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ABSTRACT

This report summarizes one of a series of workshops organized by RAND's Critical Technologies Institute (CTI), on behalf of the U.S. Department of Education, to learn from those already implementing new technologies in schools. This particular session explores the educational software market from the demand side and focuses on issues of cost effectiveness and evaluation. Five case studies of school-wide technology implementation and its benefits are presented, along with a chart comparing the costs incurred by the five schools to each other and to the national average. Synopses are provided for four presentations sampling the instructional effectiveness of educational software. The summary addresses issues of implementation such as teacher preparation, financing, rearranging the schoo' day to allow computer time, focusing the technology into cour:eware and individualized instruction, and monitoring student progress. Participants also advise on prioritizing for successful technology plans and for choosing instruments with which to evaluate software tools. Appendices offer a workshop schedule and a list of participants. (BEW)

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The Costs and Effectiveness of Educational Technology: Proceedings of a Workshop

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PREFACE

Urged by the President and the Vice President, federal officials have been exploring how to encourage greater and more effective use of modern computers and communications in the nation's schools. In July 1994, RAND's Critical Technologies Institute (CTI) completed a broad investigation of educational technology in education and training for the White House Office of Science and Technology Policy and the National Science and Technology Council. This work examined the nature and level of existing federal efforts.

Based on this work, the U. S. Department of Education asked CTI to assist the Department as it responded to new provisions in the 1994 *GOALS 2000: Educate America Act*, provisions calling on the Secretary of Education to develop a strategy for effective utilization of the new technologies in the nation's classrooms. With an original deadline of March 1995, submission of the plan to the White House and the U. S. Congress was delayed by later legislation until September 1995.

This report summarizes the fourth of five workshops organized to learn from those already involved in implementing use of the new technologies in the schools. The first examined the educational software market from the supply side; the second issues of professional development; the third local planning and financing; and the fourth the educational software market from the demand side. This workshop was primarily concerned with issues of cost, effectiveness and evaluation.

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1. TECHNOLOGY, SCHOOL REFORM'S OPPORTUNITY

INTRODUCTION

The last in a series of workshops held over a period of 18 months, this two-day workshop on June 1-2, 1995, was organized primarily to gather information and expert opinion on the potential benefits and effectiveness of the school use of computer technology. Over the course of two days, workshop participants heard and considered 14 presentations, including summary reviews of the implementation and benefits of the school-wide use of computer technology in five pioneering technology-rich schools; four reviews of experimental and empirical data on the use of computer technology in order to implement a familiar curriculum component or realize a well-defined goal in K-12 and adult education, and military training; a prepared paper on the technology related cost[1] for technology-rich schools; and a prepared paper discussing factors affecting what can be learned about technology in education from traditional evaluation methodology.

Discussion among workshop participants covered the important issues of ...

- benefits: important educational outcomes attributable to using information technology, e.g., preparing students for the world of work;
- costs: front-end and recurring, for hardware, software, teacher training, curriculum preparation, technical support staff, etc.;
- effectiveness: teaching and learning familiar school coursework better, e.g., elementary arithmetic skills, using technology;
- implementation: planning, buy-in by teachers, and financing; and,

[1]There are costs for equipment, materials, infrastructure (e.g., cabling), and technology related training. The costs may be supported either by addition of new resources or substitution for existing activities.

* evaluation: what's different about technology.

No effort was made to reach any formal workshop conclusions, but a consensus readily emerged among workshop participants on the technological opportunity that exists to improve student learning and school effectiveness at a significant but acceptable price. In addition to the prima facie benefits of motivating students to higher levels of educational attainment and preparing them for the world of work, computer technology (with suitable software) can:

* guide students to the improved acquisition of certain basic and advanced skills and knowledge;
* aid students in the conduct of projects, including projects that may require resources outside of and even remote from school, which lead to the acquisition of other advanced skills and knowledge; and,
* assist the student and teacher to track and maintain a record of the student's learning progress and performance.

A copy of the workshop agenda appears in Appendix 1; a list of participants in Appendix 2. A summary of the workshop proceedings follows.

SCHOOL-WIDE TECHNOLOGY IMPLEMENTATIONS AND THEIR BENEFITS

We can make no pretense that these school data (below) are representative of U.S. schools. Three criteria governed the selection of schools: (1) that the schools were technology-rich outlyers, along different dimensions; (2) that they willingly cooperate with Rand[2] in assembling relevant cost data; and (3) that the technology implementation[3] was sufficiently long-lived and stable so that at least

[2] B. Keltner R. and Ross, *The Cost of High Technology Schools*, Critical Technologies Institute, RAND, forthcoming.

[3] The phrase technology implementation is not intended to mean hardware alone, but includes other necessary components like software, teacher training, curriculum preparation, technical support staff, building cabling or rewiring, and so on, but merely substitutes for this clumsy locution. A technology implementation may or may not be a part

initial evidence of benefits were visible and could be cited. Representatives of five schools, elementary, middle or junior, and secondary schools meeting these criteria were selected to participate in the workshop. No doubt other schools could have served as well. The number was limited by the practical consideration of leaving sufficient time in a two-day workshop for discussion among participants. The summaries below aim to give the reader a sense of the variety subsumed in the phrase "technology-rich" school.

Blackstock Jr. H.S.

Steve Carr, a teacher, described the technology implementation at Blackstock Jr. H. S., a 6th through 8th grade school in Port Heuneme, California. The description (below) draws on Carr's oral presentation as well as excerpts from the Keltner and Ross paper. (Excerpts from the paper appear below in italics.[4]) With annual per student expenditures in 1994 of $4,060[5] for some 960 students, many eligible for Title 1[6] support, this 36-classroom school caters to a largely minority population of mostly Hispanic descent, with smaller numbers of Chinese and Vietnamese students. Twenty-two percent of the student body are characterized as having limited English-language skills.

"Blackstock's model of educational technology delivery centers on creating what are called 'smart classrooms.' There are at present eight smart classrooms, including two for instruction in 7th grade science, one for instruction in 8th grade science, two for literature and history, one for ESL instruction, one for instruction in business education, and one called the Tech Lab 2000.[7] Each has been conceived

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of a school reform effort that aims at new student outcomes, new approaches for assessing student outcomes, and new instructional strategies.

[4] Excerpts from the Keltner and Ross paper are used extensively throughout the Current Evidence section to supplement oral presentations by school representatives. They appear in italics, within quotation marks. They are taken from the draft of the paper and may differ slightly from their final report.

[5] This compares with a national average of under $6,000 in 1994.

[6] Title 1 of the Elementary Secondary Education Act of 1965 (reauthorized in 1994).

[7] A mathematics smart classroom, nearly completed, will bring the total to nine.

and designed to support a technologically-intensive educational delivery.

"The Tech Lab 2000 is perhaps most appropriately described as the futuristic equivalent of a wood or metal shop. Designed to make students familiar with the technology present in the modern workplace, the Tech Lab is outfitted with Computer Assisted Design (CAD) software, a Computer Numerically Controlled (CNC) flexible manufacturing system, pneumatic equipment, and a satellite dish. All of the other smart classrooms have between 25-30 computers on a local area network (LAN). Each is also equipped with a sophisticated file server and a SOTA switch to give the teacher maximum control over classroom dynamics. The switch makes it possible for the teacher to control which software programs are running on each individual computer. Students can all be working on the same project, e.g., a software program or an interactive video presentation, or there can be as many as 12 to 15 different activities going on in the classroom at the same time.

"There is also plenty of technology outside of the classrooms. In each of the schools' other classrooms, there are banks of ten computers and two printers. Teachers in the non-smart classrooms do not have the same sophisticated management system to control technology delivery, but are able to use many of the basic and important software applications, from word processing to interactive programs, in their instruction. They can also draw on the school's connection to the Internet to create a more technologically rich environment.

"Staff development efforts for teachers in the smart classrooms have centered on giving individual instructors large amounts of paid time-off to familiarize themselves with technology and to organize a technology-based curriculum. Of the eight teachers in the smart classrooms, four took a year off and one took two years off to prepare themselves. The other three teachers were given three weeks during the summer to prepare. In the latter cases, the teachers were setting up a second smart class in a subject area where one already existed. The presence of a teacher with technological and curricular know-how made it easier for the new teacher to get up and running more quickly. Ongoing staff development for all teachers, those in smart and non-smart

classrooms alike, is supported by four paid days of technology training per year and a considerable amount of informal networking.

"Up to the present, Blackstock has not had a technology coordinator to support staff development efforts, relying instead on paid leave time and informal networking. To keep the technology program running smoothly, there is a teacher who has devoted about a quarter of his time to technology-related problem-solving and to computer repairs. Starting next year this teacher[8] will move into the position of full-time technology coordinator."

Noteworthy points arising in Carr's presentation include:

- The technology program at Blackstock is now over eight years old, and the issue of recurring costs for hardware, software and even special furniture, often ignored in the excitement attendant on program start-up, was demanding increasing attention.
- Program start-up was only possible with a $2.5 million grant (over five years) from the California Model Technology Schools Program.
- Classroom furniture and organization are important considerations for teachers responsible for smart classroom design, and changed over time with experience.
- The technology program was implemented in an established and largely unchanged curriculum framework.
- Continuing staff development depends upon cooperation among the school's teachers, as opposed to district level efforts.
- Important outcomes of the technology implementation are improved student attitude and engagement, based on livelier classroom content, and improved student achievement, measured by test results.

[8] This is Steve Carr, a history teacher, who represented Blackstock at the workshop.

Christopher Columbus Middle School

Fred Carrigg, director for academic programs of the Union City School District, and Bob Fazio, principal of the Christopher Columbus Middle School, described the educational context and technology implementation at Christopher Columbus (CC), a small 7th and 8th grade school of 310 students in Union City, NJ. Reflecting the school district's student population, the largest number of CC's students are Hispanic. Many to most do not speak English at home, are enrolled in the ESL program, and are eligible for free or reduced cost lunch in school.

A 'whole language philosophy of education', a project-based rather than textbook-based approach to curriculum and instruction, and a reorganization of the school day into a smaller number of larger time blocks are the basis for CC's technology implementation. From Keltner and Ross: "*Technology has been used to create a 'research-based' curriculum. The school's curriculum integrates traditional subject areas, but has as it's main focus an emphasis on teaching students 'how to learn.' Students are encouraged to become active learners through the use of structures research activities and group project work. To facilitate the transition to a student-centered learning environment, instructional delivery at the school*[9] *has been reorganized. Rather than the traditional 50-minute period, classes meet for between one-and-one-half hours and two hours. The longer class periods allow students to delve deeper into their coursework and give teachers more time to act as educational facilitators.*

"*Each of the school's twelve classrooms is outfitted with five computers (a mix of Macs and PCs), a printer, and a video presentation station (VCR, laserdisk player and presentation monitors). There are 30 additional Macintosh computers with CD-ROM capabilities in the school's central computer lab. To allow students to experiment with multimedia*

[9] Bell Atlantic has worked with the Christopher Columbus Middle School over the past two years to add a high-speed school-and-home computer-communications network to the school technology program. The network involves the use of high-speed telephone lines (ISDN) to connect school computers and 150 student and teacher homes to a library of CD-ROM and software titles stored centrally on six file servers at a Bell Atlantic site. This component of the CC technology program remains experimental and is not further described here.

production, the computer lab is also outfitted with camcorders, a video projector, and a computer video editing unit. The school has two LANs, one for Macs, the other for PCs. The PCs are linked to the Internet to allow remote resources to be integrated into classroom instruction.

"To get CC's technology program up and running, each of the school's 15 teachers were given six days training in each of the first two years of implementation. After the two-year start-up period, staff development continued at a lower level of intensity, with each teacher receiving an average of three days of paid on-going training per year. To keep the school's technology program running smoothly, there is a full-time technology coordinator on-site. The technology coordinator is responsible for conducting student computer classes, supporting teachers, and making technology repairs."

Noteworthy points arising in the Carrigg/Fazio presentation include:

- External corporate financial support was critical to successful initiation of the technology implementation in order not to stimulate a competition among existing programs for traditional budget support.
- The school day has now been restructured into uninterruptible 148 minute blocks of time for whole language instruction that combines English and social studies; and 111 minute blocks of time combining mathematics and science education.
- Classroom practice emphasizes student-centered, small-group, project-based learning.
- Planning aims to expand the computer presence in classrooms, as opposed to the computer lab.
- Important outcomes of the technology implementation are rising attendance and test scores on normed standardized tests, now already above the NJ average (although below the national average) and reduced Title 1 eligibility.

E. Bakersfield High School

John Gibson, principal of East Bakersfield High School in Bakersfield, CA, described the technology-rich, school-to-work transition program of this 2400 student high school, with a majority Latino population and an educational philosophy that education equals experience. From Keltner and Ross: "*The school's chief administrator aims to have students understand early that their high school education shapes their job prospects, and that their present educational experience is a way of building job-relevant skills. Exposure to business and career-oriented themes begins immediately in the ninth grade and continues throughout their high school education, and includes resume writing, portfolio building and project activities oriented towards the local business community.*

"*The school's curriculum is organized around five career 'tracks'. The career tracks are not targeted at specific ability levels, nor do they consist of a core set of classes that each pupil must complete. Rather, they are designed to allow students to develop technical and applied skills related to broad industry groups. One career track is oriented around coursework in science, technology, engineering and manufacturing (STEM). Included in this curriculum is everything from a freshman class in the principles of technology to advance placement physics for seniors. Students in this career track can make use of the Hands on Science & Technology (HOST) Center to use technology in the design and fabrication of exhibits. A second career track prepares students for employment in health-care. The school's health careers academy has 200 professional partners throughout the Bakersfield area, which offer students internships during the school year and the summer break. A third career track is Communications and Graphic Arts, in which students have the opportunity to use video cameras, video toasters and a computer editing device.* .

"*Another career track is known as human and government services, designed to prepare students for careers in teaching, law and public administration. Particular attention is given to developing strong skills in both written and oral communication. The remaining career track is oriented towards developing business and entrepreneurial* *skills. Students can participate in a one-semester class called EB enterprises, in which they carry out projects in a high-tech office environment for teachers, school administrators or community businesses. Project work includes developing inventory programs, generating descriptions of courses and scholarships, and doing graphics for signs and brochures. Students alternate as office managers in order to learn how to manage tasks and coworkers.*

"Technology-based instruction is integrated smoothly into coursework from beginning to end. As freshmen, students take a nine-week course in keyboarding and basic computer literacy. Writing assignments in the freshman English and history core courses are organized to ensure that all students moving into their sophomore year are proficient in the use of word processing programs. As seniors, students have to complete a technology-based project as a graduation requirement. Projects involve the use of computers, graphics software or video equipment.

"General instruction between the first and final years is heavily technology-based. Math classes integrate an interactive math program. English, history and social studies teachers have access to writing labs as well as a large number of video towers equipped with CD-ROM, videodisc players and VCRs. The school building is in the process of being rewired to accommodate network technology. Next year, many of the classrooms will have Internet connectivity.

"Administrators at E. Bakersfield use a variety of measures to support technology-related staff development. There is a limited amount of funding available for paid, formal technology training – the school's staff development budget allocates an average of one paid day per teacher per year. Much of this budget goes to training new teachers. New teachers without any prior training in computer technology are expected to spend several days during the summer break in training to achieve basic fluency. New teachers with more experience are typically requested to train on their own time. To support informal development efforts, the school has a teacher lab equipped with nine computers and a laser printer. Many of the computers have CD-ROM capabilities. To keep the technology component of the school running smoothly, the school also has

a half-time technology coordinator, a full-time repair specialist and a budget for hiring network specialists on an as needed basis."

Noteworthy points arising in Gibson's presentation include:

- Multiple sources of external funding, including the California Model Technology Schools Program were critical to successful development of the school's technology program. Meeting recurring costs is a growing, serious problem.
- In-situ assessment of the student's performance is seen as a major need. Students already maintain an individual projects portfolio on diskette.
- Important outcomes of the technology program are improved student retention and improved job placement of graduates.

Northbrook Middle School

Susan Wolf, principal of the Northbrook Middle School in Houston, TX, described the school's technology implementation, initiated in an existing building with a $6 million start-up budget in 1991. This 6th through 8th grade school of under 800 students draws its students from a diverse population of ethnic families of which about 70 percent are Latino.

From Keltner and Ross: "*The school administrators understand their main mission to be the preparation of their students as life-long learners for the world of work. The school's curriculum, while centered on traditional academic subjects, places heavy emphasis on students acquiring critical thinking and problem solving skills. Teachers are expected to assist students in learning how to find and analyze information. To support this student-centered learning environment, the school is organized into four educational clusters. Teachers and students in each cluster work together to support one another in continually expanding their ability to gather information and solve problems. Technology is viewed as a primary vehicle to help students develop critical thinking and problem solving skills. Technology permits instruction to be tailored to individual student needs.*

"Northbrook's technology program is centered primarily on the use of computers. With over 400 computers in place in the school's six technology labs and 48 classrooms, Northbrook has a student to computer ratio of just under 2:1. Each of the school's classrooms is outfitted with between five and six computers. All of the computers have access to CD-ROM drives in order to expand the range of software products available for student use. Access to network resources are used to support student information searches. Computers in the classrooms, in the computer labs, and in the library are networked together in a school-wide LAN with Internet connectivity. Video technology allows viewing on three channels, including local origination. Teachers also make use of multimedia presentation equipment. Each of the classrooms is outfitted with a videodisc player, videocassette recorder, television receiver, and LCD-equipped overhead projector.

"To support the technology program, Northbrook has relied primarily on on-site staff development. Each of the school's 48 teachers received two weeks of technology-related staff development in the summer prior to the school start-up. On an ongoing basis, teachers participate in, on the average, three to four days of paid training each year. Additional personnel to support the technology program include a full-time technology facilitator and a district technology coordinator located on-site. These two individuals conduct in-house training and keep the technology program running smoothly."

Noteworthy points arising in Wolf's presentation include:

- Of the $6 million start-up budget, $1.5 million was allocated for technology. Recurring costs are a major concern. Title 1 funding used for this purpose does not adequately address the problem.
- Significant technology applications are drill-and-practice and productivity use.
- Classes have been extended to 90 minutes to allow for curriculum integration, e.g., multidisciplinary connections and collaborative project work mediated by computer.

- Sharply improved test scores cannot be attributed to technology alone. Other factors are excellent teachers, staff development and flexible scheduling for student-centered approach to learning.

Taylorsville Elementary School

Beth Stroh, Modern Red Schoolhouse[10] project coordinator at Taylorsville Elementary School described the technology implementation of this suburban pre-K through 6th grade school in Taylorsville, IN with its largely lower middle-class, white student population numbering 615.

From Keltner and Ross: "*Taylorsville is one of several schools in Indiana working with the Modern Red School House (MRSH) educational design team – a New American School Development Corp. (NASDC) activity – to bring information technology into its educational delivery. The school's technology plan, its hardware layout, and its staff development effort reflect the essentials of the MRSH design. The most important role for technology in the school's educational design is to support a commitment to self-paced individualized learning.*

Taylorsville's curriculum emphasizes core subjects, aiming for high levels of proficiency in language arts, math, science, history and geography. Despite this emphasis on standardization in content, educational delivery focuses on students proceeding through coursework at their own pace. Instructional strategies promote multi-age, multi-year groupings and stress team-based project work. The opportunities for regrouping teams during project work allows individual students to develop their skills in different areas at an appropriate speed. By virtue of their role in integrating instruction across subjects and grades, teachers play a key role in facilitating the transition to a self-paced student environment.

The school's technology plan provides students with plentiful access to networked computers. Taylorsville has one computer lab equipped with 30 Apple computers. Each of the school's 25 classrooms has a cluster of four student computers, one teacher computer, and two

[10] A New American Schools Development Corp. (NASDC) project design activity.

printers. Some of the classroom computers have internal CD-ROM drives to increase the range of software applications accessible to students. A school-wide LAN connects classroom computers to the computer lab and to administrative offices. At present, students can access the Internet from two computers in the library media center. Plans provide for Internet connectivity to each classroom. Investing in the hardware and other infrastructure required to give each classroom Internet connectivity is an outcome of the school's commitment to supporting student project activity. The same principle has led also to outfitting the library with eight IBM clones that use sophisticated software to facilitate information and reference searches.

To support its vision of a self-motivated, self-directed student population, the school invests in a fairly high level of staff development. In Taylorsville's educational paradigm, teachers serve as facilitators for student learning. Teacher fluency and comfort in using information technology determines the success of the model. In the first two years of implementation, staff received six full days of technology training per year. Thereafter, two days a year have been devoted specifically to ongoing training in technology. A full-time technology coordinator assists teachers with their technology-related problem solving. The full-time technology coordinator has the assistance of three part-time aides."

Noteworthy points arising in Stroh's presentation include:

- Once committed to the MRSH design, teachers recognized technology as an important enabling tool for developing education compacts and instructional strategies adapted to individual learners; and for continuously measuring student progress in new on-line formats, including student portfolios, and recording student scores on standard assessment instruments.
- Although initially discovered to be in short supply, an exceptionally capable instructional management software (IMS) product was finally acquired at substantial cost that provided for excellent linking between curriculum elements, maintained

individual education compacts, and provided features for on-line testing.

- Students successfully engaged in independent, self-paced work, but still challenging problems remain for teachers to manage individualized student learning and be confident that students are achieving at their highest level. Assessment of student project work remains a problem.
- Important outcomes of the MRSH implementation include increased skills and confidence with technology, increased student enthusiasm for learning, increased commitment to being responsible for own learning, and some improvement in standardized test scores, most consistently as a result of improved reading skill.

COSTS

Table 1, taken from Keltner and Ross, shows the cost of technology implementations for pioneering schools like these. In addition to data on these five schools, Table 1 includes data on three school-wide designs sponsored by NASDC.[11]

[11] As Rand is the principal planning and evaluation contractor for NASDC, these data were conveniently available.

Table 1

COMPARATIVE COST FIGURES

	Corona	E. Bakersfield	Elizabeth St.	Taylorsville	Blackstock	ALL School	Northbrook	CC
Total Annual Cost	$ 169,863	$ 299,835	$ 331,542	$ 227,942	$ 381,340	$ 233,018	$ 348,450	$ 151,940
Annual Cost per Student	$ 142	$ 182	$ 184	$ 371	$ 410	$ 432	$ 453	$ 490
Student Total	1,200	1650	1,800	615	930	540	770	310
Ratio, Students:Computer Units[a]	11:1	7.5:1	9:1	3:1	2:1	3:1	2:1	1.5:1
Hardware Subtotal	$ 50,343	$ 133,470	$ 140,341	$ 110,619	$ 213,650	$ 100,258	$ 232,600	$ 57,790
Software Subtotal	$ 16,600	$ 11,620	$ 24,700	$ 23,633	38,760	$ 15,300	$ 14,200	$ 15,800
Infrastructure	$ 8,040	$ 14,905	$ 19,001	$ 5,000	$ 22,930	$ 6,900	$ 24,750	$ 8,300
Staff Dev.	$ 24,880	$ 24,840	$ 26,500	$ 15,690	$ 85,000	$ 13,760	$ 19,400	$ 11,050
Personnel	$ 62,000	$ 105,000	$ 100,000	$ 69,000	$ 12,500	$ 92,000	$ 42,500	$ 50,000
Materials	$ 8,000	$ 10,000	$ 21,000	$ 4,000	$ 8,500	$ 4,800	$ 15,000	$ 9,000
				Percentages				
Hardware Subtotal	29.64	44.51	42.33	48.53	56.03	43.03	66.75	38.0[illegible]
Software Subtotal	9.77	3.88	7.45	10.37	10.16	6.57	4.08	10.40
Infrastructure	4.73	4.97	5.73	2.19	6.01	2.96	7.10	5.46
Staff Dev.	14.65	8.28	7.99	6.88	22.29	5.91	5.57	7.27
Personnel	36.50	35.02	30.16	30.27	3.28	39.48	12.20	32.91
Materials	4.71	3.34	6.33	1.75	2.23	2.06	4.30	5.92
				per Student				
Hardware Subtotal	$ 41.95	$ 80.89	$ 77.97	$ 179.87	$ 229.73	$ 185.66	$ 302.08	$ 186.42
Software Subtotal	$ 13.83	$ 7.04	$ 13.72	$ 38.43	$ 41.68	$ 28.33	$ 18.44	$ 50.97
Infrastructure	$ 6.70	$ 9.03	$ 10.56	$ 8.13	$ 24.66	$ 12.78	$ 32.14	$ 26.77
Staff Dev.	$ 20.73	$ 15.05	$ 14.72	$ 25.51	$ 91.40	$ 25.48	$ 25.19	$ 35.65
Personnel	$ 51.67	$ 63.64	$ 55.56	$ 112.20	$ 13.44	$ 170.37	$ 55.19	$ 161.29
Materials	$ 6.67	$ 6.06	$ 11.67	$ 6.50	$ 9.14	$ 8.89	$ 19.48	$ 29.03

[a]This line was added to the table in Keltner and Ross; computer units equals sum of student, teacher and lab computers.

The cost figures shown are not computed from actual historical prices, but rather as the amortized cost of the school configuration based on today's prices. Per Keltner and Ross, the following rules and assumptions were used:

- the current equipment inventory was used;
- current prices for equivalent computers were used for all computer hardware;
- the cost of hardware and software products was amortized over five years;
- the cost of any infrastructure, like special furniture and cabling, was amortized over ten years;
- the cost of any initial professional development for teachers was amortized over five years; and,
- the cost of any new staff, staff development, and materials and supplies was treated as an annual expense.

Three things stand out in these data. First, these schools all have lower student-to-computer ratios than the current national average of 12:1, and in most instances, much lower ratios. Second, the two dominant factors contributing to total cost per student are computer hardware and cost of additional personnel needed to run the technology programs. Third, the cost of software is small by comparison with the cost of hardware, unlike most enterprise computing[12], and small absolutely. Keltner spoke to this at the workshop

The graph below shows the sensitivity of the cost per student to the student-to-computer ratio.

[12] The expectation in enterprise computing is that the cost of software will approach and equal the cost of hardware.

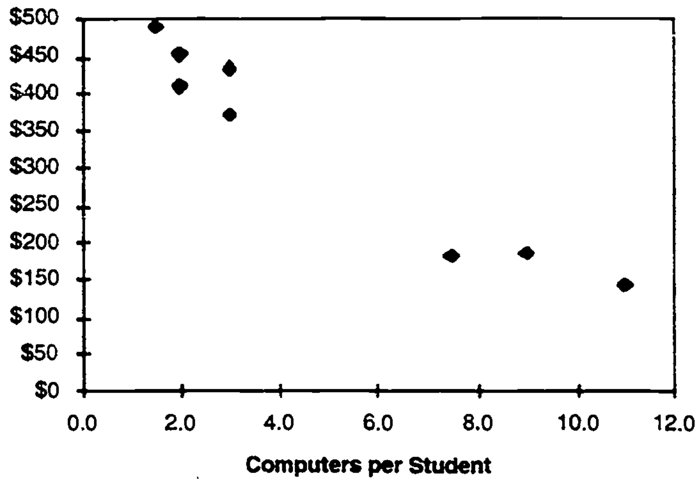

Fig. 1--Student to Computer Ratio

The chart and table suggest a story about annual student cost. When the number of school computers is relatively modest, like one for every seven to eleven students, costs like technology-related staff, staff development, and materials and supplies will tend to dominate total cost; when the number of school computers increases to one for every two or three students, variable costs for hardware, software and infrastructure will tend to dominate.

Software can include system, application, network and reference products; and application software can be further divided into tools, i.e., feature rich and content poor like word processing software; and content software, i.e., content rich and feature poor like common drill-and-practice software.[13] Keltner and Ross speak to the relatively low level of school expenditures they found for software: "*Software expenditures account for 10% or less of total technology costs at all*

[13] Drill-and-practice software is the most familiar current example of content software, closely tied to the common scope and sequence curriculum in use by most schools. Content software need not in principle exclude products that aim to support a project-based curriculum. In practice, little content software of either kind exists for junior high and secondary school grades.

eight schools. Software costs are on average one-quarter to one-fifth of total hardware costs. The school environment is not one that puts sophisticated demands on the software component of a technology program. The number of basic software programs installed on individual students' computers is typically limited. Non of the schools in this survey purchased site licenses for more than 5-6 'tool-based' software products, e.g., Microsoft Word, Clarisworks, Hypertext or Hypercard, and the average was more like three. With a site license for 25 computers costing between $1000-$1500, an expenditure of $3000-$4000 typically proved enough to outfit an entire classroom of computers with basic software applications.

"Another explanation for the low level of software expenditures is the ability of schools to generate economies of scale in the use of expensive software products. The Christopher Columbus, Corona and Elizabeth St. schools each spent $30,000-$40,000 to set up large libraries of CD-ROM and videodisc software products. CD-ROM and videodisc products are an important source of both 'content' and 'reference' software. Blackstock and Taylorsville spent $43,00 and $70,000 respectively on network and instructional management software. While expensive, these software items do not increase software expenditures per student significantly, because their cost is distributed over a large number of students. CD-ROM and videodisc products are used in the same way as library reference books – they are stored in one place for use by all students. Network and instructional management software are normally used on a school-wide or classroom-based LAN."

An earlier workshop[14] suggested an apparent market failure in content software, especially at the junior high and secondary school levels. The absence of products may be explained by the low level of school expenditures. School expenditures for software in 1994 were less than $750 million, or an average of $7500 per school for the nation's 100,000[15] or so schools. This figure compares with under $400 million in

[14] James Harvey (ed.), *The Market for Educational Software*, DRU-1041-CTI, RAND, Santa Monica, CA, May 1995.
[15] Used as a nominal figure throughout this summary.

consumer sales for CD-ROMs in the very first year that 'family' computers came equipped with CD-ROM players.

Whatever the cause, the shortfall in available content application software raises questions about whether students, on average, are realizing the full benefit of the school technology implementations, whatever the school's primary curriculum choice, linear scope and sequence, or many-pathed project-based; and the extent to which fully prepared teachers may be able to compensate for the shortfall in content applications.

EFFECTIVENESS

Data on the benefits of optimal school-wide technology implementations, especially implementations in the service of school reform that aims at new student outcomes, new approaches for assessing student outcomes, and new instructional strategies (e.g., a significant measure of individualized student learning using a many-pathed, project-based curriculum) are not and will not soon be available. James Kulik, Bill Hadley, Dexter Fletcher and Luis Osin provided different but overlapping slants on what we know from experimental and empirical data about the effectiveness of student learning using computer technology for the case of limited and well defined curriculum objectives. (We discuss later in the section titled 'evaluation' what can be inferred from this knowledge.)

James Kulik (University of Michigan)

Kulik's presentation was based on his recent article,[16] which opened with, "What do evaluation studies say about computer-based instruction? It is not easy to give a simple answer to the question. The term *computer-based instruction* has been applied to too many different programs, and the term *evaluation* has been used in too many different ways." He goes on to describe the meta-analytic approach for creating a composite picture of findings on computer-based instruction, and

[16] Meta-Analytic Studies of Findings on Computer-Based Instruction by James A. Kulik, 1994, in *Technology Assessment in Education and Training*, E.L. Baker and H.F. O'Neil, Jr., (eds.), Hillsdale, NJ: Lawrence Erlbaum.

presents an overview of these findings. We quote: "At least a dozen meta-analyses have been carried out to answer questions about the effectiveness of computer-based instruction (Table 1.1, *in original*). The analyses were conducted independently by research teams at eight different research centers. The research teams focused on different uses of the computer with different populations, and they also differed in the methods they used to find studies and analyze study results. Nonetheless, each of the analyses yielded the conclusion that programs of computer-based instruction have a positive record in the evaluation literature."

"The following are some major points emerging from these meta-analyses:

- Students usually learn more in classes in which they receive computer-based instruction. The analyses produce slightly different estimates of the magnitude of the computer effect, but all the estimates were positive. At the low end of the estimates was an average effect size[17] of 0.22 in 18 studies conducted in elementary and high school science courses (Willett, Yamashita & Anderson, 1983). At the other end of the scale, Schmidt, Weinstein, Niemiec, and Walbert (1985) found an average effect size 0.57 in 18 studies conducted in special education classes. The weighted average effect size in the 12 meta-analyses was 0.35[18]. This means the average effect of computer-based instruction was to raise examination scores by

[17] The meaning of effect size used here is the so-called standardized mean difference. This index gives the number of standard deviation units that separates outcome scores of experimental and control groups. It is calculated by subtracting the average score of the control group from the average score of the experimental group and dividing the remainder by the standard deviation of the measure. From Kulik, "For example, if a group that receives computer-based coaching on the Scholastic Aptitude Test (SAT) obtains an average score of 550 on the test, whereas a group that receives conventional teaching averages 500, the effect size for the coaching treatment is 0.5, because the standard deviation on the SAT is 100.

[18] An effect size of 0.32 can be thought of as equivalent to a gain of about three months on an age-grade equivalent scale.

0.35 standard deviations, or from the 50th to the 64th percentile.

- Students learn their lessons in less time with computer-based instruction. The average reduction in instructional time was 34% in 17 studies of college instruction, and 24% in 15 studies of adult education (C.-L. C. Kulik & J. A. Kulik, 1991).
- Students also like their classes more when they receive computer help in them. The average effect of computer-based instruction in 22 studies was to raise attitude-toward-instruction scores by 0.28 standard deviations (C.-L. C. Kulik & J. A. Kulik, 1991).

"This brief review shows that there is a good deal of agreement among meta-analysts on the basic facts about computer-based instruction. All the meta-analyses that I have been able to locate show that adding computer-based instruction to a school program, on the average, improves the results of the program. But the meta-analyses differ somewhat on the size of the gains to be expected. We need to look more closely at the studies to determine which factors might cause variation in meta-analytic results."

Kulik goes on to examine more closely a set of 97 evaluations of computer-based instruction in an attempt to reac more precise conclusions about their effectiveness, and concludes: "Meta-analysts have demonstrated repeatedly that programs of computer-based instruction usually have positive effects on student learning. This conclusion has emerged from too many separate meta-analyses to be considered controversial. Nonetheless, results are not the same in every study of computer-based instruction. No meta-analyst has reported that all types of computer-based instruction increase student achievement in all types of settings. Study results are not that consistent, nor would we want them to be. Computer-based instruction is a loose category of innovation. It covers some practices that usually work and other programs that have little to offer.

"Breaking studies of computer-based instruction into conventional categories clarifies the evaluation results. One kind of computer application that usually produces positive results in elementary and high school classes is computer tutoring.[19] Students usually learn more in classes that include computer tutoring. On the other hand, precollege results are unimpressive for several other computer applications: managing,[20] simulations, enrichment, and programming."

"The overall findings on computer tutoring compare favorably with findings on other innovations. Few innovations in precollege teaching have effects as large as those of computer tutorials. Effects are especially large and consistent in well designed programs such as the Stanford-CCC program. Programs of curricular change that provide more challenge for high-aptitude students may have produced more dramatic effects in evaluation studies, but such programs affect only a limited part of the school population. The effects of computer tutoring are as great as those of peer- and cross-age tutoring, and they are clearly greater than the gains produced by instructional technologies that rely on print materials."

Bill Hadley (Langley High School)

Hadley, a teacher on a year's leave at Carnegie-Mellon University (CMU) from Langley High School, Pittsburgh, PA, reported on the Pittsburgh Urban Mathematics Project (PUMP). Based on a curriculum that emphasizes multiple representations (words, symbols, graphs, etc.), the program partially depends for its delivery on software – a so-called intelligent tutor – designed and developed by John R. Anderson, Prof. of Psychology and Computer Science at CMU. PUMP has been operational at Langley H.S. for three years.

With many of its students eschewing algebra in favor of a general mathematics track, which practically proscribes the necessary achievement in mathematics and science education for a successful technical career of any sort, Langley sought a solution in the combination of a revised algebra curriculum[21] and Anderson's algebra

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[19] Kulik defines computer tutoring as a program in which the computer presents material, evaluates responses, determines what to present next, and keeps records of progress. Drill-and-practice software belongs in this category.

[20] As in computer-managed instruction.

[21] Developed primarily by Bill Hadley.

tutor,[22] which was developed over a period of years with National Science Foundation R&D support. A statement of Langley's main objectives is:

- to have all students be successful in first year algebra and geometry;
- to increase the number of students in higher mathematics classes;
- to have all students make conceptual and practical connections between algebra and the world outside of school; and,
- to prepare students for the 'world of work' as well as further academic study in mathematics.

Students spend five periods a week in algebra study, two with the intelligent tutor in a laboratory setting and three in a regular classroom. Carrying out exercises, which is greatly facilitated by the computer laboratory, is a primary element of an instructional strategy aimed at improving student learning.

As a result of a satisfyingly successful *experimental first year* in which 73% of the students enrolled in the PUMP first-year algebra course passed, while 56% of students enrolled in the regular algebra course failed, the PUMP first-year algebra course was made a required course of study for *all* Langley students. In the second year of the adoption, 61 of the 73 students passing the PUMP first-year algebra course enrolled in geometry; and of those 37 enrolled in Algebra 2 in year three. By contrast, 20 of the 24 students passing the regular algebra course during the *experimental first year* went on to take geometry; and of those only three enrolled in Algebra two. Two other schools in the Pittsburgh area recently adopted PUMP, despite the financial investment in hardware this step requires, but have not yet made first-year algebra a required course for all students.

[22] The computer equipment for a laboratory implementation of the program was donated by the Apple Computer, Inc.

J. Dexter Fletcher (Institute for Defense Analyses)

Fletcher, speaking to the use of technology in military training, started by remarking on a number of features distinguishing military training from K-12 education:

- Military training involves bringing individuals or collections of individuals to a required level of performance in the conduct of prescribed tasks. The time to reach this level of competence, a variable among trainees, affects training cost in several ways, and therefore cost-effectiveness, which sharply affects the selected training approach.
- The costs of training (most of which are time dependent) that employs 'hard' technology can be roughly divided into three categories: the trainee cost, the hard technology cost, and an overhead cost. The trainee is paid while in training; there is an added cost if the trainee is removed from the field and a replacement is required; and travel and living expenses for the trainee and any replacement may constitute yet another cost. The costs for hard technology, say a flight simulator, include R&D, and production and maintenance, which have to amortized over the lifetime of the equipment, and contribute a time-dependent amount to the cost of the individual's training. Overhead costs include everything else, like maintenance of the training site, and so on, which also contribute a time-dependent amount to the total cost of the individual's training. Time to train is therefore a major consideration for DoD.
- Unlike the case for schools, the locus of decision-making for the use of technology in military training is not local and decentralized, but centralized and even highly centralized where initial R&D support is required.
- In summary, the DoD uses technology to regain the benefit of individual tutoring that has been lost to the economic

necessity of training students in large classes. Bloom[23] writes that the difference between individualized tutoring and group instruction may account for as much as two standard deviations in measured achievement.

Effectiveness. Fletcher then went on to discuss the issues of effectiveness, cost and cost-effectiveness in turn, pointing out that the available data for considering these training criteria diminish in that order. Emphasizing the importance of individualization (for pace, difficulty, content, sequence and style) to effectiveness, he presented data on effect sizes for training using interactive (computer-controlled) videodisc instruction compared with more conventional approaches like platform lecture, textbooks, workbooks, and the use of actual equipment for practice. Videodisc functionalities in these comparisons give some indication of the effectiveness of multimedia approaches to instruction. The average effect size across 47 evaluations of interactive videodisc instruction used in military training, industrial training, and higher education was 0.50, or an increase from 50th to 69th percentile levels of performance. Considering the three settings separately, the effect size was 0.39 for military training (an increase from 50th to 65th percentile performance), 0.51 for industrial training (an increase from 50th to 70th percentile performance), and 0.69 for higher education (an increase from 50th to 75th percentile performance).

Little difference in effectiveness is found between knowledge and skill performance measures in interactive videodisc instruction evaluations; i.e., interactive videodisc instruction appeared to be equally effective for both. Studies that compared the interactive intensity of interactive videodisc instruction found significantly better results for the more interactively intense applications.

The average effect size in 38 studies of military training using computer-based instruction (CBI) is reported as 0.40 for experimental

[23] B. S. Bloom, "The Two Sigma Problem: The Search for Methods of Group Instruction as Effective as One-to-One Tutoring," *Educational Researcher*, 13, 1984, pp. 4-16.

groups numbering less than 20, in the same range as effect size in education reported by Kulik; and 0.30 averaged over 35 studies for experimental groups numbering greater than 20.

Effect size has also been used to assess simulation applications for training to maintain and repair devices, that is, the use of simulated equipment is compared to the use of actual equipment, with training time held constant and success in maintaining or repairing actual equipment used as the final performance measure. Average effect size in these studies has been found to be 0.40 (an increase from 50th to 66th percentile performance). And most notably, the cost of training using simulated equipment was found to be about a third the cost of training using actual equipment.

Evaluations of interactive videodisc used to simulate actual equipment have been performed using two approaches: videodisc used only in simulator mode and videodisc used in both simulation mode and for tutorial guidance during the simulation. Effect sizes for these two approaches were 0.14 (an increase from 50th to 56th percentile performance) and 0.41 (an increase from 50th to 66th percentile performance), respectively. This finding is consistent with others that have found an interaction effect between the sophistication of the students and the amount of tutorial guidance needed in simulation-based training. 'Naive' students benefit from tutorial assistance.

Finally, Fletcher reported on a group of assessments of computer-based instruction in K-12 education, which predicted performance on standardized achievement tests solely on the basis of the amount of time each student spent to complete a preparatory program of computer-based instruction. Scores on the comprehensive tests of mathematics achievement could be predicted to the nearest tenth of a grade-placement using these time measures exclusively. Faster learners are better learners.

Cost. In military training, the time required to train to a required level of performance sharply affects almost all cost elements contributing to total cost. Repeated analyses have found that, on average, technology reduces the time to reach criterion levels of knowledge and performance by about 30 percent, in the same range of reduced instructional time in education reported by Kulik.

Cost Effectiveness. For the case of military training by simulation, which can never entirely replace the 'real thing',[24] assessing the cost-effectiveness of simulation, whether by general-purpose hardware or special equipment, (and setting aside any other costs,) requires consideration of an additional factor, the transfer effectiveness ratio (TER). For a flight simulator, for example, this would be computed as the difference between actual aircraft time without simulator training and aircraft time with simulator training (each of which has a cost) divided by simulator time.

That is, up to the limit for which the simulator can realistically simulate general air work, an hour of simulator time saves an hour of training time in an actual aircaft. For this case, if the cost of an hour of simulator training is less than the cost of an aircraft hour, simulator time is cost-effctive.

For K-12 education, Fletcher summarized his paper[25] comparing the costs (in constant 1985 dollars) to increase comprehensive mathematics scores (computation, concepts and word problems) one standard deviation using different approaches: tutors, reduced class size, increased instructional time, and providing computer based instruction. The results appear below.

[24] K-12 education does not much consider this, which would give new meaning to the stated goal of preparing students for the world of work.

[25] J. D. Fletcher, D. E. Hawley, and P. K. Piele, "Costs, Effects and Utility of Microcomputer Assisted Instruction in the Classroom," *American Educational Research Journal*, 27, 1990, pp. 783-806.

Approach	Cost for 1 sd gain ($)
Tutoring (20 min/day)	
by peers	286.
by adults	1612.
Reduced class size	
35 to 30	983.
30 to 25	1171.
25 to 20	1367.
35 to 20	1195.
Increased instructional time	
30 min/day	2667.
CBI (10 min/day 3rd grade and 11/2 min/day 5th grade))	
grade 3 (computation)	338.
grade 3 (concepts)	208.
grade 3 (word problems)	192.
grade 5 (computation)	462.
grade 5 (concepts)	490.
grade 5 (word problems)	206.

Peer tutoring and CBI are revealed by these data to be the most cost-effective approaches. Fletcher observed these two approached could be combined and reconciled by having two or three students clustered together at a single CBI terminal.

Summing up the military experience, Fletcher offered the following principles to guide the use of technology for training:

- for practice rather than initial learning;
- to simulate expensive equipment or dangerous field conditions;
- to provide self-study for remote or dispersed learners; and,
- to closely monitor progress in student learning.

Concerning the conceptualization and practice of assessment, he suggested assessments should:

- be designed to inform specific choices;
- address both formative (design issues) and summative issues;

- expand the range of instructional outcomes considered and support the development of principles of instructional design that emphasize specifiable outcomes;
- validate instructional objectives to assure not only improved instruction, but improved instructional objectives;
- consider broad ranges of instructional inputs and outcomes, rather than narrow ones;
- consider group performance; and,
- consider cost.

Luis Osin (Centre for Educational Technology, Israel)

Luis Osin, on leave at the Learning Research & Development Center of the Univ. of Pittsburgh from the Centre for Educational Technology (CET) in Israel, reported on the CET computers in instruction program in Israel, where almost 700 schools use CET computer systems comprising some 18,000 student stations utilized by nearly 180,000 students annually. With the goal of adapting instruction to the individual learner – the learner's current knowledge, cognitive learning style and pace, CET offers a full range of services, including advice to schools and education authorities, supply and installation of computerized systems, in-school teacher training, and full system maintenance of hardware, software and courseware (application software). Indeed, almost 30 communities with some 150 schools have elected to operate under the direct supervision of CET, while hundreds of additional schools have adopted some of its adaptive teaching and learning methods.

Starting with the observation that individualized instruction is necessary to overcome the well-known distribution of the age-grade of students at any grade level, (e.g., nominally 4th grade students typically range in achievement between 2nd and 6th grades; nominally 6th grade students typically range in achievement between the 3rd and 9th grades; and so on,) Osin went on to describe the role of computers in CET's adaptive teaching and learning strategy:

- Individualized dialog with every student. By interacting with the computer, every student may learn according to his/her cognitive level and learning speed, independently of the cognitive styles and learning pace of the student's classmates. The student is able to hold a 'conversation' with the (software) author, and receive explanations matched to his/her level of learning.

- Tools for information processing. Teachers and students may enjoy using general purpose (feature rich) tools like text and graphic editors, spreadsheets, etc. The teaching and learning of many subjects can be based, at least partially, on the utilization of these tools.
- Access to remote information. Today, it is possible to access large and updated databanks, located not only in one's own country, but dispersed around the world.
- Communication with others around the world. Students in different schools, cities and countries can cooperate on a common project. Teachers can benefit from advice and support of remote educational R&D centers.
- Stimulating presentation. Material can be presented to the student with all of the expressive possibilities of modern cinematography.

A well-rationalized program includes intensive teacher preparation and the engineering design of content software (i.e., many cycles of trial and improvement), which may be more top-down than would be acceptable in U.S. schools. The result was revealed in one example of a school with a low SES population in which an exceptionally and unusually high percentage of the entire student body was performing on or above grade level in mathematics achievement.

Osin observed that the principal beneficiaries of individualized instruction were slow or low-aptitude learners, and that computer resources could be allocated in such a way as to prevent them from falling behind their age cohort, with the usual educationally destructive consequences.

IMPLEMENTATION ISSUES AND STRATEGIES

For schools, the problems of implementing a technology based approach to improve student learning include teacher buy-in and preparation, a reorganization of the school day to allow time for student use,[26] and financing the cost. Focusing the technology implementation on individualization of instruction introduces issues of computer curriculum (i.e., courseware or content software), and assessment and monitoring of individual student progress towards the achievement of consensual learning goals. Refocusing the implementation on the regnant definition of school reform introduces the additional issues of an instructional strategy defined by a project approach to student learning and a portfolio approach to student assessment. Barbara Means, Martin Huntley and David Dwyer spoke to individual school implementation problems and strategies.

Barbara Means (SRI)

Means reviewed a U.S. Department of Education (Office of Educational Research and Improvement) sponsored study of social and organizational factors affecting technology and school reform.[27] The schools had various motivations for their bottom-up efforts to adopt technology, including:

- the belief that use of computer-based technologies could support the development of the student's thinking processes;
- the belief that use of computer-based technologies could stimulate student motivation for learning, and tend to elevate self-esteem for low-SES students especially;
- promote equity for students less likely to experience computer technology at home;
- prepare students for the world of work; and,

[26] H. J. Becker, *Analysis and Trends of School Use of New Information Technologies*, prepared for the Office of Technology Assessment of the U.S. Congress, October 1993.

[27] Details of nine case studies of schools, with high concentrations of students from low-income homes, using technology to support their education reform efforts may be found at http://www.ai.sri.com/edtech/.

- support changes in school structure.

Means reviewed the implementation story for two of the nine schools, both middle schools, one arguably a success in its effort and the other a patent failure, for the lessons these different outcomes offered. The technology adoption goal was initially conceived at the school district level in both cases; both schools expended significant new resources on the implementation; both schools were new, opening in 1991 and 1989 respectively; and both schools served the children of mostly low-income families.

The approach towards the goal of technology adoption of one school was characterized by:

- careful planning, with a principal hired for the express purpose one year in advance;
- technology manager hired to manage the school network;
- a school schedule organized to give teachers 90 minutes a day for planning and collaboration;
- building renovation designed to support interdisciplinary teacher teams with common students and shared office space;
- technology distributed throughout regular classrooms; and,
- extensive teacher training provided before the school opening, and continuing regularly with faculty meetings and in-service training days;

with something like the following observed outcomes:

- the majority of teachers use technology for instruction;
- students and teachers take pride in their school;
- students value their teachers first, technology second;
- low teacher turnover;
- students have technology skills;
- students perform better than their counterparts in other schools on State assessments.

Perhaps by contrast, the approach of the second school towards the goal of technology adoption was characterized by:

- extensive planning at the school district level, with hand-picked lead teacher responsible for development of curriculum framework hired just before school opening;
- aim to individualize student educational program based on individual interests;
- a system for tracking student learning goals and accomplishments;
- innovative staffing concept with lead and associate lead teachers responsible for curriculum framework and curriculum design, and general classroom teachers added as newly opened school added grades;
- use of outside resources like museums and art galleries on a regular basis; and,
- specially designed spaces to support specific kinds of learning and instruction;

with something like the following observed outcomes:

- by five years after opening and initiation of technology adoption goal, excitement dissipated and period of very high staff turnover began;
- some hardware was dispersed to other schools, and much of the remainder lay idle on most days;
- many teachers did not use technology in their teaching; and,
- student test scores were lower than expected, and school acquired reputation as a 'dumping ground'.

In explanation of this unsatisfactory result, Means offered the following:

- a mismatch between district-selected technology and the staff's instructional philosophy;

- planned investment in training teachers was never carried out;
- schism developed between lead teachers responsible for curriculum framework and teachers responsible for classroom instruction;
- part-time technology coordinator had little contact with classroom teachers; and,
- publicity turned sharply negative after small, initial drop in student test scores.

Drawing on the nine case studies, Means ventured the following features required for a successful technology adoption:

- jointly developed school goals and technology's place in fulfilling them;
- adequate technology access provided in regular classes;
- technical support readily available and non-judgmental;
- professional growth opportunities, recognition, and rewards provided for exemplary technology use by regular teachers;
- technology use as a choice, not by fiat;
- mechanisms for teacher choice in what technology to use and how to use it;
- opportunities provided for teachers to work together; and,
- supported time for teachers to learn to use technology and to design technology-supported learning activities.

Martin Huntley (BBN)

Huntley briefly described phase 2 of a National Science Foundation sponsored testbed project aimed at assisting schools "to build the local information infrastructure (LII) in such a way that all participants in schools and local communities can actively construct networked services affecting all aspects of learning, teaching, administration and community access to education." Designed as a grass-roots effort, the project has attracted the participation of 95 member organizations, representing some 200 schools with Internet connectivity in 39 States; some state education agencies, regional education labs, museums, educational R&D organizations and universities; and some commercial firms like school publishers, service providers and system vendors.

Three key project assumptions are that:

- the school and community LII needs to be locally constructed to support the community educational mission;
- the construction must go hand in hand with creating a learning environment, which supports and promotes achievement with respect to new and emerging standards; and,
- the testbed activities will provide an environment for collaboration in addressing the daunting and complex array of issues faced by project members.

Year one project priorities are:

- teacher development: building a technology culture within the teaching community;
- funding, financing: helping communities develop strategies to foot the bill;
- collaboration mechanisms: tools and strategies for on-line collaboration for use within the testbed community and by members within their LIIs; and,
- evaluation: helping members tell whether their technology initiatives are making a difference.

David Dwyer (Apple Computer)

Dwyer reviewed the Apple Classroom of Tomorrow (ACOT) project, initiated in 1986 in seven classrooms representing a cross section of U.S. education. Providing two computers (one for school and one for home use) to each student and teacher, and ample teacher support in a project that depended principally on *teacher initiative*, ACOT also initiated a long-term, university-based project to track developments and classroom change. Two years into the activity, findings included:

- Teachers were not hopeless technical illiterates.

- Students did not become social isolates.
- Student's interest in and engagement with the technology did not decline with routine use.
- Students, even young children, did not find the keyboard a barrier to fluid use of the computer.
- Software did not prove to be a limiting factor, even in high school classrooms where Macintosh computers were the machines of choice, and hardly any educational software existed.
- Attendance was up, and test scores were generally unchanged. At one site, where computers were purposefully used to raise student test scores, ACOT students outscores non-ACOT students significantly on the California Achievement Test in vocabulary, reading comprehension, language mechanics, math computation, and math concept/application.
- ACOT students wrote more, more effectively and more easily than non-ACOT students.

In the third and fourth years of the activity, as teacher comfort with the equipment was established, (some) teachers began experimenting with new tasks for students and most K-6 teachers had successfully modified daily schedules to permit students more time to work on computer-based projects. Teachers struggled with the issue of methods of assessment that would capture the novel ways in which students were demonstrating their mastery of skills and concepts.

Dwyer summarized the catalytic impact of technology in stimulating educational improvement and classroom change:

- Technology encourages fundamentally different forms of interaction among students and between students and teachers.
- Technology engages students systematically in higher-order cognitive tasks; and,
- Technology prompts teachers to question old assumptions about instruction and learning.

He concluded by remarking that successful classroom change catalyzed by the computer depended upon new methods of assessment of student and teacher performance, and required broad support by administrators in the school and school system in their role as instructional leaders.

EVALUATION

Evaluating technology effectiveness in education poses special problems, because of additional educational changes, beyond the technology, needed to reveal the technology's full promise. Douglas Merrill of Rand spoke to this problem. Larry Frase volunteered that in the circumstance of rapid technological change, the much slower pace of educational software development, and the relatively glacial rate of change in new knowledge from research on software usability and on models of implementation in different subject matters, an engineering approach to evaluation might be preferable to the idealized scientific model of controlled experimentation. He subsequently wrote on the subject from which we quote below.

Douglas Merrill (RAND)

Merrill emphasized that the opportunity of using technology to improve student learning and school effectiveness could readily be thwarted by an evaluation approach that was collinear with existing educational practice and ignored factors affecting an effective technology implementation like:

- pedagogy, e.g., more student-focused than teacher-centered; and,
- time and curriculum framework, e.g., longer, multidisciplinary classes.

He went on to say that the metrics employed in an appropriate evaluation should focus on the interaction of student, institutional and task factors. From a paper by Merrill[28]: *Naturally, the student's personal characteristics interact with the educational intervention to produce differing outcomes. For example, there are students who exhibit higher abili y than others, regardless of one's beliefs about the nature of the vague construct 'ability'. Higher ability students tend to react differently to feedback than students who are having more difficulty. ... differences in feedback behavior are often directed at maintaining students' motivation, another key personal characteristic affecting pedagogical outcomes. Thus one would expect ability – however defined – and motivation to be important factors to consider when evaluating educational technology.*

Concerning institutional factors, Merrill writes: *Student factors are not all that should affect the metrics used by an evaluation. The way the technology is integrated within the school setting also can change the set of appropriate measures. For example, it is often the case that schools do not place computer-based tools in many classrooms, but rather centralize them in a computer laboratory, run by a set of 'high priests'.*

This design does not lend itself to a tight integration of technology into curriculum, because using the machines requires reserving the laboratory, getting the students there, ... For example, one common early measure of the effect of technology on education was the total time spent using the computers per class. Given a laboratory design, this particular metric is virtually guaranteed to be small – but interpreting this small amount of time on computer tasks as indicative of a failure of technology is probably short-sighted.

Again, *Thus, another possible source of interference with evaluation of educational technology is variance in the training of teachers, and the consequent differences in comfort level and curricular integration.*

On task factors, Merrill writes: *The nature of the task put to students and the knowledge they are expected to acquire should also*

[28] Douglas C. Merrill, "Evaluation of Educational Technology: What Do We Know, and What Can We Know," Institute on Education and Training, RAND, Santa Monica, CA, March 1995.

affect the evaluation metrics selected and their interpretation. A task could be primarily procedural in nature, requiring the application of a sequence of steps, but not necessarily drawing on many facts, known as declarative knowledge. Much of mathematics consists of procedural tasks, with the declarative portion devoted solely to selecting a procedure to apply. In contrast, the study of history involves the recognition of relationships between actors and events – declarative knowledge. Again, an evaluator must determine which of these two types of knowledge to measure and to interpret the results accordingly.

Finally, *Future evaluations of educational technology should not focus single-mindedly on simple outcome measures, such as post-tests, without also attending to more complex metrics describing the learning process, such as cognitive modeling. Furthermore, the research must also take the institutional factors into account, such as where a changed curriculum fits and what other changes must accompany its introduction. Similarly, each different task proposed as part of a new curriculum could require different sorts of evaluations.*

Larry Frase (ETS)

Frase wrote later summarizing his thoughts about the workshop. We quote on the issue of evaluation.

"The workshop showed that we can expect increasing demands for teacher training, partnering to achieve the best and most efficient educational implementations, demands for new research and measurement techniques and for more formal approaches to educational implementation, and demands for the development of broadly applicable telecommunications and educational software tools.

The technologically derivative revolutions in education and research pose a peculiar problem, because of the temporal discontinuities associated with technological change. Consider the time scales within which progress takes place in technology, education, and research and what these discontinuities portend. The rapid advance of computing speed and miniaturization is well known. The development of software, to make use of those capabilities, appears to lag, but research on software usability and models for educational implementation in different subject matters lags even more. Developments in educational software, in fact, are impeded by archaic models of educational theory.

"The idealized model of scientific research, as controlled experimentation leading to the resolution of major theoretical issues, is probably the wrong model for education in an age of rapid technology development. A more appropriate model would be an engineering approach, using the tools and techniques of science to evaluate evolutionary (formative) changes in educational products and processes. Companies, such as AT&T and IBM, have already pushed their research communities in this direction. It is only a matter of time before the academic community does the same.

"The concept of educational achievement, as represented by the measurement of outcomes, must change. The outcome evaluations reported in this workshop were all the more impressive, because they represent weak tests — many of the evaluative instruments were quite general, only weakly focused on the concepts taught and quite probably containing irrelevant elements. In short, the concept of educational achievement, as represented by global outcome tests, lacks conceptual validity. We know that educational outcomes consist of more than what we can see on a few test items. If we can better define the processes involved in thinking in different subject matter domains, more reasonable instruction and assessment will follow. To the extent that this is true, the data on the effects of educational technology presented in this workshop were an answer to the wrong question. In cases where the elements of instruction were developed concurrently with tests of achievement, very strong educational effects were seen."

APPENDIX 1

Workshop on Technology-Supported Student Learning: Outcomes, Effectiveness and Cost

Rand's Wash., D.C. Office 2100 M St., NW - 8th floor	Tel : 202-296-5000, x5321 Fax : 202-296-7960
Chair: Tom Glennan Co-chair: Arthur Melmed	Rapporteur : Jim Harvey Secretary : Nancy Rizor

Thu 1 June

8:30 AM - 9:00 AM	Continental breakfast	
9:00 AM - Noon	Opening remarks	Linda Roberts, U.S. Dept. of Education Ed Fitzsimmons, White House O.S.T.P.
	Three school presentations with discussion (50 min. each)	Steve Carr, Blackstock JrHS Fred Carrig & Bob Fazio, CC MS John Gibson, East Bakersfield HS
Noon - 1:00 PM	Lunch provided	
1:00 PM - 5:00 PM	Three school presentations with discussion (50 min. each)	John Hadley, Langley HS Susan Wolf, Northbrook MS, Beth Stroh, Taylorsville, ES
	Martin Huntley, BBN	School technology implementation strategy

Fri 2 June

8:00 AM - 8:30 AM	Continental breakfast	
8:30 AM - 11:30 AM	Douglas Merrill, Rand James Kulik, U. Michigan Dexter Fletcher, IDA Luis Osin, CET	What we can know; and how (25 min.) What the education data say (50 min.) What the training data say (50 min.) What Israeli school data say (50 min.)
11:30 AM - 12:30 PM	Lunch provided	
12:30 PM - 4:00 PM	Barbara Means, SRI David Dwyer, Apple Computer	Social and organizational supports (50 min.) The ACOT experience (50 min.)
	Group discussion	What do we think we know; what more should we try to learn; and how.

APPENDIX 2
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