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Abstract

Interactive technology facilitates modes of processing and/or sharing of information which until recently were unachievable. The expanded potential of the new machines allows them to gather and present information in several media at speeds which keep pace with normal attention spans for learning. They have the potential to increase educational effectiveness and efficiency by offering the student on-demand access to numerous services and by overcoming geographic and other barriers to the use of educational resources.

Interactive educational applications are the logical outgrowth of the advances in three key areas: (1) processing and storage capacity; (2) the ability to maintain and transmit the clarity of data signals among the components of individual machines and the nodes of networks; and (3) the compatibility of systems from different manufacturers. These conditions are increasingly commonplace in advanced industrial countries with sophisticated technological infrastructures and qualified technicians. Universities and researchers have been the first to incorporate interactive technology and electronic networks into their work by devising ways for computers to perform learning, classroom management, and information sharing tasks. Successful use in education is characterized by significant attention to curriculum design early in the process of innovation. Innovators usually possess a high degree of expertise in their specific fields and are motivated by a desire for increased prestige. Institutional structures which reward time spent in technological pursuits with peer recognition or professional advancement aid the development of interactive applications. Successful projects provide ample assistance to end-users in traditional or easy-to-use formats, such as telephone "help-lines" or help-desks manned by technicians.

The use of sophisticated technology is still conditioned by considerations which are unrelated to the potential of the machines. These sociological considerations often mean that the most basic services of high tech computers receive the greatest use, especially in initial phases. Strategies for successful use consider pedagogy and the sociological factors which influence use along with the technical capabilities of the interactive machines.

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Introduction

Interactive technology (IT)[1] is the forefront of advances in electronic information management and the implications of its use are significant for both the production sector and for education. Organized electronic signals allow information to be recorded and manipulated in a fraction of the time and at a fraction of the costs of mechanical systems of information management. Advances in this field have greatly reduced the transaction costs of gathering, organizing, storing, and distributing information. The result has been significant changes in information-intensive industries, such as the financial services industry, as well as general reductions in transaction costs for all firms which have captured the advantages of this new technology.

An education system which uses technology-rich instruction produces workers who adapt to technology in the workplace, both because they are familiar with technology in general and because its use raised the quality of instruction. It also aids the production of scientific advances which are incorporated into modes of production. The consequence is an increased ability to adapt efficiently to the technological changes which leads to sustained economic growth.

Higher education and research have pioneered educational applications of the new technology. The organization of higher education and research systems in countries with technologically advanced industrial economies is being affected in three ways: (i) administrative tasks at all levels, from the management of individual classes to the dissemination of research results, are being accomplished by computer mediated means; (ii) interactive technology is being used to improve the effectiveness of instruction; (iii) access to higher education is increasing as technological solutions overcome obstacles which previously isolated potential learners.

Meanwhile, higher education and research in developing countries is facing the crisis of simultaneous expansion of enrollment and deterioration financing systems.[2] The results have been the sharp decline in quality generally and the potential collapse of individual systems. In this context, interactive technology represents both a potential problem and a potential solution.

Universities in developing countries are facing accelerating obsolescence as developed countries improve the effectiveness and (in some cases) efficiency of their higher education and research systems. Unless the situation is addressed, the "knowledge gap" between developed and developing countries will widen, adding to the difficulties that developing countries face in a global economic environment where growth is increasingly knowledge-driven.

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1 All technology is interactive to some degree, but some programs are sophisticated enough to choose the direction of the application based on un-predetermined end-user input. For purposes of this paper interactive technology will be considered the electronically accomplished processing and manipulation of information which a computer directs based on continuous and open-ended input from an end-user. Networks are devices which mediate such interaction between two or more end-users.

[2]See Higher Education: The Lessons of Experience p.2.

Selective use of interactive technology in universities in developing countries can potentially overcome the resource shortages which are responsible for the decline of quality. Intelligent tutoring systems, interactive distance education, computer-mediated instruction, data retrieval, and electronic libraries have a combined potential to close the gap in learning and research opportunities between universities in developing countries and those in the developed world.

This can only be accomplished if use of these tools is well-targeted to the specific circumstances of a particular educational institution. Success is likely only where both the "hardware" considerations of the technological capacity of a given institution and the "software" considerations of the use and support of these systems for learning are well understood. This paper examines innovative uses of IT in universities, analyzes the sociological dimension of its use, and explores the factors which constrain the actual physical functioning of the interactive education technologies.

Part I examines innovative uses of the technology for the improvement of research and education. Part II explores the sociological factors which contribute to the successful adoption of the new technologies in university and research settings. Part III explains the basic conditions under which interactive technology is usable for educational purposes.

How Educational Interactive Technology is Used.

Innovations in Developed Countries.

The use of IT is rapidly increasing (the number of Internet subscribers has been increasing 15 percent per month for the last two years) very comparatively little data exists on types and quantities of actual use. Rapid changes in hardware and software create a fluid environment which encourages innovation but which is difficult to accurately survey. The National Science Foundation estimates that scientists at work account for less than 10 percent of the traffic on the Internet (Vasaturo, 1994).

There is general agreement, however, that a "convergence" of the technologies which support interactive learning is underway in developed countries. Stand-alone interactive programs and services available over networks are increasingly integrated to create media-rich learning environments. The mutual complementarity for learning of instructional software and information sharing networks is being recognized. Furthermore, any expansion and familiarization of learners with one aspect of IT aides the overall incremental process of adoption and efficient use of the technology in general.

Users of interactive CD-ROM adapt quickly to the Internet and vice versa, while applications which require the use of both are proliferating (Davies, 1994). The following examples illustrate successful adoption of IT to support learning and research.

The state of Maryland was able to provide dial-up access to the vast resources of the Internet for 96 percent of its 4 million citizens. Marylanders can access the Internet for the price of a local phone call, get e-mail accounts for $35 per year, and other services such as Telnet, which permits users to log-in to remote computers, and File Transfer Protocol, which down-loads file off the Internet, at similarly reasonable rates.

The fixed investment of about $1.5 million in this project also electronically connected the catalogues of all the libraries in the state system, as well as many school and university libraries. In addition, every high school library in the state was provided access to the Internet, special databases with state commercial statistics were put on-line and are available worldwide, as are on-line listings of municipal, state, federal government and community services. Statewide Inter-Library Loan requests will be handle on-line in the near future (Crawford, 1995).

The Internet's e-mail capabilities are changing modes of instruction in some universities. Clemson University gives each incoming student as well as all staff and faculty Internet access and e-mail accounts. Dr. Donald Polling (Polling, 1994) documented ten ways in which e-mail was an *effective supplement for management of instruction: (i) answering direct questions from students;* (ii) counseling; (iii) distributing class assignments; (iv) posting general class announcements; (v) giving occasional quizzes; (vi) direct communication with individual students; (vii) posting grades; (viii) providing help with homework or exam preparation; (ix) recording attendance; and (x) saving written records of class-work.

Dr. Polling noted the negative aspects of increased time spent answering student questions, lack of adoption of e-mail by a few stubborn students, and loss of the conversational nuances. Overall, he reported the use of e-mail to be "overwhelmingly positive and effective" because of (i) improved communications between himself and his students and among students themselves; (ii) increased adoption among students of other uses of IT during the course, including international remote exchange of information; (iii) increased overall cohesiveness of the class; (iv) an increase in reported feeling of "security" on the part of students who know that they have means of access to their professor; and (v) satisfying continuation of communication via e-mail with former students (Polling, 1994,).

Several electronic media can be integrated for the sake of curriculum presentation enhancement and improved lecture comprehension. Dr. Robert Cavalier, professor of philosophy at Carnegie Mellon University, developed a "course processor" which aids in the development and display of classroom materials. Lecture notes can be down-loaded prior to class and the professor's PC screen is displayed overhead during class, giving students and professor freedom from class record-keeping and allowing the class "to focus on content" (Cavalier, 1992). The professor can switch easily between text, graphics (including timelines, photos, and maps) and video segments.

The use of class-specific bulletin boards creates a round-the-clock electronic forum for classroom discussion, replacing the traditional "ten minutes for questions at the end of class." The combination of anonymity and 24 hours access has produced deeper meditations on issues, group advancement and independence from the professor, and collaboration among students

which has, according to Dr. Cavalier, 'the appearance of the phenomenon which John Dewey described as 'social intelligence.'"

Box 1: Electronic Classrooms: Connecting Students and Teachers through Medi-Rich Teaching Tools

At the forefront of this type of instructional improvement are electronic classrooms. These are Local Area Networks within a classroom with special display capabilities which allow computer screens to be projected overhead for all to see. In these educational settings each student has a terminal at their desk which runs both "course processing" and "database access" software. At the University of Maryland, Art History classes taught in the IBM Electronic Classroom provide each student's terminal with access to a database containing the Art History department's entire slide collection. Digitization of the slides permits computer analysis of images.

In U.Md's electronic classroom, students can also electronically conference as a class or in groups. The computer can analyze and display the results of the work on an overhead projector. The professor can take control of a student's screen, display it overhead, and input on it from his keyboard. The students can provide constant, anonymous feedback to the professor by pressing input keys which indicate whether or not they are following the lecture. The professor receives an automatic tabulation in graphical form of the percentage of students who indicate that they are following the material.

Medical education and research has gone the furthest in using the Internet's vast information-sharing potential. The National Library of Medicine licenses access to a database called Medline to Internet subscribers (mostly medical schools and universities). The database contains the abstracts and texts of over a million article from over 4,000 journals which can be down-loaded. Researchers can use various types of bibliographic assistance and keyword searches to locate data.

In addition to the resources available on Medline, the National Library of Medicine is creating a database of detailed, three dimensional pictures of an entire male and an entire female human body. Computed Tomography and Magnetic Resonance Imaging photos from nearly two-thousand "slides" will make a three-dimensional electronic cadaver available on the Internet. The 40 gigabytes of data, which would fill 70 CD-ROM disks, will be served worldwide from a single specialized computer.

Medical instruction is alongside medical research on the forefront of interactive technology. Dr. Jeff Galvin of the Department of Radiology at the University of Iowa Medical College, created and made available on the Internet the Virtual Hospital at the University of Iowa (Boettcher, 1993). Dr. Galvin pioneered on-line continuing education for physicians by employing the Internet to serve the need for up-to-the-minute information on diagnosis procedures and drugs. With $50,000 in seed money from his department, he put on-line patients' oral histories, digital photographs of ailments, audio recordings of data such as heart sounds, videotapes of surgery, and papers relevant to particular conditions.

Physicians may log-on the virtual hospital via the Internet and have access to these files as well as multi-media medical textbooks, the teaching files of prominent physicians, patient simulations, and current diagnostic algorithms. The technical details of digitizing the still and motion pictures and organizing the components of the teaching files are handled by a former journalist who now works full-time for the virtual hospital.

The College of Dentistry at the University of Iowa has created a stand-alone interactive education program which use the gigantic memory capacity of videodisk. Students learn diagnosis and problem solving skills from simulated patients. The simulations were designed by a group of faculty from five departments with the help of an instructional designer. The programming was done in conjunction with the university's computing center and the video center produced the videodisk.

The program consists of sixty patient simulations representing all fields but concentrated in oral pathology. The student sits in front of two screens. One displays the videodisk images the other displays text and graphics. The videodisk atlas presents high-resolution visuals of clinical, radiographic and histological features of the patients disease. Students gather visual and textual information, make a diagnosis, and prescribe the sequence of treatment. The program provides extensive feedback on the problem-solving process (Johnson et al. 1993).

The simulations are "served" to students over a local area network. A management system in the same central computer that stores the simulations assigns individual simulations to students on the basis of past performance and course requirements, tracks their progress, and generates reports.

Most of the $500,000 used to develop the system went to dental faculty salaries. Other human resources were the instructional designer who works with the faculty and the monitors who are present during simulations to assist with technical operation and hardware problems. The system can be operated as a stand-alone or served over a network from a central computer. Evaluations showed that students using the system out-performed the control group, which studied the same curriculum with traditional teaching methods.

The system has brought the university much recognition, including an award for innovation in teaching and an endorsement by the American Association of Dental Schools to help other schools develop similar programs. Success has been attributed to assembling a team of qualified content specialists, instructional designers, programmers and video specialists. Also crucial for success was the enthusiasm of Dr. Gilbert Lilly, the projects director, and the willingness of administrators to support the project vocally and with raises and promotion for the faculty who committed time to it.

Additional hardware expenditure for a university with a competent computing center which wanted to create this type of simulation would be about $7000 (for videodisk hardware and components). This figure does not internalize any of the uncounted costs of program development which are drawn from the intellectual and technological resources of the university or from industry or society at large (universities generally have a great deal of technology and human

capital at their disposal). The costs for such projects seem low because they account only for the hardware, not for the research and development costs.

In the field of IT nothing succeeds like success. Familiarity with media-rich systems fuels innovation and increases human capital while simultaneously facilitating further use and therefore driving down per-unit costs of high-tech inputs.

Planning for Interactive Futures in Developing Countries

The dictum that "nothing succeeds like success in interactive technology" could sound ominous to scientists and educators in developing countries, who are awakening to the consequences of being left behind in this revolution . Concerned about the isolation of African scientists, the African Academy of Science acknowledged that the technologies which permit IT "have been only tenuously established within the African Scientific Community."

Developers of networking systems for Africa are careful to point out the need to develop human resource capacity along with technical capacity. Even relatively simple technologies will not function without a sufficient number of qualified on-site personnel. FIDONET technology, the durable, low-tech system currently in use on the continent, provides relatively reliable "store and forward" e-mail, database searches, and limited local computer conferencing. This technology uses error-correcting modems to clean the distortion from noisy phone lines. The system, however, will not transmit graphics, audio, or video. It does not begin to approach the sophistication and capability of the latest systems from developed countries.

The Pan African Development Information System Network (PADISNET) was established by the United Nations Economic Commission for Africa. It is one of the largest networking projects in Africa, yet it has fewer than 20,000 subscribers. During its implementation it experienced problems with (i) a lack of skilled personnel to install and configure data communication equipment and software; (ii) insufficient mastery of computer-mediated communications software; (iii) unavailability of direct phone lines for communications links; (iv) poor communications lines; (v) management and administrative problems; (vi) unavailability of hardware and theft of equipment; and (vii) underappreciation of the benefits of personal contacts made through networking.

Sociological Constraints on the Use of Interactive Technology

The last problem identified by the PADISNET evaluation may be the key to solving the others because it places the emphasis on <u>how systems are used rather than what they can do</u>. Understanding and emphasizing use allows systems to propagate "organically." The growth that drives current demand for interactive services also creates demand for new and more sophisticated services, as users become experienced.

While networks provide a powerful tool for the completion of educational and scientific tasks and for the sharing of information, their simple use by scientist to "get in touch" may be their most fruitful use. This simple facilitation of communication has some of the most important consequences, especially for science.

A study of the uses of networks by scientists (Bishop, 1991) found that networks were more widely used in the initial phases of research than in the task completion phase. Scientists were likely to collaborate over networks during the problem definition, project preparation, and research formulation and design phases of an endeavor. Data collection, solution testing and initial data analysis were likely to be done off-line, reflecting a concern about ill-defined ownership of data and distribution of credit. Scientists tended to resume collaboration over networks for interpretation and presentation of results.

Studies on collaboration in science (Koch, 1994) found that scientists discuss their work and maintain collaborative contacts with those colleagues who have greatest physical proximity. The study concluded that "the social dimension of research relationships is as important for their continuation and productivity as is the task dimension" (Bishop, 1991). Collaborations increased as networks allowed scientists to create and maintain the social dimension of relationships through the "virtual proximity" to colleagues that electronic networks provide. Networks were influential in bringing collaboration to fruition through the maintenance of professional contacts and relationships even in instances where they were not used for task completion or sharing computer resources.

Bishop's study suggests that the adoption of networks by the elite of a given scientific discipline would be more crucial to their widespread use than the technical capabilities of the network. According to models developed by Merton and Storer, scientific disciplines perpetuate themselves by means of a self-selecting elite structure that is capable of bestowing prestige on its members. This elite structure, sometimes referred to as the "invisible college," sets standards of professional recognition according to the information it receives. Individual scientists exchange information in the hopes of gaining professional recognition. Increased professional recognition leads to not only improved reputation but also to greater access to resources with which to further carry out work. The more networks are adopted by elites, the more they will be used as channels for information and recognition exchanges. The proliferation of peer-review on-line journals indicates the growing role of elite structures in the legitimization of networks.

The University of Iowa's College of Dentistry simulation project illustrates this process. The success of the program was due to the enthusiasm of the project leader and the cohesion of a team of skilled professionals, despite the fact that "demands on their time" were constantly threatening completion of the project. Although project staff received some compensation, it is likely that this was less than or equal to what they could have earned in alternative pursuits. Crucial to the cohesion of the project team was the administration's policy of linking promotion to project participation. Furthermore, winning the American Association of Dental Schools (AADS) award for innovation in instruction for five consecutive years established the Colleges reputation as the leader in the field. The AADS's subsequent endorsement of Iowa as an expert

consultant for other schools wishing to create similar programs is increasing the access to resources of the staff involved along with their professional reputations.

Even in cases where no increase compensation accompanies advancement, recognition and status as innovators in the field can sustain many projects. Maryland's Internet provision project assembled a group of professionals who worked long hours with no increased compensation. A principal member of the project development and implementation team who estimated that his overall professional responsibilities grew by 25 percent to 50 percent due to the project reported that personal satisfaction and professional recognition as an innovator motivated his continued involvement (Wallace, interview).

***Box 2:* Training in Curriculum Design is as Important as Technical Training**

Course designers who work with IT almost universally report attention to training as essential for overall success. The University of Maryland's University College distance education curriculum designer stated that the success of their instructional courses which utilize IT comes from the separation of training into two distinct parts. Strict hardware and software capacitation is done by computer technicians while instructional design experts handle all other aspects of training which integrate content of courses with the capabilities of the machines.

Nearly every successful IT project surveyed has ample access to technical support at any time it may be necessary. On-line help for end-users or call-in "help lines" are the most common forms of assistance for students. When a professor is using equipment for a scheduled lecture, a monitor or technician who sole job is to assist the smooth functioning of the machines is often necessary. These positions can often be filled by students at relatively low cost to the program.

From the institutional point of view, prestige and the desire to maintain status within an elite structure can be a more influential factor in decisions to invest in interactive technology than the financial return on the investment. Once some in a group of universities decide to invest in the latest equipment, investment decisions for the other must balance the costs of investment against the losses suffered in ability to attract student and staff due to a relative diminution of reputation.

Another sociological factor which affects the successful adoption and use of IT is the familiarity and comfort of students and administrators with the technology. Dr. Daniel Goroff, a Harvard Mathematician who, in 1988, pioneered an interactive calculus course using audiographics, reported great success with the course itself. Dr. Goroff attributed the failure of administrators to adopt the course as a standard part of the curriculum, despite its obvious usefulness, to their unfamiliarity with the technology. Ironically, the same administrators who did not support the continuation of the pilot project in 1989 expressed interest in the project in 1994, when professor Goroff had moved on to other pursuits (Goroff, 1994).

Despite the applicability of much of the technology available to the sciences, humanities courses are often the point of entry for technology into a higher education system. The technology facilitates basic communication before it is used for advanced applications. At the outset, few individuals either understand or feel sufficiently comfortable with the new technologies to fully exploit their capabilities. The technological capacity of the IBM Teaching Theater is well suited to math and science instruction, but it is more in demand from business students and their professors, due to the relative ease of course adaptation and the immediate salability of experience with interactive technology. Diana Davies, Director Curriculum Development at U. Md's University College, states that the advantages to interactive technology in humanities courses are the general familiarity and comfort it produces with technology and an improvement in writing skills, due to the increased use of e-mail for assignments

New Tools: The Current Capabilities of Machines.

The sociological factors affecting use need to be combined with some understanding of the technological capabilities of IT if effective strategies for its use in education are to be achieved. The pace of change in this field often makes this latter task baffling, as one 'break-through" can relegate current cutting-edge technology to instant obsolescence. It is profitable to concentrate on the most basic conditions necessary for the physical functioning of IT rather than on the abstruse details.[3] Despite the proliferation of innovative applications for microcomputers, there are some fundamental characteristics of the machines which limit what they can accomplish.

The flow of electric current is the life-blood of any computer, including an interactive one. Advances in the ability to manipulate electricity have made degrees of interactivity commonplace today which were unfathomed less than two decades ago. The basic physical constraints on the ability of computers to manipulate electric current will continue to determine under what circumstances computers can accomplish sophisticated interactive tasks.

This is true because the heart of a computer is the Central Processing Unit (CPU) which processes the electronic signals which are displayed to the end-user as data. The CPU is a silicon chip composed of switches (called transistors) through which electric current either flows or waits. In this binary system, if the switch is on, the current flows through the transistor and creates one type of signal; if the switch is off, the current cannot flow and a different type of signal is created. [4] A switch which is on represents a "0" and one which is off represents a "1".

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[3]This paper will not exhaustively document the latest applications of IT. For such a survey see Boh, 1994.

[4] In some instances currently, light and laser beams rather than electric current create signals. However, currently this is only in specialized and supplemental applications, such as the use of lasers to read data from CD-ROM disks. Electric current flow is still by far the most important media for signal creation in computing.

These signals are useful because (i) they can be sent from one switch to another, which in turn can direct equal or greater amounts of electric currents to various physical locations within the computer to further this process of organized signal generation; and (ii) the results of these signals can be displayed in a form which is easily recognizable and manipulable by human-end users. The web of signals shows up on the screen as an application which awaits further input from the keyboard to continue organizing series of signals to accomplish tasks for the end-user.

The great advantage of computers is the tremendous speed, accuracy, and consistency with which they generate these organized signals. They are only essentially constrained by speed at which electric current flows through the conductive materials which make up the transistors and wires, and the speed at which the internal components of the machine can work together. The high conductive (low resistance) capacity of today's chips and wires means that little mechanical energy is needed in the process. Subsequently, despite doing vastly more complicated tasks at greater speeds, today's computers generate little heat and therefore, unlike there predecessors, physical degradation of the machine due to heat is not a concern.

From the technical point of view, interactivity is primarily technologically constrained by processing ability, signal integrity, and hardware compatibility[5]. From the technical point of view, interactivity is successful when (i) processing chips have enough memory capacity; (ii) wires can carry current properly; and (iii) signals produced by machines from different manufacturers or by machines which run different software can be translated and mutually recognized.

Processing Ability & Memory Capacity

As the ability of computers to rapidly process huge amounts of information in several media increases, so does the sophistication of applications which mimic heretofore normal modes of learning. When these applications can keep pace with an accepted "attention span of learners," they become powerful aides to instruction (Fletcher, 1991).

Much of the advance in interactive technology in this area, especially advances which affect non-network, stand-alone units, is due to simultaneous expansion of the processing capability of chips and quantum improvements in devices for information storage. The improvements in information storage have overcome some of the drawbacks of the digitization of all data files. Compared to analog storage of information, used by devices such as video cassettes or audio tapes, digitized data requires much more storage space. However, because a computer's logical circuit manipulate binary data (zeros and ones) it is difficult to integrate analog information into software while the maintaining flexibility necessary for educational applications.

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[5]The **usefulness** of interactive technology is, of course, constrained by the ability of software programmers to invent the command series which the machines can use to accomplish the goals of the end-user.

Box 3: Digitization of Sound and Video Data Files: Sophisticated Processing of Simple Digits

The most dazzling pyrotechnics of the world's most advanced supercomputers are only the successful completion of immensely long series of "if/then" and "either/or" questions and commands displayed in a recognizable form. We are dazzled because the simultaneous flow of electrons through millions of circuits (a single average PC micro-processing chip currently contains about 1.5 million circuits) does not become confused, whereas most people become confused if they try to accomplish more than one logical operation at a time. The size and complexity of these chains of data expand geometrically when computers handle frequent and sophisticated end-user input (as in interactive intelligent tutoring systems) or when they collaborate over geographic distance, but the nature of the interaction does not change.

Computers are constrained by the physical degradation of signal clarity, but not by mechanical fatigue. As computers attempt more sophisticated applications, their speed is limited by the need to break-down and direct signals to several specialized components which perform tasks. The revolution in interactive technology is the result of new forms of "displaying" data. Until recently, computers were limited to displaying text and limited graphics on their monitors. Now, new types of processors such as sound and video cards expand the ways in which computers can "display" information. Digital codes which represent instruction for speakers and monitors are sent to these special processors, which in turn produce voices, sounds, still and motion images.

Because such instructions are in digitized codes, the computer much more easily and flexibly integrate them into a family of components which displays an education application to the end-user. These binary signals form long chains to represent different pieces of data or commands. Since the computer can access any the chains of instruction at any point, it can display instruction material in several media "on demand." The machine to serves the student the combination of sounds and images that are demand by the learner for mastery of the material. To keep pace with the learner, the machine must analyze what data should be presented and coordinate its presentation to the learner. This process places great demands on the processing capabilities of machines.

For example, video images used in interactive learning programs are now usually transformed into digital files. Each "pixel" (picture element or cell) of each frame of the video must have a digitized code, which the computer can read and display as a color signal on the screen. The "motion" of the video is dictated by color changes as the computer reads the immense digitized data file. The demand for memory space to store all this information is enormous. While it is possible with some hardware to "overlay" educational applications onto analog video which does not exist as a file, the flexibility which these programs call for is really achieved in a digital format.

Digitization of sound, graphics, and video files is the key that unlocks the educational potential of technology because it permits on-demand access to any part of a file. On-demand access permits the pedagogically significant information in a file to be displayed to the learner according to the learner's needs. Text, graphics, sound, and video can be displayed individually or together as often as necessary for the student to achieve comprehension. In addition, the idiosyncratic pathway toward comprehension can be determined by either the student, the teacher, the computer program, or (as in most successful applications) a combination of the three. Cooperation among student and teacher in the analysis and correction of mistakes, which ultimately leads to the mastery of material, is enhanced by the computer's flexibility to conveniently present the relevant pedagogical information to the student in several media. Interactive computers can mimic some of a teachers crucial functions with great efficiency and without tiring.

The trend is toward programs which devolve more responsibility for the completion of educational tasks and the determination of the learning pathways to software designed by educators and implemented by computers. Early interactive educational applications simply marched students through material by prompting questions and requiring correct responses; they did not modify the course of instruction based on individual student comprehension. These early programs are analogous to teachers who use exclusively rote learning techniques. Neither are very successful in teaching students. Depending on the relative quality of the teacher compared to the application, the gains in efficiency <u>may</u> be accompanied by losses in quality. Even the most enthusiastic proponents of interactive instruction acknowledge the negative aspects of decreased student-teacher interaction.

Truly responsive interactive learning can now be accomplished, for example, with a digitized video of open-heart surgery integrated with computer-generated questions for the medical student. If the content of the software is written by a knowledgeable professor, it could likely approximate all the teaching opportunities that the professor has in the lecture hall or operating theater. Moreover, the answers the student gives can determine whether the program proceeds toward cardiac arrest or recovery, with the accompanying visual displays. The memory requirements for such applications are formidable, but so are the instructional possibilities.

The memory requirements are in the process of being overcome by various means, including the laser technology of Compact Disk Read Only Memory systems (CD-ROM for

short). Rather than tiny electro-magnetic storage, the CD-ROM depends on a laser to read data. The thinness of the laser beam path permits one CD-ROM disk to store over 500 times more data than a magnetic diskette. CD's are written at production and may be copied at fairly low cost. Currently, most CD-ROM computers don't permit end-users to write data on the diskettes the way they can with the magnetic versions, but the technology is evolving which may make this possible. Various combinations of magnetic and laser memory storage systems are expected to keep expanding the size of data files which PCs can manipulate.

Vast files only become effective applications if correctly processed. Chip capability is expected to continue to improve. Prior to the introduction of the 80386 chip (or "386" computer), processing chips could only handle 16-digit chains of zeros and ones, corresponding to 65,536 decimal numbers. The 80386 and 80486 chips can process 32-digit chains, corresponding to 4,294,967,296 decimal numbers (White, 1993). This doubling of the size of processable digit-chains permits a 2-3 times speed increase and a significant processing power expansion. Multi-media machines, which process these vast digitized files, only became feasible with the invention of this more powerful chip.

Several other hardware advances have increased the efficiency with which chips move and interpret signals. What is important for IT, though, is that the technological threshold which permits quick machine response and quality applications to run has been approached or crossed. The integration of computer-manipulable sound and video (less so, still) are now affordable features in many computers currently on the market

Signal Integrity & Data Transmission

Interactive technology encompasses more than the only interaction between a single end-user and a sophisticated application processed by a stand-alone computer unit. The advances in the ability of computers to share information and capacity across geographical distances is arguably the greater part of the information revolution. This ability is limited by the extent to which they can send and receive clear data signals.

Since all electric current of the same intensity is qualitatively indistinguishable, it makes no difference to a computer's central processing unit whether the signal arrived from an adjacent component fixed to the same circuit board or from a satellite on the other side of the world. All that matters is that the signal be in readable form. Moving readable signals to and from processing units involves (i) input/output devices in the machines themselves; (ii) wires or other modes for moving the signals across geographical distances (iii) software which creates a common language and traffic control system for information.

Although PCs were generally designed to be used as stand-alone units, they increasingly come with components which allow them to be attached through networks. Network interface cards integrate signals which have traveled through lengths of connecting wires into the computers circuitry. In addition, PCs have serial input/output ports which send and receive data in series. PCs can greatly increase their capabilities by connecting to network resources.

Computers can exchange signals directly if they share wiring connections that are sufficiently short to avoid distorting the signals. Machines which are physically connected can share some software which controls data flow; computers which generally provide data and direct traffic are called servers, those that generally request and receive are called clients or nodes. These configuration are known as a Local Area Network or LANs. LANs are the simplest, cheapest, and most common form of multi-node networks.

Basic LAN configurations send a stream of data through wires without directing it to a specific node. The specific nodes fish data from this stream as they need it. The large streams of data are only extendible to a few thousand feet before induced noise and distortion in the wires renders the signals unintelligible to the machines. These networks allow several network terminals or nodes to share hardware and files. One of the most common uses of a LAN is to let several nodes share one printer.

When geographically-distant computers which are not physically connected wish to communicate, they generally do so over telephone lines. Since telephone lines carry analog voices signals, the computer's digital signals must be modulated and de-modulated, using a device known as a MODEM (from modulate-demodulate). A modem establishes a connection with a distant computer, negotiates the standards of data delivery, and then, translates its series of zeros and ones into varying electronic frequencies which can be carried over phone lines and de-modulated back into zeros and ones.

No matter what the physical distance between machines, the interoperability of computers depends on having "reliable and high-quality connections between nodes" (Derfler, 1994). Such sharing of information is possible due to the invention of new programs which send, translate, and interpret transmitted data. This software is capable of cleaning and strengthening weak and distorted signals, up to a point. Excessive noise, interference, or interruption in current flow will cause a signal to be unreadable and its program to crash.

Box 4:

Capability of Data Transmission Lines Is Keeping Up With Increased Demand for "Bandwidth"

Globally transmitted signals are obviously going beyond the "local area" of the network. Prices for renting communications lines overland generally vary according to the speed with which the line can transmit data, measured in bits-per-second (recall that a bit is a zero or a one, the fundamental unit of computer operations). Lines sizes run from the lower-end of 2.5 k(ilobits) or 96k up to the T1 and T3 lines (which connect the major regional hubs of the Internet) which transmit 1.5 and 45 megabits-per-second respectively). The next generation of lines are expected to significantly increase data throughput capability, despite the fact that current lines are not yet at capacity.

The major difficulties in creating quality connections are that (i) flowing electrical currents encounter resistance in all conductive materials, which degrades the quality of the signal; and (ii) other currents close to these wires (from other computers, appliances, or high-tension wires) induce extraneous currents in wires which create interfering 'noise." Noise is cumulative over distances in metal wires. Fiber-optic cables, which transmit light rather than current, are not susceptible to induced noise.

Non-physical connections in networks are also possible. Radio transmitters can connect portable computers to networks over short distances (within a room or a building). Cellular phone technology or radio broadcasts from towers extends the range of these connections to roughly the size of a metropolitan area. Satellite connections can accurately send data world-wide. Satellite communication offer several advantages, especially to remote networks: (i) they are relatively interference free; (ii) connecting ground attennae to existing satellite networks is relatively simple, and; (iii) satellites are distance-insensitive. That is, one pays to rent time from a satellite transponder regardless of where on earth the messages originate or terminate. Physical wire connections (known as 'dedicated lines'), once installed or rented, usually permit unlimited use for a given distance, but charge varies directly with the length that the signal travels. Clearly, the particular needs of a given network influence choice of connection media. \

The technology for virtually unlimited data transmission exists and is affordable where use is high and a basic telecommunications infrastructure exists. Methods for transmitting data to remote locations may be accomplished at affordable unit costs, depending on the amount of data transmitted. Unit costs come down as use increases, and since most networks are under capacity, there is no cost other than connection fees for adding an additional user. This is the situation on the Internet, where high numbers of end-users can access networks at low or no per/unit cost.

Summary

Looked at from the point of view of the functioning of the machines, interactivity and interoperability are not conceptually difficult to understand. While myriad's of particular problems require the combined intellects of the best software and hardware engineers to overcome, the fundamentals remain constant. The ability of researchers and educators to put the power of the world's computers and its stock of knowledge at their service is fundamentally only constrained by the processing and memory capability of the machines, the ability to transmit large quantities of simple signals across distances, and the existence of a common language and traffic rules among different machines.

Box 5: Hardware Compatibility: Internet Protocols Permits Unprecedented Communications Among Personal Computers

The Internet, the world's network of networks, is essentially a globally expanded Local Area Network with very sophisticated traffic control and relay devices, including a few regional hubs (still funded by the National Science Foundation) which act as servers and connectors between various regions. Unlike LANs, which are physically connected by dedicated wires and which generally send all signals to all nodes on the network, every node (or end-terminal) on the Internet has an address. Because every machine on the Internet has a readable "address", the specialized computers which control traffic flow are able to direct information from one node to another with astounding speed and accuracy, regardless of the physical distance separating the two nodes.

The specialized computers called routers which manage traffic flow don't "serve" everything to all 20 million users on the Internet, they "route" data in packets over data-transmission lines to specified addresses. These routers are also very good at monitoring the congestion on lines, choosing alternate routes when direct ones are busy and sending data in ways automatically maintain the efficiency of all existing connections.

Routers are the computers which direct traffic on networks. The simplest are repeaters, which connect different types of wires, retime and regenerate data signals (strengthen and clean distortion) and then send the signal along the data path. Bridges, in addition to retiming and regenerating signals, read part of the address of a data packet and forward towards it ultimate destination. Unlike routers, bridges do not have the ability to choose best paths, read entire addresses, or make sure that data was received in by the node in a readable form.

Assuring delivery and readability among machines from different manufacturers required the development of standardized transmission software called Transmission Control Protocol/Internet Protocol (TCP/IP). These standards for data transmission are the result of a quest by the Department of Defense which began over two decades ago to link together computers from different vendors. Because of these protocols, owners of Apple and IBM compatible computers (as well as numerous other machines) can exchange E-mail messages freely. Standard protocols for E-mail remove the need for translating programs like those necessary to make files from different word-processing software compatible.

To grossly over simplify, the TCP portion of package translates data from your computer into packets which can be sent over different hardware on the networks and decoded upon arrival. The IP portion either knows the 32-bit address of every computer on the network and sends the packets of data to that address, or forward the packets closer to their destination where another router will be able to complete the connection. The reliability of TCP/IP is the key to the current unprecedented expansion in global computer networking.

Conclusions

Interactive technology facilitates modes of processing and/or sharing of information which until recently were unachievable. The substantial decrease in the transaction costs of manipulating, sharing, and storing information suggests that the pace of expansion of interactive technology will be sustained, with important implications for education. The expanded potential of the new machines allows them to gather and present information in several media at speeds which keep pace with normal attention spans for learning. They offer the student on -demand access to numerous services and are often not distance sensitive.

The convergence of multi-media and network technologies aids the student in the completion of learning tasks and in access to educational resources, both of which raise the effectiveness of education. Interactive educational applications are the logical outgrowth of the advances in three key areas (1) processing and storage capacity; (2) the ability to maintain and transmit the clarity of data signals among the components of individual machines and the nodes of networks, and; (3) the compatibility of systems from different manufacturers. These conditions are increasingly commonplace in advanced industrial countries with sophisticated technological infrastructures and qualified technicians but sophisticated applications will not function in the absence of such conditions.

Universities and researchers have been the first to incorporate interactive technology and electronic networks into their work by devising ways for computers to perform learning, classroom management, and information sharing tasks. Successful use is characterized by significant attention to curriculum design early in the process of innovation. Innovators typically possess a high degree of expertise in their specific fields and are motivated by a desire for increased prestige in those fields. That is, they seek recognition as teachers and researchers, not as technological innovators. Institutional structures which reward time spent in technological pursuits with peer recognition or professional advancement are apparently as effective as those which offer increased compensation. Failure of administrators acknowledge the importance of technological innovation as a legitimate professional activity greatly inhibits the collaboration necessary to complete interactive learning projects.

Successful projects provide ample assistance to end-users in traditional or easy-to-use formats, such as telephone 'help-lines" or help-desks manned by technicians. Projects which recognize that simple problems will recur, and which provide low-cost technicians (grad students or undergrads) to deal with such problems have greater overall success.

Finally, use of sophisticated technology is still conditioned by considerations which are unrelated to the potential of the machines. These sociological considerations often mean that the most basic services of high tech computers receive the greatest use, especially in initial phases. Business and humanities courses which use only E-mail for composition have proliferated faster than science courses at universities. Similarly, maintenance of social dimensions of research

relationships via E-mail is at least as important to research productivity as the sharing data and scarce computer resources.

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