, and all of society must be addressed. While progress is being made in rolling out information technology to the schools, the rollout is uneven and inadequate. Current Federal efforts are helpful, but not enough; these include the e-rate, the Technology Challenge Fund, Community Technology Centers, and PT3.

A variety of approaches can be used here. The program of the National City (CA) Adult School, a site near San Diego visited by the Panel, is an example. San Diego County retires about 3,000 desktop computers per year and turns them over to this school. Students who are learning computer repair and network management fix these machines and get to keep one each for home use; the rest are placed in the community, the second-poorest in California. Free Internet access is provided through local schools.

The Federal government should continue to encourage and co-fund such creative solutions, increase the size and scope of access programs, and establish mechanisms so that creative approaches can be scaled up nationwide.

The Panel suggests that for current Web-based technologies and materials, state-of-the-art desktop personal computers are not necessary for every seat at every school. Programs may gain leverage, as in the National City example, from trailing the hardware state of the art, perhaps substantially. Low-cost hand-held computers appear to hold particular promise for enabling all learners to have low-cost access to learning applications, particularly as wireless infrastructures become widespread.

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