The Technologies Driving the National Information Infrastructure: Policy Implications for Distance Education

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This study is one of three companion pieces on various policy themes emerging in distance education; the analysis is targeted to the pre-college level, but many of the themes generalize into all aspects of distributed learning. The other two studies focus on equity issues and on professional development. This piece centers on the emerging technologies and national priorities driving the evolution of the National Information Infrastructure, the new opportunities this creates for distributed learning, and the types of policy issues for distance education that arise as a result of these trends.

The first portion of this study presents an overview of how the emerging National Information Infrastructure is expanding our capabilities for distributed learning and what types of policy issues this evolution raises. The status of the America's current information infrastructures is then discussed to give a sense of the competing forces striving to shape the NII. In the next sections, the body of this paper describes briefly and in a non-technical manner the hardware and software advances driving new educational capabilities on the National Information Infrastructure. Alternatively, the reader can peruse Appendices A and B, which present this information in a more detailed and technical context, including two case studies of emerging educational applications.

Following these sections, the study depicts the implications of the NII, when completed, for distance education. The major education policy issues stemming from emerging technologies empowering the National Information Infrastructure are then discussed, with some potential policy interventions and instruments highlighted. This paper concludes with a summary of why the material discussed is of vital importance to the national interest.

The Emerging National Information Infrastructure

Distance educators today use a variety of channels—physical infrastructures—to transmit educational material and to communicate with learners, creating information infrastructures. Historically, distributed learning has evolved from physical transmission via surface mail (correspondence courses) to electronic communication (Schlosser & Anderson, 1994). Many types of physical infrastructures are currently used in distance education; these include the telephone system for faxing materials, audioconferencing and videoconferencing; cable television channels or wireless technologies such as microwave, broadcast television, and satellite for video-based programming; and computer networks like the Internet for transferring educational materials and computer conferencing. The National Information Infrastructure (NII) is evolving as a synthesis of these alternative media and the services they support.

Whatever vendors and media underlie its functioning, when completed the National Information Infrastructure will comprise a sophisticated web of high-performance computing and communication devices that have great potential value for distance education. As a cluster of capabilities, to users it will seem much like an external nervous system that empowers sensing, acting, and learning across barriers of distance and time. To accomplish this, the NII will weave together software tools across the spectrum of applications—including databases, multimedia, groupware, and artificial intelligence—into a single interface transparent to participants. However, at present many of the emerging technologies necessary for the NII are not yet able to deliver the full range of these features.

Even when its hardware and software are fully developed, for the National Information Infrastructure to become a powerful vehicle for distance education, a critical mass of knowledgeable teachers must create a “social infrastructure” that complements this technological platform (Hunter, 1992). As the Internet evolves in its capabilities and increasing numbers of educators gain access, watching innovative instructional interactions and ideas emerge is exciting. The best measure of a new medium’s value is whether new types of messages and human interconnections spontaneously develop; thus far, the rate at which “bottom-up” distributed learning projects are appearing is impressive.

For example, two types of distance education strategies rapidly spreading on the Internet are distributed science projects and "net-the-experts" help services. Distributed, hands-on science involves geographically dispersed learners gathering local data, then aggregating the results. Illustrations of this approach are National Geographic's "KidsNet" (acid rain), the Technical Education Research Center's "Global Lab" (ecology), and less formal endeavors such as a group of teachers measuring the circumference of the earth by the length of the noontime shadow cast by a standard object at various localities. As an alternative educational modality, "net-the-experts" help services bring together educators who need subject matter specialists in a particular curriculum area with domain experts willing to provide aid. One example is the American Foreign Service Association's "Diplomats-On-Line" project, which enables social studies teachers to access the knowledge of retired State Department foreign service personnel.

As more educators become involved with the Internet, other new types of distance learning approaches are developing. Such innovations demonstrate the importance of user-driven services on the National Information Infrastructure (i.e., participants can develop new applications and can exchange information among themselves, without waiting for services to be offered by firms that operate the NII). Unless a social infrastructure of user-driven evolution is encouraged, commercial providers will tend to focus on automating and scaling-up conventional profitable services (for example, home shopping) rather than facilitating the innovation of new approaches to distance education.

The following questions illustrate and prefigure for the reader the major policy themes that flow from the issues above:

- How can advances in National Information Infrastructure hardware and software best be translated into gains in educational effectiveness and excellence?
- How can government encourage the investment of private funds in distance education to leverage its own financial resources for instructional improvement?
- How can current federal and state education initiatives alter to build on the emerging national investment in the NII?

- How can the implementation of these new technologies be managed to minimize barriers to innovation?
- How can educational equity best be enhanced via these new technologies?
- What new problems, threats, and side-effects do distributed learning technologies pose?
- How can schools make maximum use of the physical infrastructure the NII is creating throughout society?

Students and educators can gain many benefits from the NII without needing to understand the details of its functioning or vendors' competition. However, comprehending how information infrastructures work and who provides them is important in charting the NII's evolution from a planning and policy perspective: When will each new set of features be widely available? What value will these add to the educational process? Who will control the delivery and pricing of those features? What equipment and expense will accessing these capabilities entail? What patterns of usage will emerge, and who may be left behind? What side effects and undesirable consequences may occur from implementing these technologies? The answers to these questions depend on fiscal and policy and technical factors, all of which educators can influence if they choose.

The special interest groups, vendors, regulators, judges, and legislators currently resolving these issues often have little information about the challenges and opportunities now emerging in distributed learning. As the history of television indicates, the initial policies that govern a medium are difficult to alter once its delivery systems mature and therefore are very important in determining its eventual impact on society. Unless distance education practitioners are involved in the ongoing design of the NII, including setting the policies that regulate its development, the infrastructure that emerges may be a hand-me-down from the business and entertainment sectors that is ill suited to instructional uses.

The Status of America's Current Information Infrastructures

Before depicting emerging technologies and related policy issues driving the evolution of the National Information Infrastructure, an overview of America's major current information infrastructures and the physical infrastructures that support them (i.e., computers, cables, telephones) will provide a baseline of where we are today. In keeping with the framework currently used by various national commissions, this policy study is written primarily from the perspective of the publicly sponsored Internet as the emerging metaphor for the NII. One advantage of depicting the National Information Infrastructure as a "network of non-commercial networks," as opposed to an upgraded cable television or telephone system, is placing the focus on capabilities for distance education rather than on proprietary technologies and media underlying these features. Also, present demand for distributed learning is growing most rapidly in computer conferencing and remote information access, rather than the video-based applications telecommunications companies and cable vendors are developing.

However, the ultimate form of the NII is still uncertain, especially given a recent shift in federal policy from the U.S. government providing central coordination and funding to private vendors competing under government regulation to build pieces of a decentralized National Information Infrastructure. Moreover, many people's visions of the NII include services beyond what a scale-up of the Internet could provide, capabilities more suited to the telephone or cable television systems. Therefore, rather than assuming that the Internet model will inevitably prevail, this study includes material on all the ways the NII might eventually evolve.

Today's Internet developed bottom-up from a series of prior computer networks (ARPANET, NSFNET) originally created by the U.S. Department of Defense and the National Science Foundation to facilitate communication among military and scientific researchers. As of May, 1994, the Internet comprises over 31,000 interconnected networks serving two million computers and tens of millions of users in eighty countries, with one new network added to the system every ten minutes (Leiner, 1994). Most participants use the Internet for electronic mail (e-mail), which is faster than surface mail, does not require the simultaneous presence of the participants (as do the telephone or teleconferencing), and is relatively inexpensive (at least from the perspective of many individuals, who enjoy free access because their organization pays the costs). Beyond e-mail, some participants use the Internet:

— to search for archival material;
— to access various computers at remote locations;
— to retrieve or send large packets of data;
— to access audiocasts, graphical materials, or videoconferences;
— to engage in simultaneous text-based conversations;
— to view webs of interlinked information; and
— a host of other emerging uses described later in this study, such as entering simulated environments to learn from surrogate experiences.

Over the next year, as the Internet moves from federal sponsorship to increasing management and pricing by commercial vendors, many educators are concerned that costs of access will rise and the types of messages allowed on this medium will be constrained.

As the description of emerging services above illustrates, a whole new class of capabilities is developing with which distance educators must become familiar to gain the full benefits of the Internet. In response, specialized educational telecommunications groups have evolved to provide a more transparent interface for teachers to access Internet resources. One example is K12 Network (Murray, 1993), which has curriculum-based computer conferences (e.g., life skills education), discussion groups in which dialogue is conducted only in a foreign language, electronic libraries for remote access of educational materials, and teacher-generated distributed science projects.

Reinhardt (1994a) presents a moderately technical overview of the major competing physical infrastructures (telephone, cable television, the Internet) vying to become the heart of the NII. The telecommunications companies providing POTS (plain old telephone service) have some advantages for distance education; phones are very reliable, designed for point-to-point communication, capable of tracking and billing individual usage, and almost universally available (ironically, schools are the one institutional exception). However, the telephone-based physical infrastructure suffers from the crucial disadvantage of limited bandwidth (as will be discussed later), which constrains the number and richness of the messages this installed base of media can transmit. Moreover, local phone service providers are currently regulated in a restrictive manner (e.g., they have little flexibility to give distance educators special rates) and have limited experience with providing content or services beyond simple transmission of data. As "smart telephone" technology matures (Udell, 1994), these disadvantages are waning in importance.

The advantages for distance learning applications the cable television companies have are access to sixty million U.S. households, broader bandwidth capable of carrying more complex messages, and some experience with providing content. However, cable television service is somewhat unreliable, is based on incompatible proprietary standards (making the interconnection of local cable franchises into a national network very difficult), and has little current capacity for significant two-way interaction (i.e., services are based on consumption rather than communication). As "set-top box" devices evolve that enable interactive television (ITV) and individual addressing of messages broadcast through the cable system (Halfhill, 1994), these problems with cable as an information infrastructure for distance education are eroding.

Other types of physical infrastructures are potential competitors for the NII as well. For example, the electric utilities have wires that run into virtually all buildings and a potential national backbone of largely unused fiber optic cable spaced every five kilometers across the country. Also, computer vendors are providing networking services not based on the Internet, such as IBM's Prodigy™, as are independent commercial services (e.g., America OnLine™). Since each of the groups described above would like to become the heart of the NII, all these alternative information infrastructures are currently engaged in an elaborate dance of alliances, acquisitions, and cutthroat competition, with hundreds of billions of dollars in revenue at stake. As discussed later, this situation creates many opportunities for distance educators to receive outside funds and technical support by entering into partnership with vendor coalitions, but also—because of intensive lobbying—greatly complicates the regulatory and political climate for distributed learning.

One important distinction between information infrastructures based on computer networks versus those currently implemented by telephone and cable television companies is the ease with which a longitudinal record of interactions can accumulate. Typically, services on a phone or cable television system are ephemeral; for example, a television program is broadcast once or twice, then is no longer available on-demand (unless the program is purchased). In contrast, the information archives on computer networks are generally cumulative; once accessed, data can readily be stored, cross-referenced, and retained as a growing body of interconnected material. To achieve its goals, the NII must be a cumulative information infrastructure, but offering non-ephemeral services is a major shift for the telephone and television providers. Similarly, user-driven services are easier to develop on Internet-like infrastructures than on current telephone and cable television media.

As discussed earlier, comprehending how information infrastructures work and who provides them is important in charting the NII's evolution from a planning and policy perspective. A brief, non-technical discussion on hardware advances driving the NII is presented in the next several sections. [Readers desiring more technical detail about hardware developments, a case study of how new hardware devices enable alternative models of teaching/learning, and references to resources for further exploration should skip the sections below through page 13 (up to "Implications of Hardware Advances for Vendors") and instead should read Appendix A ("Emerging Hardware Devices").]

Hardware Advances Driving the NII

The core hardware technologies that provide a foundation for the National Information Infrastructure are wide-area, broad-bandwidth networking and high performance computing. A national commitment by Vice President Gore and the Congress to High Performance Computing and Communications (HPCC) has hastened the development of these technologies. The National Research and Education Network (NREN) is an HPCC initiative oriented toward enhancing the collaboration of U.S. researchers and educators in studying phenomena and in distributed learning activities. Thus far, the "R" in NREN has received the lion's share of the funding—and researchers are more influential than educators in specifying the types of user applications the network should support—even though this program has been sold to Congress more on the basis of its "E" benefits.

Wide-Area, Broad-Bandwidth Communications

Unlike electricity or water, information can be transported in a variety of ways, so different types of communications technologies carry data around the NII. For all telecommunications (wireless, copper, fiber), an important issue is bandwidth. Bandwidth is analogous to the diameter of a pipe; higher bandwidth means more information per second is transmitted along a channel. What does increased bandwidth mean in terms of distance learning? For most users today, some types of wires carry conversational interactions (telephone), others deliver video (television), and still others enable data transmission (computer networks). Expanding bandwidth means that many users can simultaneously send combined voice/video/data information over the same central channel, with sophisticated switching devices delivering each message to its proper destination.

For distance education, high-bandwidth transmission enables powerful instructional technologies such as distributed, interactive multimedia. In addition, falling costs for networking technologies mean that more sites can afford access to distance education services on the National Information Infrastructure. However, learners accessing information infrastructures via low bandwidth networks or using older desktop computers with limited processing power and memory are locked out of many of the most useful distance education services (remote access to archives, videoconferencing) emerging on the NII.

Wire-Based Telecommunications

When the special capabilities of wireless technologies are not necessary, twisted-pair copper wire (phone lines), coaxial copper wire (cylindrical television cables), or fiber-optic cables that carry light waves via super-transparent glass are typically used to convey data. As networking technology improves, the capacities of all these media are steadily rising. Using telephone media today, at the low end an educator or learner might have limited, slow access to data through a modem (a device that links a computer to a telephone). At the high end, one channel of interactive video is possible on special leased telephone lines, which are still relatively expensive.

In contrast, cable television companies have much higher bandwidth along their installed medium of coaxial copper wire. Technical breakthroughs may soon expand this to enable 500 channels of television quality video. In practice, few users would want this many broadcast video channels; instead, providers would likely offer a mixture of broadcast video, interactive television, pay-per-view and video-on-demand, access to computer networks, voice telephony, and videoconferencing. However, the hardware cable television providers currently use is configured for broadcast only; retrofitting the installed base of television sets for interactive communication rather than passive consumption will be both technically challenging and expensive. Thus, both the telecommunications and the cable television companies face different set of problems that block an easy scale-up of their existing information infrastructures to provide the services promised for the NII.

No matter which type of vendor services the school , many older buildings lack the electrical outlets needed for classroom computing, necessitating expensive rewiring. The public pledges by vendors to wire "every school" get cabling only to the door of the building, the least expensive and challenging part of creating a classroom-centered infrastructure. In addition, the need for stronger links between school and home necessitates tackling the even more complex challenge of equitably upgrading the physical media running throughout neighborhoods—rich and poor—to provide full access to NII services such as education on-demand.

Overall, this is a very complex and confusing context in which to make decisions as a distance education provider or consumer. The level of service given types of media can support is shifting, and which emerging technologies will prove practical and affordable is unclear. Which providers will dominate the competitive market is also uncertain, and the costs of replacing an investment in the wrong type of infrastructure are very high.

Unfortunately, choices about wire-based telecommunications are intrinsically higher risk than decisions about computers. Individual computational devices have an effective lifetime of five years or so before a whole new class of capabilities is available at comparable cost by substituting newer machines. Because computers are purchased individually, educators can experiment with a mixture of low- and high-end devices with little penalty for correcting suboptimal initial choices. In contrast, wire-based telecommunications infrastructures have an effective lifetime of several decades, must be installed all-at-once to be useful, and are very expensive to replace. Since the level of likely demand for future services must be anticipated far in advance, planning for sufficient long-term capacity in telecommunications infrastructures is vital—better to overestimate the bandwidth learners need than to underinvest, barring access.

Therefore, educators planning to utilize distributed learning strategies are confronted with the difficult situation of making high-risk, expensive choices about telecommunications at a confusing and uncertain period in the industry's history. However, to ignore distance education and full access to the NII as options cheats a generation of students of reaching their full potential for learning.

Wireless Telecommunications

Wireless technologies (e.g., cellular phones, remote control devices, satellites) transmit and receive data without needing a physical medium. This is essential for mobile usage, which is becoming increasingly easy as the cost of handheld devices drops. Also, when putting in cables would be expensive or dangerous (e.g., in an old school with asbestos insulation and thick concrete walls), wireless telecommunications are very useful. Moreover, unless a site is connected to coaxial cable, wireless media are its only means of accessing high-bandwidth educational material, such as video, without the physical delivery of media to the site (e.g., shipping videotapes to a school).

Of the wireless technologies, distance educators historically have utilized broadcast media (e.g., satellite, broadcast television, microwave-based ITFS [Instructional Television Fixed Service]) because these provide cost-effective point-to-multi-point delivery. Wireless high-bandwidth broadcasting made interactive through telephone and computer linkages is a proven, flexible means of providing distributed learning services. Similar to the situation with wire-based telecommunications, emerging technologies are now increasing the interactivity and bandwidth of wireless media, creating a confusing array of new delivery options for distributed learning. However, since wireless devices are relatively limited in their bandwidth compared to wire-based delivery, all such services are likely to complement, not replace, existing telephone, computer networking, and cable television systems.

Unfortunately, an unresolved issue with all wireless media is the safe limits of human exposure to this type of radiation. For example, Germany, which has a history of deep concern for ergonomic issues (the effects of machines on humans) has recently classified all infrared devices as "lasers," even remote controls for television sets. This places severe limitations on their usage and on the types of devices that can be imported. Until unresolved questions about the health hazards from wireless radiation are answered through controlled studies, the use of these technologies, particularly around children, poses risks of potential concern to many educators. Yet wireless networking is a very promising means of giving schools, especially in older urban areas, access to the National Information Infrastructure. Further, young people will be exposed to this type of radiation from other sources whether or not schools adopt wireless technology.

Historically, educators have not taken full advantage of wireless frequencies dedicated to their usage. For example, instructional access to ITFS frequencies is now limited because much capacity restricted to educational purposes sat idle for years. When the FCC relaxed rules constraining usage of these frequencies, public-private partnerships formed that emphasized wireless cable television applications rather than instructional outcomes. If educators do not aggressively pursue the use of new wireless technologies, their eventual access may be limited as other providers appropriate frequencies potentially available for distributed learning.

Schools' Installed Base of Telecommunications

Teachers' and students' access to the educational services now appearing on the Internet is problematic, because few schools have information infrastructures capable of routing data to individual classrooms. Unlike higher education, K-12 institutions typically have neither host computers powerful enough to allow direct access to the Internet nor a web of telephones and modems that could enable individual Internet usage through dialing up a provider. Further, many schools do not have networks that transmit data around the entire building, and the networks in individual classrooms often have such low bandwidth that sending educational material from computer to computer is very slow. Interconnecting different types of networks within a school or district is also a complex technical challenge.

Some districts are now passing bond issues to enable building-wide installation of higher bandwidth networks and the purchase of Internet servers with specially configured software to allow a non-specialist to serve as systems administrator, but this reconfiguration process is slow and expensive. Further, even bond issues do not provide ongoing support in yearly budgets for equipment depreciation, repair, professional development, and monthly telecommunications access costs—expenses for which American businesses routinely budget, but not typically part of school districts' fiscal planning. Until a sustainable shift in schools' telecommunications base occurs, students are blocked from accessing the power of even today's Internet, let alone the emerging National Information Infrastructure.

Simple innovations such as wireless networks for basic file exchange and printing provide an inexpensive means of beginning to address these challenges. In addition, point-to-multi-point broadcast technologies such as satellites, television, and ITFS offer proven, cost-effective ways to provide schools with some degree of interactivity. Too often, however, districts isolate the power of this distribution system to a single room in the school, a specially configured "distance education" place that teachers can visit when needed. However, as with desktop computers, the greatest benefits for learning are attained when technological delivery is seamlessly integrated into every classroom rather than limited to a computer labs or special distance education classrooms.

As schools expand their use of local area networks to access the NII, human resource development policies will be vital in preparing educators to manage local "social infrastructures" that tap the full power of new physical media. For example, schools will need systems operators, computer conferencing facilitators, and people adept enough in software programming to customize interfaces to each district's specific educational goals. As with the introduction of desktop computers into schools, if too much emphasis is placed on hardware acquisition without regard to corresponding professional development, the devices purchased will be underutilized.

High-Performance Computing

At both ends of telecommunications channels, high-performance computing technologies decode transmitted data into messages people can comprehend and utilize. The power of processing chips is increasing exponentially, with doubling times of two years or less at constant cost; comparable gains are occurring in the capacities of memory chips and storage mechanisms; and emerging types of computer architectures enable new machines to be linked in ways that expand their collective power. As a result of advances in performance, computing technology has progressed from crunching numbers through processing data into manipulating all types of symbols and even simulating virtual "worlds."

Increased computational power potentially aids every aspect of distance education. Unfortunately, at present the installed base of computers in schools is old technology incapable of supplying the processing power necessary for new distance learning applications. The Apple II™ computers purchased by many schools even into the early 1990s are based on late-1970s technology. The other major type of desktop machines schools purchased during this period, MS-DOS™ computers with 80286 processors, is early- to mid-1980s technology. Today's PowerPC machines are the emerging standard for which current networking and productivity applications are written; these computers are literally hundreds to thousands of times more capable of processing information than the majority of the installed base now in K-12 schools. Without a shift to these more sophisticated devices, many of the most useful distance education services on the NII will be inaccessible to learners.

Merging and Shrinking Devices

As a capstone to these hardware advances, networking technologies, computing machines, and all other types of information devices are fusing together into a synthesis in which the whole (the NII) is more than the sum of its parts. Think of the information technologies as similar to a biological ecology, with each type of device a different species. First came the telegraph, then the telephone, the radio, television, videotape players, videodisc players... Now this ecology is incredibly crowded; every few months a new species appears, such as the Personal Digital Assistant. From their individual niches, a bewildering variety of species cooperate, compete, and become extinct, just as in nature's ecological systems.

The National Information Infrastructure is different than prior evolutions of information technology because this century-old trend towards a crowded ecology of devices is dramatically reversing. Because all hardware is becoming digital, different species can fusing together; the radio, television, telephone, copier, fax, scanner, printer, and computer will eventually co-exist inside a single case. In two decades, the ecology of information technologies will have only a few super-species remaining ("teleputers?" "compuvisions?") that synthesize the capabilities of all devices. Users will no longer wrestle with interconnecting many types of quasi-compatible technologies.

As hardware advances continue, information technologies will shrink in size until they vanish into everyday objects, such as pens, just as during the Industrial Revolution motors gradually disappeared from view inside the cases of machines. Eventually, the hardware portion of the NII will be largely invisible, universal within our everyday context.

Implications of Hardware Advances for Vendors

Beyond ease of use from a consumer's perspective, this fusing and shrinking of devices has enormous implications for the information technology vendors. Merging technologies mean merging markets. All the telecommunications companies, computer corporations, radio stations, television broadcasters, cable narrowcasters, publishers, on-line databases, newspapers, and libraries are realizing that the services they provide are fusing into a single type of business. The separate niches are disappearing in which isolated segments of the information industry enjoyed the benefits of limited competition.

As discussed later, if the evolution of the NII is shaped by policies that enable proprietary standards and bar open access, tens of thousands of current organizations will ally, acquire, and expire into just three or four partnerships that will be the core information providers for our society. If instead companies must provide an infrastructure that makes available to competitors both physical and semantic interoperability with their underlying proprietary technologies, a broader and more diverse mix of vendors will survive. Either way, this is the largest war in the history of American business, with hundreds of billions of dollar at stake, and educators can track its tactical maneuvers in the financial news every day.

This war is atypical for the business community because the outcome will be determined by factors beyond the quality and cost of competing products and services. Telecommunications is a regulated industry in which public service plays an important role, so judges, legislators, and regulators may well determine which alliances succeed, which fail. This opens up a window of opportunity for educators seeking financial and technical resources to implement new strategies for distributed learning. An analogy can be drawn to the early-1980s competition among cable TV vendors to receive exclusive franchises from communities. Those schools smart enough to participate in the bargaining process received substantial resources—buildings wired for free, dedicated channels, sophisticated production equipment—because the vendors knew public service applications would help decide who won.

In the same manner, during today’s war in the information services industry, educators who can demonstrate distributed learning applications that aid difficult societal problems can find vendors happy to share implementation costs in exchange for help with the regulators, legislators, and judges who are determining which coalitions will manage the NII. In addition, educators can form buying cooperatives to specify the capabilities they desire for distance education devices and to drive prices down through large-scale ordering. Further, educators can band together as citizens to demand that policy decisions favor investment and depreciation strategies by vendors that aid distance learning providers. All these approaches provide educators with a means of upgrading the computational and telecommunications hardware in schools without demanding that local communities pay the full price of the new information infrastructure.

Understanding emerging software capabilities and their implications for vendors and users is as important as understanding hardware advances. The discussion in the next several sections on software advances driving the NII is brief and non-technical. [Readers desiring more technical detail about software developments, a case study about educators using an emerging software capability, and references to resources for further exploration should skip the sections below through page 20 (up to "The Implications of the NII for Distance Education") and instead should read Appendix B ("Emerging Software Capabilities").]

Software Advances Driving the NII

Sophisticated software provides the instructions that enable hardware to process data into meaningful patterns and to accomplish tasks. Emerging classes of software important to the functioning of the National Information Infrastructure include multimedia/hypermedia, data visualization, artificial intelligence, groupware, distributed simulation, and immersion interfaces. Each type of software makes possible new ways geographically separated users can collaborate and learn, but bottlenecks in software development are impeding how rapidly new applications can take advantage of the power hardware advances are generating.

Multimedia/Hypermedia

One class of software applications important for distance education is distributed multimedia and hypermedia, ways of structuring information based on studies of how the mind assimilates ideas. Multimedia software displays data in multiple formats simultaneously (text, still images, animations, video, voices, sounds, music). This enables people with various learning and working styles (visual, auditory, symbolic) to peruse material formatted in their preferred mode of communication. Also, multimedia is interactive; rather than passively viewing preprogrammed instruction, as in educational television, users can tailor presentations by selecting paths through the material customized to their interests. In many training applications, multimedia has proven its ability to deliver high quality instruction at reasonable cost.

Hypermedia adds a further dimension to multimedia: associations among pieces of data. People can interrelate a wide range of ideas in part because human memory is associative; for example, the word "apple" conjures memories about the computer corporation, Snow White, Isaac Newton, the Beatles' record company, the Garden of Eden, orchards, and pies. Often, the interconnections among pieces of information are more important than individual bits of material; the route to knowledge is via comprehending patterns of relationships, not through storing isolated facts.

From an educator's perspective, the important trends to note about these developments in information creation and dissemination are:

—while still somewhat arcane, the interface applications students and teachers use for developing or accessing distributed learning materials are becoming easier, and

—the minimal hardware needed to run these multimedia/hypermedia tools is steadily rising in power, making the installed base in schools even more obsolete.

The spoken word, the written word, still images, and moving images each have their own types of rhetoric: formal structures for presenting material to aid rapid understanding. High-performance computing and communications have spawned multimedia and hypermedia as emerging styles of rhetoric, with multiple formats for presenting information, user selection of customized paths through material, and networks of interlinked ideas. To receive the greatest benefit from distance learning services on the National Information Infrastructure, both students and educators must master the new types of literacy associated with assimilating and creating communications in multimedia and hypermedia format.

Data Visualization

Data visualization is another emerging type of rhetoric; it enhances distributed learning by using the human visual system to find patterns in large amounts of information. People have very powerful pattern recognition capabilities for images; much of our brain is "wetware" dedicated to this purpose. As a result, when tabulated data compiling variables such as temperature, pressure, and velocity are transfigured into graphical objects whose shape, texture, size, color, motion convey different values of each variable, increased insights are often attained. For example, graphical data visualizations that model thunderstorm-related phenomena (e.g., downbursts, air flows, cloud movements) are valuable in helping meteorologists and students understand the dynamics of these weather systems.

As the National Information Infrastructure increasingly enables people to access large databases across distance, visualization tools can expand human perceptions so that we recognize underlying relationships that would otherwise be swamped in a sea of numbers. Literacy in understanding and creating data visualization images is an important emerging skill driven by the NII's real-time access to massive distributed learning resources.

Artificial Intelligence

Artificial intelligence (AI) programs impart to information technologies a semblance of people’s cognitive abilities. As one illustration, "expert systems" can solve narrow, but complex technical problems—such as differentially diagnosing various pulmonary diseases—but do not have common sense and the ability to learn characteristic of people's broad-based, evolving expertise. In a similar manner, “smart” neural networks enable machines to recognize speech or handwriting, converting people’s natural means of communication into digital code, but the computer does not comprehend the meaning of the messages it processes.

In the near term, the major impacts of artificial intelligence software on distance education will be (1) empowering people to flexibly interact with machines and (2) automating repetitive tasks. For example, specialized sensing devices and AI software allow users to input data in many ways (speech, handwriting, even gestures), eliminating the necessity of always using a keyboard. Similarly, voice output frees users from continuously watching a monitor; this is valuable in mobile distance education situations, such as when driving an automobile. In addition, machine-based "agents" with artificial intelligence can automate simple classification, reply, and retrieval tasks, freeing learners to focus on creative interpretation of educational services they are receiving and helping students to filter the massive archival information available on the NII.

Groupware

Artificial intelligence, multimedia/hypermedia, and data visualization are classes of software primarily targeted to enhancing an individual’s effectiveness; but we know that workplace environments increasingly emphasize teamwork and collaborative interaction. “Groupware” facilitates team performance; effective teamwork requires building common conceptualizations by communicating each person’s ideas, structuring group dialogue and decision making, recording the rationales for choices, and facilitating collective activities.

To accomplish this, groupware tools have several types of features not needed in software applications oriented to improving the performance of individuals. These include a window on the screen that presents the same information to all team members (a "What You See is What I See" interface). Another useful groupware feature is the capability to automatically archive the material displayed on each participant's monitor. Also, in meetings convened to accomplish structured outcomes (e.g. a debate), groupware can provide specialized information tools to aid each stage of the collective process. Finally, "telementoring" is an alternative model of instruction based on CSCW features; a virtual apprenticeship under the tutelage of an expert can bridge the gap between abstract concepts presented in formal education and the specific competencies required in particular work settings.

Given the power of face-to-face collaborative learning, facilitating distributed sharing of concepts, skills, and social interactions is fundamental to the evolution of distance education. In particular, by increasing the diversity of human resources available in every American classroom, this is a powerful means of enhancing equity. Virtual interactions via groupware can complement alternative means of increasing classroom diversity, such as bussing, and can bring outside expertise into urban and rural settings without the specialist devoting time to commuting.

Distributed Simulation

Another software capability that enhances shared performance and collaborative learning is distributed simulation. The NII is not only a medium for transmitting messages, but also a communal virtual environment that students can enter and explore. Just as single-user simulations allow an individual to interact with a model of reality (e.g., flying a virtual airplane), distributed simulations enable many people at different locations to inhabit and shape a common synthetic environment.

The U.S. Department of Defense developed distributed simulation software as a means of creating virtual battlefields on which learners at remote sites could develop collective military skills. The appearance and capabilities of graphically represented military equipment alter second-by-second as the virtual battle evolves ("dial-a-war"). On the NII, distributed simulation can empower a much broader range of educational uses (e.g., virtual factories, hospitals, cities). Defense conversion funding is now providing resources for translating military distributed simulation architectures into software systems that can run on today's desktop workstations, opening the educational and commercial market for applications of this technology.

The continual evolution of distributed simulations based on participants' collaborative interactions keeps these shared virtual environments from becoming boring and stale. In contrast to standard adventure games, in which you wander through someone else's fantasy, the ability to personalize an environment and receive recognition from others for a addition to the shared context is attractive to many people. Because of all these novel capabilities, distributed simulation on the

National Information Infrastructure is creating a powerful new method of communication. Since it focuses on modeling effective actions for others, this class of software complements groupware applications, which center on sharing ideas.

Immersion Interfaces

As an extension of distributed simulation, advances in interface technology also are enabling physical immersion in “artificial realities.” This class of software application involves manipulating human sensory systems (especially the visual system) to enable the suspension of disbelief that one is surrounded by a virtual world. Using an immersion interface, the impression is that of being inside an artificial reality rather than looking through a computer monitor "window" into a synthetic environment: the equivalent of diving rather than riding in a glass-bottomed boat. The entertainment industry is devoting substantial resources to developing inexpensive immersion interface technologies that could sell into the large market for videogames. This provides a potential installed base of devices that could deliver educational applications, including immersive simulation in synthetic environments that model real world social, economic, and political issues.

Young people like magical alternate realities; and the entertainment industry profits by providing amusement parks, videogames, movies, and television programs that build on this fascination. Educators too can profit, in a different way, by building eerily beautiful virtual environments that arouse curiosity and empower shared fantasy, leading to guided inquiry. If we forswear "edutainment," we risk losing the generation growing up with high-performance computing and communications to the mindless mercies of arcades—or consciousness altering drugs.

The emerging software capabilities underlying distributed learning on the NII include multimedia/hypermedia, data visualization, artificial intelligence, groupware, distributed simulation, and immersion interfaces. Features of these software applications that also satisfy the needs of the entertainment or business markets will be readily available to educators. However, software capabilities customized to educational uses have consistently lagged the advance of computing and communications hardware (Melmed, 1993); in the absence of policy interventions, this will also occur for the National Information Infrastructure.

Some of this lagging is inevitable; new and innovative uses of information technology will always be at the margin—first utilized by the wealthy, hobbyists, and business people reaching for a competitive edge—and only later becoming standard in resource-strapped educational settings.

The new software approaches hardest to implement are be those requiring changes in the installed base of computers and networks now in schools. Distributed multimedia applications that require a new PowerPC-level machine, an Ethernet port, and a CD-ROM drive will be slower to diffuse than e-mail enhancements that necessitate adding inexpensive random access memory to students' current machines. Vendors often deliberately limit the compatibility of emerging software and networking applications as a means of selling their latest hardware, forcing schools either into expensive upgrades or into limited access to powerful new educational services.

These issues particularly impact schools with limited financial resources located in communities with little opportunity to supply added dollars beyond state and federal funding. Thus, this situation widens gaps in equity; the more rapid the advance of the NII, the larger the distance between leaders and laggers in implementing new instructional technologies. Developing policies that mandate a "moving target" of minimum distributed learning services all schools must provide—without slowing the advance of new approaches while everyone catches up to this "floor" of required access—is very difficult.

The Implications of the NII for Distance Education

All the hardware and software capabilities described above reflect a steady evolution in communications technology. The advent of "motion pictures" about a century ago ushered in civilization's fourth medium, another dimension to communication beyond spoken language, written language, and still images. Later, new technologies appeared to embellish the capabilities of moving images: broadcast and narrowcast television, videotapes, videodiscs, high-performance computing and communications, multimedia and hypermedia, distributed simulation, immersion interfaces. Now, enhanced with artificial intelligence, visualization, and groupware, all of these are merging into a synthesis so far beyond its individual parts that a new medium is evolving: the NII.

Part of the distance education implications of this fifth medium center around its channel, which is rich and powerful enough to mimic the meta-medium in which we live: the real world. Other instructional implications come from the environments for learning that this channel makes possible. Together, channel and content form the message of this new, immersive medium, which at present is both fascinating and frightening.

Any powerful information technology is a double-edged sword: a source of either propaganda or education. To succeed as a vehicle for learning rather than for bias, as well as to compete with the escapism that entertainment-across-distance fosters, distance education must aspire to a mission more powerful than automating and broadcasting traditional instruction. The most important ways the NII enables alternative models of distributed learning are:

- knowledge utilities that enable access to experts, archival resources, authentic environments, and shared investigations;
- virtual communities that provide support from people who share common joys and trials; and
- shared synthetic environments that, through illusion, help us to appreciate and understand reality.

Knowledge Utilities

"Knowledge utilities" are the most familiar of these capabilities. We are accustomed to asking a well-informed person in our immediate vicinity for guidance, to consulting printed information or watching a news program, to visiting exhibits (such as a zoo) to learn about different types of environments, and to conducting informal experiments to understand how reality works. Often, these information gathering and creation activities are constrained by barriers of distance, restricted access, scheduling difficulties, and the limits of one's personal expertise in scientific investigation.

Via the National Information Infrastructure, educators and students can join distributed conferences that provide an instant network of contacts with useful skills, a personal brain trust with just-in-time answers to immediate questions. In time, these informal sources of expertise will utilize embedded groupware tools to enhance collaboration. On the NII, webs of multimedia information enable structured access to archival data; these are constantly augmented by additional links to new items. Eventually, visualization and artificial intelligence-based guides will facilitate navigating through huge amounts of stored information.

Virtual exhibits that duplicate real-world settings (e.g., museums) are emerging as part of the NII; these environments make possible a wide variety of experiences without the necessity of travel or scheduling. Within a decade, distributed simulation and immersion interfaces may intensify our ability to learn within these "mirror worlds" (Gelertner, 1992). As discussed earlier, distributed science projects enable conducting shared experiments dispersed across time and space, each team member learning more both about the distributed phenomenon being studied and about scientific investigation than possible in isolation. Combined, all these capabilities to enhance information gathering and creation can make the National Information Infrastructure a "knowledge utility."

However, simple access to data does not automatically expand students' knowledge; the availability of information does not automatically create an internal framework of ideas that learners can use to interpret reality. While presentational approaches transmit material rapidly from source to student, often this content evaporates quickly from learners' minds. To be motivated to master concepts and skills, students need to see the connection of what they are learning to the rest of their lives and to the mental models they already use. Even when learners are drilled in a topic until facts are indefinitely retained—we all know that the sum of a triangle's internal angles is 180 degrees—this knowledge is often "inert"; most people don't know how to apply abstract principles in solving real-world problems.

Using distance education to automate conventional models of "teaching by telling" is only the first step toward reaching the true potential of the NII for enhancing learning. To move students beyond assimilating inert facts into mastering better mental models, teachers must structure learning experiences that highlight how new ideas can solve intriguing problems. However, achieving this shift is very difficult within the constraints of traditional school structures and culture, such as:

— little professional development for teachers on how to incorporate new models of learning into their pedagogical style and classroom management techniques;

— class sizes too large for teachers to facilitate collaborative inquiry experiences, with little flexibility to pool students into big presentational settings as a means of enabling small-group sessions;

— the rigid structure of the school day, with short blocks of time allocated for each subject;

— curricular segmentation into disciplines, with narrowly trained instructors, subject-centered texts, and tightly focused tests; and

— the expectations of both students and community for conventional instructional processes.

As one illustration of how time constraints hamper distance learning, the live professional development programs presented by the U.S. Department of Education's Star Schools are taped by most participating districts for later viewing. The inflexible scheduling of teachers' time results in losing the opportunity for customized interaction with expert resources. While taped materials can be designed to allow some types of interactivity, freeing teachers' schedules for spontaneous learning activities is an important lever for educational improvement.

The curriculum is already overcrowded with low-level information; teachers frantically race through required material, helping students memorize factual data to be regurgitated on mandated, standardized tests. Using the NII as a fire hose to spray yet more information into educational settings would make this situation even worse. Without skilled facilitation, many learners who access current knowledge utilities will flounder in a morass of unstructured data. New media create new forms of literacy and rhetoric; mastery of these is central to success in the post-industrial workplace. One emerging form of literacy is transforming archival information into personal knowledge, building on the new models of learning described earlier.

This requires educational tools that empower knowledge construction by unsophisticated learners, helping them make sense of massive, incomplete, and inconsistent information sources. When these types of tools are embedded in all knowledge utilities on the NII, it will serve as a powerful force for enriching the information environment of many schools, modeling new pedagogical strategies for teachers and parents, and aiding individuals engaged in informal learning. Achieving this vision will require many people who care about distance education to work together, both constantly updating distributed resources for information gathering and weaving those knowledge utilities into the curriculum and culture of local schools.

Virtual Communities

Virtual communities that provide support from people who share common joys and trials are a second capability for enhancing distributed learning. We are accustomed to face-to-face interaction as a means of getting to know people, sharing ideas and experiences, enjoying others' humor and fellowship, and finding solace. In a different manner, distance education via the NII can satisfy these needs at any time, any place. Some people (shy, reflective, comfortable with emotional distance) even find informal written communication often more authentic than face-to-face verbal exchange. They can take time before replying to compose a more elegant message, as well as to refine the emotional nuances they wish to convey. This alternative conception of authenticity may reflect a different dimension to "learning styles" than the visual, auditory, symbolic, and kinesthetic differentiations now used.

One challenge for distance education is to balance virtual and direct interaction in sustaining communion among people. A relationship based only on telephone conversation lacks the vibrancy that face-to-face interchange provides. Similarly, while digital video will broaden the bandwidth of virtual interactions on the National Information Infrastructure, teleconferencing will never completely substitute for direct personal contact. We can expect a variety of social inventions to emerge that provide the best of both worlds; for example, national professional conferences may sponsor pre- and post-conference virtual communities on the NII that enable participants to make the most of the limited face-to-face time they have. In many regions across the U.S., community networks are emerging that, among other missions, enhance education by enabling distributed discourse among all the stakeholders in quality schooling (Schuler, 1994).

To dramatically improve learning outcomes by evolving to new pedagogical strategies and school structures, distance educators also need the virtual communities the National Information Infrastructure makes possible. Learning is social as well as intellectual. Individual attempts to make sense of complex data can easily fail unless the learner is encouraged by some larger group that is constructing shared knowledge. In addition, institutional evolution is a communal enterprise; educational innovators need emotional and intellectual support from others who have similar challenges in their lives.

Moreover, formal education comprises only 19% of how students spend their time. No matter how well schooling is done, achieving major gains in learning requires that the other 81% of pupils' lives be educationally fulfilling as well. This necessitates close cooperation and shared responsibility among society's educational agents (families, social service agencies, workplaces, mass media, schools), a vital goal for virtual communities on the National Information Infrastructure. In particular, involving families more deeply in their children's education may be the single most powerful lever for improved learning outcomes. Virtual parent-teacher conferences and less formal social interchanges make such involvement more likely for parents who will never come to a PTA meeting or a school-based event.

Creating a sense of communion among a distributed group linked by low to moderate-bandwidth networking is a complex challenge. Some people favor technology-mediated communication as their most authentic way of sharing ideas and enjoying fellowship. Most people prefer face-to-face interaction, but find the convenience of just-in-time, anyplace access to others outweighs the disadvantages of distributed sharing of ideas, experiences, and support. Groupware tools, a capable moderator, and shared interactivity and control are important for sustaining the vitality of virtual communities, as is occasional direct contact among participants.

One illustration of a distributed learning use for virtual communities is peer tutoring. This instructional approach aids all students involved both intellectually and emotionally, but is difficult to implement in traditional classroom settings. Outside of school, virtual interactions enhanced by groupware tools readily enable such student-student relationships, as well as preparing their participants for later use of distributed problem solving techniques in adult workplace settings. The telementoring strategies described earlier are another illustration of applying virtual community approaches to distance education. The recent evolution of services on user-driven information providers such as America Online™ illustrates the value that participants place on virtual community capabilities.

Shared Synthetic Environments

The third generic National Information Infrastructure capability for enhancing distributed learning is shared synthetic environments that, through illusion, help us to appreciate and understand reality. In contrast to the factual orientation of knowledge utilities, part of why we read fiction or watch dramatic productions is to escape the ordinary in a manner that increases our insights or refreshes us to plunge back into real world challenges. One good way to enhance creativity is to make the familiar strange and the strange, familiar; virtual worlds make abstract things tangible and vice versa. The ability to immerse oneself in an artificial reality with magical properties opens up new horizons for understanding and appreciating the real world, with its laws and limits. Shared, immersive, and interactive, virtual experiences on the NII can complement books, plays, television, movies, and concerts in their ability to take us beyond the daily grind—the challenge is to move past pure escapism into metaphorical comprehension and catharthis.

One usage of synthetic environments in distance education is simulating scientific equipment and experiments. In some aspects of science, giving students guided inquiry experiences using physical apparatus is difficult, expensive, time-consuming, and even dangerous. Other important topics are too complex to simulate in classroom settings (e.g., how manufacturing systems convert raw materials into products, the flow of information as Congressional decisions are made). As a result, these subjects are taught by less effective methods such as lectures and reading; or this content is omitted from the curriculum, leaving students ill-prepared as future workers and citizens.

Simulation via synthetic environments provides a means of effectively teaching these types of material. Through guided inquiry, students comprehend how changing an underlying process alters the outcomes of experiments, production systems, and political structures. This builds important design skills; for example, educational innovators can use synthetic environments to model alternative ways to structure flows of information and pupils in school settings. Such simulations provide insights on how to evolve toward more effective learning environments.

Knowledge utilities, virtual communities, and synthetic environments potentially enable alternative models of distributed learning. Beyond the use of these new types of learning modalities in educational settings, what will people really purchase for home use from the plethora of potential on-line services? A recent public opinion survey conducted by *MacWorld* magazine (Piller, 1994) found a very different set of user preferences than the conventional wisdom about the National Information Infrastructure as expressed by vendors and policy setters. While video-on-demand and entertainment services are assumed by providers to be what consumers want, the responses *MacWorld* obtained indicate that the number one preference for on-line services was voting in elections, followed by being a part of public-opinion polls; participating in interactive, electronic town-hall meetings; and sending e-mail to elected representatives.

Learning activities such as on-demand access to reference materials, distance education courses and how-to programs that allow distributed interaction with a class or instructor, interactive reports on local schools, and access to information about government services and training all ranked above video-on-demand. Thirty-four percent of the sample would pay $10 or more per month for distance learning; only nineteen percent would pay $10 or more per month for video-on-demand or entertainment services. If this survey is typical of the emerging market for NII services, edutainment and education may play a more major role than the powers-that-be expect. Both America Online™ and Prodigy™ have found ways to make money serving their subscribers' educational needs. Perhaps mindless escapism is less a threat on an communicative medium than on a consumption-only channel such as television. On the other hand, the readers of *MacWorld* are a non-representative subset of potential NII participants; more entertainment-focused viewers responding to a *TV Guide* survey may well have generated a very different set of responses.

This study's discussion to this point provides a context for delineating the major policy issues for distance education stemming from emerging technologies empowering the National Information Infrastructure. The next sections of this study describe these policy issues and their interrelationships, at times suggesting possible policy interventions and instruments that could address these concerns. As a means of highlighting, policy actions that might be taken are presented *in italics.*

Policy Themes in Distance Education

Overarching policy themes that affect all types of distance education are the evolution of hardware, software, and social infrastructures; excellence; equity; and the implementation of new models of teaching/learning. Since this study centers on technology drivers for distance education, this discussion will focus on those policy issues most closely related to that topic. Hardware, software, and social infrastructure evolution issues focus on how vendor and government creation of the National Information Infrastructure poses challenges and opportunities for distance educators. Excellence concerns center on standards and accreditation, as well as user-driven evolution of NII services. Equity concerns focus on ways that powerful learning technologies can narrow —not widen—existing gaps in educational opportunities and outcomes. The implementation of new models of teaching/learning necessitates tackling thorny policy issues that stretch beyond educational applications, such as protecting intellectual property and individual privacy.

Policy Issues Related to Evolving Hardware, Software, and Social Infrastructures

The major hardware-related policy issues for distance education center on two themes: how the war among vendors poses challenges and opportunities for distributed learning, and how government creation and regulation of the National Information Infrastructure influences the options of distance educators. The discussion above has prefigured the former theme; educators are a pawn in a large, long war among information technology providers as to which alliances will dominate the NII. As a group that could demonstrate public service applications, distance educators have leverage to seek funding and expertise from vendors to retrofit existing information infrastructures. However, since education to date has been a relatively unprofitable market, information technology corporations might sacrifice the best interests of schools to the expediency of focusing on business, entertainment, scientific, and medical applications for the National Information Infrastructure.

The major software-related policy themes for distributed learning are similar to the hardware-related issues. As with new types of computing and networking technologies for distance education, government policies (e.g., investment and depreciation incentives) are needed to encourage vendor development of software applications specialized for distributed learning. Resources for studies on new types of pedagogical strategies (such as data visualization) are also important, as is research on the relative effectiveness of different kinds of distance education. Some software originally developed for military purposes (e.g., multimedia authoring systems, distributed simulation architectures) has potential for dual use conversion to pre-college distance education. Finally, sophisticated software requires a computational and telecommunications infrastructure in schools much more powerful the existing installed base. The financial challenges involved in retrofitting, particularly for old urban and rural schools, threaten educational equity.

As discussed at several points earlier in this document, providing sufficient resources to enable development and research—building social infrastructures to create evolving models of distributed learning—is essential to achieving the full educational potential of the NII. So that teachers can incorporate distributed learning into their everyday practice, policies that ensure funding for professional development are also vital. Pre-service and in-service models for distance education skills are beginning to emerge (LeBaron & Bragg, 1994). This topic is so important that a separate policy study was commissioned to chart its dimensions.

Possible policy interventions:

— ***Ensuring that educational needs are paramount among the HPCC National Challenges.*** *As one illustration, the proportion of HPCC funding devoted to educational applications on the National Research and Education Network could be increased. Also, a larger percentage of educators could be represented on the various bodies designing, funding, and regulating the National Information Infrastructure. For example, at present only two of the twenty-six members on Vice President Gore's Advisory Council on the NII are educators.*

— ***Enabling partnerships between public education and the private sector.*** *Such alliances require careful policy consideration, as they raise issues of public intervention in free market mechanisms and incite concerns about commercial interests biasing the school curriculum (e.g., Whittle's Channel One project). The policy instruments that could be used are illustrated by the dual-use funding the U.S. Department of Defense is currently providing to encourage government-business alliances. As another example, the National Institute of Standards and Technology, U.S. Department of Commerce may begin an Advanced Technology Program initiative in Learning Technologies; this could enable government support for educator/industry coalitions to develop new approaches to distance education.*

These federal programs are primarily oriented to developing hardware and software capabilities for enhancing physical infrastructures; comparable programs could be initiated by other agencies to build social infrastructures. For example, although public/private partnerships are only a small part of its activities, the National Science Foundation's program on Networking Infrastructure for Education is a step in this direction. As another illustration, the National School Network Testbed (funded by the National Science Foundation) is a promising approach to attracting large-scale investment in distance education by industry, as well as local, state, and federal agencies (Bolt, Beranek, & Newman, 1994).

The publishing industry is a particularly promising target for such partnerships. Policy initiatives oriented to commercializing current federal R&D efforts through partnerships with publishers could bring substantial amounts of private funding into improving distributed learning. In recent years, National Science Foundation funding guidelines have stressed such alliances; these illustrate the types of policy instruments that could be used. As discussed later, revising copyright and intellectual property policies to make software and *materials development for distance education more attractive is an important incentive for publisher involvement.*

— ***Providing funds to study challenges and opportunities unique to distributed learning.*** *Such studies could range from assessing the potential side-effects of wireless radiation exposure to demonstrating the potential of new pedagogical approaches based on nomadic devices to forecasting the evolution of HPCC technology so that educators can make wise choices on current infrastructure investments. In particular, developing generalizable models for aiding schools with the complexities of physical infrastructure planning would be useful. Pilot projects illustrating the advantages to educators of using new frequencies set aside for their benefit is also a promising means of ensuring that opportunities are not lost through inaction.*

— ***Reformulating the fundamental technical approach of the U.S. Department of Education's Star Schools projects.*** *Scaling up the Internet to include satellite-based services may be a better model for the future of distance learning than scaling up satellite delivery to include the Internet. Star Schools are currently swimming against the tide by taking an "interactive television plus..." approach to their evolution. The fundamental assumption of replicating the traditional classroom model across distance via technology is suboptimal. More attention could be focused on innovative networking technologies for distance education, such as net-the-experts and distributed science projects.*

— ***Favoring educational applications via regulatory, investment, and depreciation policies.*** *As an illustration, the allocation of licenses for wireless frequencies could place higher priority on potential applications for learning. The policy instruments necessary are exemplified by legislative initiatives such as Senate Communications Subcommittee Chairman Inouye's bill (S. 2195) that would reserve up to twenty percent of the space on the NII for schools; libraries; public broadcasters; and non-profit organizations that promote local artistic, political and social speech. In all such policy interventions, providing funding mechanisms is essential to ensure that the vendors creating the National Information Infrastructure find such mandates practical and sustainable.*

— ***Creating dedicated sources on ongoing financial support for innovation in distributed learning.*** *As one example of a policy intervention, rather than the Federal Communications Commission auctioning off the rights for new allocations of the electromagnetic spectrum, telecommunications companies could rent these rights, with the revenues dedicated to federal support for distance education initiatives.*

— ***Defining the relative roles of the States and the Federal sector in funding and regulating the educational aspects of the NII.*** *State-level cooperation could be enhanced via strengthening joint initiatives with the Governors and the Chief State School*

> *Officers. Federal NII-related education and training activities (e.g., the National Science Foundation's State Systemic Initiatives, the U.S. Department of Education's Star Schools grants, the U.S. Department of Commerce (NTIA) Infrastructure programs, the White House Office of Science and Technology Policy Committee on Education and Training) could also be more closely coordinated (National Coordinating Committee on Technology in Education and Training, 1994).*

All of these types of policy initiatives are interconnected. As one example, regulatory, investment, and depreciation policies have a strong influence on the potential success of public/private partnerships. For this reason, coordination of federal and state policy interventions is vital.

A full discussion of all the ways that telecommunications regulation affect distance education is beyond the scope of this study. The crucial issue of universal service and competition is discussed below, in the section on equity. A good overview of how telephone-related policies currently influence distributed learning is given in Wagner (1994).

Excellence

Perhaps the most central policy issue in distance education is the same concern that plagues conventional schooling: At present, many Americans disagree on the goals, content, and processes of public education. Such controversial issues as prayer in schools, sex education, creationism, and outcomes-based assessment illustrate how deeply the polity is divided. The one area of agreement for most people is that public education, in general, is not effectively preparing students as future workers and citizens (although parents tend to be satisfied with their local school). Reflective statements on how distributed learning via the NII could contribute to national educational reform movements (e.g., the America 2000 goals) are beginning to appear (Computer Systems Policy Project, 1994). However, until more consensus is reached on the mission and method of public education overall, finding support for broad reaching policies to enhance distance education via the NII will be difficult.

Possible Policy Interventions: *Continuing governmental activities that build a consensus on the goals and objectives of schools (e.g., Goals 2000) aid attempts to increase educational effectiveness via technology. Explicitly incorporating into all such goal statements what role the NII can play in achieving proposed objectives would underscore ways this national resource could be useful for educators.*

Quality control is important for all types of educational activities, so credentialing and accreditation agencies are concerned to ensure that distributed learning activities attain—at minimum—the same standards of excellence applied to conventional face-to-face instruction. Much is known about the strengths of traditional distance education; Threlkeld and Brzoska (1994) provide a summary of current research, and SWRL's study of Star Schools is providing valuable new information. However, emerging methods of distributed learning have been used for too short a period to allow detailed studies of their effectiveness, and changing HPCC technologies create a moving target by constantly adding new pedagogical capabilities. In addition, many of the monitoring and evaluation strategies used for face-to-face education do not generalize well into distance education. Without quality control, the "dumbing down" that sometimes threatens the success of educational reform movements may appear in distance education.

Possible Policy Interventions: *Providing resources for developing assessment strategies optimized for distributed learning, as well as mandating formative and summative evaluation as routine parts of distance education, are important policy initiatives to promote quality. New assessment and evaluation methods based on sophisticated information technologies are emerging (Hawkins et al., 1993). To be effective at promoting excellence in distance education, such methods must focus on all aspects of the learning process: content, materials, teaching, ancillary services, delivery system, and student accomplishment.*

A policy issue central to excellence is the degree to which the National Information Infrastructure is user-driven (i.e., participants can develop new applications and can exchange information among themselves, without waiting for services to be offered by firms that operate the NII). The U.S. Department of Commerce report, The National Information Infrastructure: Agenda for Action (1993), cites user-driven activities and universal service (available to all at an affordable price) as the two crucial guiding principles that should underlie the design of the NII. Commercial services from the providers of the National Information Infrastructure naturally will focus on those applications with the greatest potential for immediate profitability (e.g., health, big science, entertainment), even though the long-term profit potential of distributed, on-demand learning services may be higher. Without the protection of user-driven evolution, many of the emerging, potentially powerful means of distributed learning discussed in this study are unlikely to soon appear on the NII—undercutting attempts to promote excellence. Further, through forming production consortia, educators can speed the development of quality materials by aggregating demand and keeping control over the instructional design process.

Possible Policy Interventions: *Support for policies that stress the user-driven evolution of the National Information Infrastructure, rather than allowing vendors to control which types of services are provided, is important for the development of new distributed learning approaches. Innovative funding programs that enhance educators' abilities to form production consortia would also be useful; these tie into the public/private partnership policy themes discussed earlier.*

Equity

This topic is so important that a separate policy study was commissioned to chart its dimensions. Initially, all new media reduce equal opportunity; those who first have access to innovative, powerful capabilities gain an advantage over members of society who do not. In time, as the technology matures and is universally available, that inequity erodes and the gap between haves and have-nots narrows. The dissemination of the telephone is a good example of this evolution.

Unfortunately, enhancing equity via educational technologies is not so simple. Computers are more expensive than telephones: Households with incomes of $50,000 or more are five times more likely to own a personal computer and ten times more likely to have access to online services. In a survey of college graduates with children, 49% had personal computers, compared to 17% of homes in which the parents had only high school diplomas. Providing all learners with access to equipment that enables equal usage to the National Information Infrastructure is very challenging, yet students who participate in its services may gain a lifelong advantage over those who do not. Still, television provides a powerful installed base for scaling up to educational services into homes; 98% of American households have a television—only 92% have a telephone.

Important from a policy perspective is the distinction between "universal service" and "open access" (Browning, 1994). Universal service, the model America uses to guarantee the opportunity for telephone services to all households, begins with affordability: determining how much a consumer should have to pay for a given, minimal package of services. The goal is to maximize social benefit rather than profit. If the cost of these services is higher than its affordable price, the deficit is balanced by raising the price of some other service designated as less worthy. For example, when the U.S. Congress recently decided to provide a new class of service for deaf telephone users, the cost of this shift was tacked onto the price of everyone's long distance service.

The companies providing telephone service fall under universal service and are designated as "common carriers"; cable television companies, however, do not fall under these regulations, since decades ago Congress wanted to stimulate this industry as an alternative to broadcast television. This discrepancy in regulatory controls is a major factor in the current war between the vendors on who will control the NII. Because universal service policies require extensive government price regulation and distort free market dynamics, many are concerned that using this model for educational access to the NII may reduce opportunities for innovation and competition. Relatively less profitable activities, such as distributed learning services, tend to remain relatively stagnant under universal service regulation.

In contrast, open access regulation focuses on opportunity rather than duty. Price is not regulated; but network operators are required to make available to everyone, on a non-discriminatory basis, whatever services they do provide—and the underlying technological infrastructure on which those services are delivered. To highlight the contrast between open access and universal service, consider television set-top boxes. Universal service might mandate access to 200 channels for $25 per month; other services would have to be priced higher than cost to make up the difference. Open access assumes competition will keep pressure on price and quality: Companies must provide an infrastructure that allows all customers to potentially purchase the same services, plus make available to their competitors both physical and semantic interoperability with their underlying proprietary technologies. In other words, a consumer could buy programming from one vendor, the set-top box from another, and intelligent agent services from a third—a most unlikely situation under universal service regulation.

Overlapping bills in the U.S. Congress that wrestle with how to regulate access to NII services—via universal service, open access, or whatever—include the Markey Communications Competition and Information Infrastructure Act of 1994, the Antitrust Reform Act of 1993, and the Communications Act of 1994. What mix of regulations would best advance the cause of distance education is unclear (S. Miller, 1994). Certainly, if universal service is the regulatory approach that emerges, the minimum set of educational services defined should be a moving target that scales up as new technologies appear. Otherwise, have-not constituencies will be locked into an increasingly obsolete set of distributed learning services. For example, retrofitting services for learners with disabilities into the National Information Infrastructure will be prohibitively expensive (Blanck, 1994); these must be designed into the NII as it evolves.

Possible policy interventions: *Support for policies that stress open access regulation of the National Information Infrastructure, rather than simply scaling up traditional approaches to universal service, is vital for the development of innovative distance education strategies. To limit the maximum gap between have and have-not students in access to powerful technological resources, the minimum cluster of educational services mandated for all students could steadily increase in its functionalities as hardware and software capabilities advance. Ensuring that physical infrastructures are installed at equal rates in rich and poor neighborhoods is also an important policy concern.*

Beyond regulatory approaches, access to educational services does not equal effective use. To get the most from the NII, students need to understand new styles of literacy and rhetoric, their school setting must complement presentational instruction with guided inquiry, and the curriculum must center on the complex concepts and skills central to 21st century work and citizenship. Equal access to the National Information Infrastructure is only the first step toward the crucial goal: reducing the outcome gap in American education. The most important negative social consequence distributed learning technologies raise is widening the chasm between haves and have-nots. Preventing this requires much more than making equipment universally available. Public education as a whole must be redesigned to take full advantage of the National Information Infrastructure.

Possible policy interventions: *Raising the minimal standards for student outcomes could help to ensure that all future workers and citizens have mastered the new content and skills central to prosperity and democracy. Also, schools with limited resources and at-risk student populations could receive special funding for the types of implementation supports discussed in the next section.*

Policy Issues Related to Implementing New Models of Teaching/Learning

Overall, several types of policy themes are associated with implementing new models of teaching and learning in distance education, especially in moving beyond simply dumping data into classrooms. Too often, schools isolate networking and distance education technologies into special labs and rooms rather than integrating these in classrooms throughout the building. Another common type of error is not making on-going technology costs, including equipment depreciation, part of the regular budgeting process. Also, implementing new types of instructional resources presents challenges in developing social as well as physical infrastructures. For example, "net the experts" programs are worthwhile, but scaling up this type of knowledge utility to thousands of schools and millions of teachers is very challenging.

Possible policy interventions: *Programs that disseminate to schools model approaches for technology integration and budgeting could reduce common mistakes in implementing telecommunications initiatives. Funding is needed for studies that develop distributed, cascading allocation strategies for requests to receive expert aid, as are policies rewarding organizational incentives that encourage employee participation in net-the-experts activities.*

Digitizing existing archives to infuse rich sources of information into the National Information Infrastructure raises another set of policy issues. Selecting from an overwhelming mass of potential data the most crucial resources to translate into digital form requires careful thought about integrating archival materials into the school curriculum. Without sophisticated navigational tools and widespread professional development, simply making archives accessible via telecommunications will likely do little to improve educational outcomes. How to balance funding allocations between digitizing existing information and creating new types of distributed learning resources is another challenge. Further, should millions of teachers begin to transfer complex data across the NII, even a high speed network backbone would likely be overwhelmed, so understanding when data should be stored locally rather than accessed across distance is important.

Possible policy interventions: *Current Smithsonian, National Science Foundation and U.S. Department of Defense initiatives in digital libraries could be coordinated and infused with more emphasis on educational applications.*

Protecting intellectual property is yet another thorny problem. A thorough discussion of copyright issues in distributed learning is beyond the scope of this study; a good summary of copyright policy themes related to distance education is given in Bruwelheide (1994). New technologies are raising questions about how to interpret existing copyright laws (e.g., what constitutes "face-to-face" instruction?) Also, a recent Supreme Court ruling that compilations of data (such as the telephone book) cannot be copyrighted unless they contain "original expression" (i.e., creative value added by the compiler) may undercut the development of low-level indexing systems on the NII (Samuelson, 1992).

Possible policy interventions: *Appropriate rewards for the use of intellectual property in educational settings are vital for developing high quality content for distance education. Revisions to copyright policies that enhance the potential profitability of distributed learning initiatives are important. Also, metered access to networked information would help to relieve the current gridlock in using intellectual property for educational purpose . Accurately determining the value of intellectual property is much easier when usage is billed, since frequent access (connoting worth for educational purposes) results in proportionate rewards to the copyright holder. Research could be funded on implementing this type of sophisticated recordkeeping for educational materials on National Information Infrastructure.*

Another complex policy issue deals with restricting the types of information students can access. Internet newsgroups contain some content that would violate the standards of local communities for what children should be reading in school (e.g., discussions of a sexual nature, propaganda from clearly ideological sources presented as factual information). While similar material is likely available to the same students outside the classroom, on the magazine shelves at the local drugstore, communities historically have held educators responsible for the content children encounter in classrooms settings. Technical strategies such as information filters can forestall most types of forbidden access, but ultimately wise consumption by students— a skill learners should master anyway—is the best defense against inappropriate content entering classrooms via the NII.

Possible policy interventions: *Funding research on low-cost information filters schools can readily implement on their existing network access equipment could allay public fears about inappropriate materials entering classrooms.*

Two other major policy themes heightened by implementing new approaches to distance education are integrating social services and protecting individual privacy. Many reasons exist for greater integration among America's public social services. As illustrations, considerable money could be saved through eliminating overlapping efforts, and understanding every aspect of the client is important in providing effective services. However, the policy complexities of combining education reform with health reform, welfare reform, criminal justice reform, etc. are staggering. For this reason, large-scale use of the NII to integrate schooling with other social services will likely come only after efforts to restructure each sector of public effort are well underway.

Central to integrating social services—as well as any use of information networks for personalized services—is the protection of individual privacy. On the Internet, few mechanisms exist for controlling antisocial behaviors (e.g., "flaming" at people with whom one disagrees, posting trivial messages to everyone on the network, unleashing an avalanche of electronic advertising). Electronic impersonators can commit slander or solicit criminal acts in someone else's name; they can even masquerade as a trusted colleague to convince someone to reveal sensitive personal or business information (Wallich, 1994). Other countries already restrict the flow of data records into the United States because our national standards set a lower threshold for the protection of individual privacy than do their laws (Computer Professionals for Social Responsibility, 1994).

Current efforts toward educational reform often pay scant attention to privacy concerns. For example, as the Seattle Chapter of Computer Professionals for Social Responsibility (1994) documents:

> Publication 93-03 of the National Education Goals Panel, a federally appointed group recently empowered by the Goals 2000 bill to oversee education restructuring nationally, recommends as "essential" that school districts and/or states collect expanded information on individual students, including:
> - month and extent of first prenatal care,
> - birthweight,
> - name, type, and number of years in a preschool program,
> - poverty status,
> - physical, emotional and other development at ages 5 and 6,
> - date of last routine health and dental care,
> - extracurricular activities,
> - type and hours per week of community service,
> - name of post-secondary institution attended,
> - post-secondary degree or credential,
> - employment status,
> - type of employment and employer name,
> - whether registered to vote.
>
> It also notes other "data elements useful for research and school management purposes":
> - names of persons living in student household,
> - relationship of those persons to student,
> - highest level of education for "primary care-givers,"
> - total family income,
> - public assistance status and years of benefits,
> - number of moves in the last five years,
> - nature and ownership of dwelling.
>
> Many of these information categories also were included in the public draft of the 'Student Data Handbook for Elementary and Secondary Schools', developed by the Council of Chief State School Officers to standardize student record terminology across the nation. State and local agencies theoretically design their own information systems, but the handbook encourages them to collect information for policy makers at all levels.
> Among the data elements are:
> - evidence verifying date of birth,
> - social security number,
> - attitudinal test,
> - personality test,
> - military service experience,
> - description of employment permit (including permit number,)

> - type of dwelling,
> - telephone number of employer.
>
> Officers, employees and agents of local, state and federal educational agencies and private education researchers may be given access to individual student records without student or parent consent, according to the federal Family Educational Rights and Privacy Act of 1974 (20 USC 1232g) and related federal regulations (34 CFR 99.3)...
>
> This type of program is described in detail in the book, Together We Can, published jointly by the U.S. Department of Education and the U.S. Department of Health and Human Services. The book speaks of "overcoming the confidentiality barrier," and suggests creating centralized data banks that gather information about individuals from various government agencies - or in other ways ensuring agencies, "ready access to each other's records." The book calls for a federal role in coordinating policies, regulations and data collection. A group in St. Louis, MO, called Wallbridge Caring Communities, is cited as a model for seeking agreements to allow computer linkups with schools and the social service and criminal justice systems to track school progress, referrals and criminal activity.
>
> In Kennewick, WA, over 4,000 kindergarten through fourth graders were rated by their teachers on how often they lie, cheat, sneak, steal, exhibit a negative attitude, act aggressively, and whether they are rejected by their peers. The scores, with names attached, were sent to a private psychiatric center under contract to screen for "at-risk" students who might benefit from its programs. All of this was done without the knowledge and consent of the children or their parents.

As the Internet scales up to the National Information Infrastructure and virtual communities become more prevalent, opportunities for abusing privacy— by individuals, corporations, and government agencies— will multiply.

Distance education activities are intrinsically easier targets for antisocial behaviors and invasions of privacy than face-to-face encounters. For this reason, technical protections are needed, such as encryption standards, confidentiality, data origin authentication, and connectionless integrity (Kent, 1993).

Potential policy interventions: *This is a very controversial area of public policy, as recent debates about the Clipper chip (a means of ensuring that the government can read encrypted messages) illustrate (Rivest, Hellman, Anderson, & Lyons, 1992). Funding is needed for research both on technical protections and on social infrastructures that promote data sharing while protecting privacy. Such policy initiatives could be jointly undertaken with other groups interested in integrating social services.*

The types of possible policy interventions discussed in this study center on technological advances related to distributed learning. Their implementation would need to be contextualized in a larger framework of other types of policy concerns in distance education.

Conclusion

Today, leading-edge approaches to distributed learning are primarily used in selective situations to overcome problems of scale (not enough students in a single location) and rarity (a specialized subject not locally available). Distance education is often seen as "half a loaf" instruction; better than nothing, but not as good as face-to-face teaching. The global marketplace and the National Information Infrastructure are changing this situation. Schools must make all students adept at distanced interaction, for skills of information gathering from remote sources and of collaboration with dispersed team members are as central to the future American workplace as learning to perform structured tasks quickly was to the industrial revolution (Rockman, 1991). Also, by increasing the diversity of human resources available to students, distance education can enhance equity, as well as pluralism to prepare for competition in the world marketplace. Virtual classrooms have a wider spectrum of peers with whom learners can collaborate than any local region can offer and a broader range of teachers and mentors than any single school can afford.

Keeping a balance between virtual interaction and direct interchange is important, however. Technology-mediated communication and experience supplement, but do not replace, immediate involvement in real settings. The NII won't be a "silver bullet" that magically solves all problems of schools—even though it is potentially a powerful force for improvement.

In a few years, the hardware and software will be in place to make knowledge utilities, virtual communities, and shared synthetic environments as routine a part of everyday existence as the telephone, television, radio, and newspaper are today. Certainly, more technology via the NII does not automatically make our lives better; thoughtful and caring participation is vital for making these new capabilities truly valuable. Even then, at times a sloppy, handwritten note delivered through surface mail will mean more to the recipient than an instantly transmitted, elegantly formatted electronic message. New media complement existing approaches to widen our repertoire of communication; properly designed, they do not eliminate choices or force us into high tech, low touch situations.

Information technologies are more like clothes than like fire. Fire is a wonderful technology because, without knowing anything about how it operates, you can get warm just standing close by. People sometimes find computers, televisions, and telecommunications frustrating because they expect these devices to radiate knowledge. But all information technologies are more like clothes; to get a benefit, you must make them a part of your personal space, tailored to your needs.

How a medium shapes its users, as well as its message, is a central issue in understanding distributed learning on the NII. The telephone creates conversationalists; the book develops imaginers, who can conjure a rich mental image from sparse symbols on a printed page. Some television induces passive observers; other shows, such as Sesame Street and public affairs programs, can spark users' enthusiasm and enrich their perspectives. The National Information Infrastructure is an interactive medium capable of great good or ill. Unless we apply the types of policies discussed in this study to shape the NII's evolution, today’s “couch potatoes,” vicariously living in the fantasy world of television, could become tomorrow’s “couch funguses,” immersed as protagonists in 3-D soap operas while the real world deteriorates. The most significant influence on distance education will not be the development of more powerful technologies, but the professional development of wise designers, educators, and learners.

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Appendix A: Emerging Hardware Devices

The core hardware technologies that provide a foundation for the National Information Infrastructure are wide-area, broad-bandwidth networking and high performance computing. A national commitment by Vice President Gore and the Congress to High Performance Computing and Communications (HPCC), exemplified by special funding through federal agencies such as the Department of Defense's Advanced Research Projects Agency (ARPA), has hastened the development of these technologies (Kennedy, 1992). A series of computationally intensive Grand Challenges (e.g., supercomputing simulations of sufficient power to address societal problems such as forecasting global climatic changes, modeling nuclear reactor dynamics, or improving automobiles' fuel efficiency) is providing a framework for organizing the evolution of HPCC (Tentner, 1994).

A similar series of information intensive National Challenges delineates application areas important for the NII (Committee on Physical, Mathematical, and Engineering Sciences, 1994); one of these is Education and Lifelong Learning. The National Research and Education Network (NREN) is an HPCC initiative oriented toward enhancing the collaboration of U.S. researchers and educators in studying phenomena and in distributed learning activities. Thus far, the primary focus of the NREN is on gigabit-level telecommunications development among high-end research labs and universities, rather than broad based service enhancement for pre-college distance education. In general, the "R" in NREN has received the lion's share of the funding—and researchers are more influential than educators in specifying the types of user applications the network should support—even though this program has been sold to Congress more on the basis of its "E" benefits.

Wide-Area, Broad-Bandwidth Communications

Unlike electricity or water, information can be transported in a variety of ways, so different types of communications technologies carry data around the NII. For all telecommunications (wireless, copper, fiber), an important issue is bandwidth. Bandwidth is analogous to the diameter of a pipe; higher bandwidth means more information per second is transmitted along a channel. What does increased bandwidth mean in terms of distance learning? For most users today, some types of wires carry conversational interactions (telephone), others deliver video (television), and still others enable data transmission (computer networks). Expanding bandwidth means that many users can simultaneously send combined voice/video/data information over the same central channel, with sophisticated switching devices delivering each message to its proper destination.

For distance education, high-bandwidth transmission enables powerful instructional technologies such as distributed, interactive multimedia. In addition, falling costs for networking technologies mean that more sites can afford access to distance education services on the National Information Infrastructure. New types of compression strategies are increasing bandwidth by squeezing data into a compact form, then expanding it again on arrival; this enables greater numbers of more complex messages to travel on the same physical medium.

However, these compression strategies necessitate more processing power in users' machines to rapidly decompress data. Similarly, file transfer methods (such as the ftp protocol on the Internet) require powerful desktop machines and high performance networks to transmit large amounts of data quickly. All this means that learners accessing information infrastructures via low bandwidth networks or using older desktop computers with limited processing power and memory are locked out of many of the most useful distance education services (remote access to archives, videoconferencing) emerging on the NII.

Wire-Based Telecommunications

When the special capabilities of wireless technologies are not necessary, twisted-pair copper wire (phone lines), coaxial copper wire (cylindrical television cables), or fiber-optic cables that carry light waves via super-transparent glass are typically used to convey data. Without too much technical detail, an understanding of the bandwidth limits of various media and their relative costs is vital to charting the evolution of distance education. At present, "trunks" or "long lines" owned by the long distance telecommunications companies provide the backbone along which content travels both nationally and internationally. These lines are almost entirely fiber optic now and use a digital telephony standard termed SONET (Synchronous Optical Network). Trunk lines range in capacity from T1 (1.544 Megabits per second [Mbps]) to OC-48 (2.4 Gigabits per second) and beyond. Today's Internet backbone, for example, is built on T3 lines (45 Mbps) operated by MCI. As networking technology improves, all these capacities are steadily rising (Reinhardt, op. cit.).

Local access by telephone or Internet users from the desktop to hosts and from hosts to the backbone is based on speeds ranging from 2400 bps to 28.8 Kbps (and rising) for standard dial-up service on the two- or four-wire unshielded copper lines installed in most buildings. Alternatively, one can lease special lines from local telecommunications companies at multiples of 56 Kbps or 64 Kbps up to the T1 rate of 1.544 Mbps. The lowest level of leased line gives enough bandwidth to support basic-rate ISDN (Integrated Services Digital Network), the minimum service that combines voice, video, and data on a single channel. However, for *dynamic* video (rather than still or slowly shifting images), about 1.544 Mbps (T1) is needed for high image quality, although vendors are experimenting with lower-grade compressed-video implementations down to 384 Kbps.

Thus, at the low end an educator or learner might have access to data through a 2400 bps modem (a device that links a computer to a telephone); at an intermediate level, an individual computer might use a 14.4 kbps modem with SLIP (Serial Line Internet Protocol); at the high end, a desktop device could be connected to the backbone by a T1 line. As one might expect, the prices for higher levels of bandwidth rise rapidly, although ISDN prices have recently fallen to be more competitive with dial-up service. However, because ISDN is based on digital rather than analog technology, users must replace all their standard analog devices (e.g., modems) with digital hardware that is significantly more expensive. (All digital hardware processes information as strings of ones and zeros, while analog devices have a variety of ways of processing data. Analog machines are incompatible with digital devices and with other types of analog hardware, but digital machines can interchange data and have other advantages that make them an emerging universal standard.)

In contrast to local telephone providers, cable television companies have much higher bandwidth along their installed medium of coaxial copper wire. Analog video channels are currently broadcast in 6-MHz bands (a MHz is a million cycles per second) from 50 MHz to 450 MHz; new technologies are extending this to 750 MHz. Today, most homes with a single coaxial input can receive about 60 channels of one-way, NTSC analog video (the image standard used by American television sets). Moving to fiber lines and a digital video signal with current compression technologies would enable 500 channels of television quality video.

In practice, however, few users would want 500 broadcast video channels; instead, providers would likely offer a mixture of broadcast video, interactive television, pay-per-view and video-on-demand, access to computer networks, voice telephony, and videoconferencing. A shift in America's standard for television image quality from NTSC to HDTV (High-Definition Television) would erode the number of channels possible because each signal would require more bandwidth. Still, most home users would find the potential range of available services ample for their needs.

Unlike the companies providing telephone service, however, cable television uses a networking architecture oriented to broadcast data rather than two-way communication. In addition, shifting from mutually incompatible, proprietary analog standards to a universal digital standard is an expensive, complex transition for the cable television providers. Moreover, the set-top box used to decode compressed digital signals at the television set could be costly; with current technology, the specialized types of processing power required are comparable to a high-end desktop computer. Users are unlikely to pay $1000 up front for the privilege of accessing broadband video services; $300 for home use is a more realistic price point.

Thus, both the telecommunications and the cable television companies face different set of problems that block an easy scale-up of their existing information infrastructures to provide the services promised for the NII. But, to further complicate this situation, experimental compression technologies may soon widen the bandwidth of all these media. For example, ADSL (Asymmetric Digital Subscriber Line) is an emerging approach that lets conventional copper telephone wires deliver up to 1.544 Mbps of data, enough for a single channel of compressed, high-quality digital video. Such a signal is decompressed at the desktop by a special set-top box that also converts it back to analog NTSC video format. Currently, the compression strategies to create an ADSL signal require processing power too large to deliver in real-time (i.e., one could pre-compress a movie for delivery over phone lines, but could not compress a news conference for broadcast as it was happening). Over the next few years, with advances in technology, ADSL is expected to use real-time compression strategies and to reach 6 Mbps of video signal, enabling ancillary services along with broadcast video.

Cable television companies also plan to utilize emerging technologies to increase bandwidth. Via reconfiguring the network architecture of the current coaxial cable infrastructure, providers could create the equivalent of 6 video channels upstream to complement about 120 channels broadcast downstream. This level of two-way communication would support voice telephony, video telephony, two-way data exchanges for Internet-like services, and PCS (personal communications services from wireless hand-held devices [described later].) A variety of other compression technologies may also enable expanded bandwidth on copper wire, such as the Broad-Band Technologies (BBT) approach that sends complementary signals over telephone and coaxial cable wires into the home.

Finally, the special glass used in fiber-optic cables is rapidly decreasing in price while increasing in data-carrying capability. Eventually, all networking media will be either fiber-optic or wireless; the TCP/IP protocol suite that governs Internet traffic will likely run on top of a much more powerful digital standard termed ATM (Asynchronous Transfer Mode) [A. Miller, 1994]. In theory, this means that distance educators should view copper-based wiring as an interim solution, rather than as an investment that will allow indefinite access to the full capabilities of the NII.

In practice, while information infrastructure providers are now routinely laying fiber "to the curb" for new installations, the national price tag for a totally fiber national network that would retrofit all existing buildings could reach $400 billion. Even if wireless technology is used for internal local area networks, many older schools lack the electrical outlets needed for classroom computing, necessitating expensive rewiring. The public pledges by vendors to wire "every school" get cabling only to the door of the building, the least expensive and challenging part of creating a classroom-centered infrastructure. In addition, the need for stronger links between school and home necessitates tackling the even more complex challenge of equitably upgrading the physical media running throughout neighborhoods—rich and poor—to provide full access to NII services such as education on-demand.

Overall, this is a very complex and confusing context in which to make decisions as a distance education provider or consumer. The level of service given types of media can support is shifting, and which emerging technologies will prove practical and affordable is unclear (DeSonne, 1992). (The wireless computing options discussed next will further complicate this state of affairs.) Which providers will dominate the competitive market is also uncertain, and the costs of replacing an investment in the wrong type of infrastructure are very high.

Unfortunately, choices about wire-based telecommunications are intrinsically higher risk than decisions about computers. Individual computational devices have an effective lifetime of five years or so before a whole new class of capabilities is available at comparable cost by substituting newer machines. Because computers are purchased individually, educators can experiment with a mixture of low- and high-end devices with little penalty for correcting suboptimal initial choices. In contrast, wire-based telecommunications infrastructures have an effective lifetime of several decades, must be installed all-at-once to be useful, and are very expensive to replace. Since the level of likely demand for future services must be anticipated far in advance, planning for sufficient long-term capacity in telecommunications infrastructures is vital—better to overestimate the bandwidth learners need than to underinvest, barring access.

Therefore, educators planning to utilize distributed learning strategies are confronted with the difficult situation of making high-risk, expensive choices about telecommunications at a confusing and uncertain period in the industry's history. However, to ignore distance education and full access to the NII as options cheats a generation of students of reaching their full potential for learning.

Wireless Telecommunications

Wireless technologies (e.g., cellular phones, remote control devices, satellites) transmit and receive data without needing a physical medium. This is essential for mobile usage, which is becoming increasingly easy as the cost of handheld devices drops. Also, when putting in cables would be expensive or dangerous (e.g., in an old school with asbestos insulation and thick concrete walls), wireless telecommunications are very useful.

Unless a site is connected to coaxial cable, wireless media are its only means of accessing high-bandwidth educational material, such as video, without the physical delivery of media to the site (e.g., shipping videotapes to a school). Of the wireless technologies, distance educators historically have utilized broadcast media (e.g., satellite, broadcast television, microwave-based ITFS [Instructional Television Fixed Service]) because these provide cost-effective point-to-multi-point delivery. Wireless high-bandwidth broadcasting made interactive through telephone and computer linkages is a proven, flexible means of providing distributed learning services.

Similar to the situation with wire-based telecommunications, emerging technologies are now increasing the interactivity and bandwidth of wireless media, creating a confusing array of delivery options for distributed learning (Imielinski & Badrinath, 1994). As distance education moves toward two-way communication, at present the most widespread, general purpose wireless communications service is the analog cellular telephone network (Ryan, 1993). To complement this type of voice telephony with data interchange, educators need a modem that translates digital wireless signals into the standard analog telephone format. These modems are more complex and expensive than the typical device that connects desktop computers to wired telephones. In addition, because wireless connections are subject to much greater interference from conflicting signals, robust error correction techniques are necessary (Mahle, 1993).

For the next few years, microwave, broadcast television, and satellite technologies will continue to be important in wireless distributed learning. As the NII develops, many types of wireless technologies will converge to provide seamless services across a range of frequencies and compression approaches (Thiel, 1994). The most dramatic shifts will come in satellite technology. For example, Direct Broadcast Satellites (DBS) use high-powered signals to enable reception with smaller, cheaper receiving devices (dinner-plate sized dishes costing around $700), although thunderstorms still create some reliability problems in transmission. The Public Broadcasting System's initiative with digital satellites and Vsat terminals to provide interactivity is an ongoing experiment in expanding the role of satellites in two-way educational telecommunications.

Low Earth orbiting (LEO) satellites provide a different class of mobile, business-oriented services such as global voice telephony, paging, geolocation, and wireless data exchange and facsimile (Frieden, 1994). Many of these features are also useful for educators, as discussed in the next section on "Classrooms with Electronic Walls." LEO systems avoid the problems typical of geosynchronous satellites (expensive receivers needed for weak signals, echoes in voice transmission). However, because LEO satellites are not stationary above a geographic region, more are needed (as many as 77 in Motorola's Iridium project and up to 840 in the Microsoft/McCaw Teledesic initiative, as opposed to 3 for equivalent geosynchronous coverage). Also, wireless devices are relatively limited in their bandwidth compared to wire-based delivery, so such services are likely to complement, not replace, existing telephone and cable television systems.

Wireless technologies are important not only for transmitting educational material across distance into schools, but also for intercommunication among devices within individual classrooms and buildings when installing wiring would be problematic or prohibitively expensive. Infrared devices (e.g., the remote control for changing television channels) can provide wireless networks within a single room (Eglowstein, 1994). Radio-frequency media can pass through walls, creating local-area networks over a range up to 300 feet, with relay stations able to increase that distance.

In America, the Federal Communications Commission regulates use of the electromagnetic spectrum for communications, including radio-frequency media such as wireless networks. All countries must carefully coordinate their regulations on such usage to ensure that devices are compatible worldwide and that transmissions do not interfere with each other across national borders. In Europe, frequency allocations are made predominantly on the basis of the public good; in the U.S., free market dynamics prevail, and the FCC has been auctioning off licenses for portions of the spectrum to whichever providers are willing to bid the most for that privilege. The proliferation of different types of wireless devices (e.g., baby monitors, "invisible fences" to control the movement of pets) has made inter-country coordination quite complex, since the spectrum is increasingly crowded with equipment broadcasting at overlapping frequencies.

As a result of all these factors, American educators' access to inexpensive wireless radio-frequency networking has become problematic, for the less expensive frequencies to utilize (in the Megahertz range) are now cluttered with interfering devices. The FCC may open up educational access to frequencies in the 1.5 GHz band, but networks using this band will be of higher cost since their electronics are more sophisticated. Because of this, many schools are interested in infrared media for internal wireless networking; this is unregulated by the FCC because of its limited range.

However, an unresolved issue with all wireless media, including infrared devices, is the safe limits of human exposure to this type of radiation. For example, Germany, which has a history of deep concern for ergonomic issues (the effects of machines on humans) has recently classified all infrared devices as "lasers," even remote controls for television sets. This places severe limitations on their usage and on the types of devices that can be imported. Until unresolved questions about the health hazards from wireless radiation are answered through controlled studies, the use of these technologies, particularly around children, poses risks of potential concern to many educators. Yet wireless networking is a very promising means of giving schools, especially in older urban areas, access to the National Information Infrastructure. Further, young people will be exposed to this type of radiation from other sources whether or not schools adopt wireless technology.

Historically, educators have not taken full advantage of wireless frequencies dedicated to their usage. For example, instructional access to ITFS frequencies is now limited because much capacity restricted to educational purposes sat idle for years. When the FCC relaxed rules constraining usage of these frequencies, public-private partnerships formed that emphasized wireless cable television applications rather than instructional outcomes. If educators do not aggressively pursue the use of new wireless technologies, their eventual access may be limited as other providers appropriate frequencies potentially available for distributed learning.

Case Study: Classrooms with Electronic Walls

One emerging capability that wireless technologies provide for distance learning is “classrooms with electronic walls” that can be superimposed on real-world settings. By using notebook-sized computers, pen-based interfaces, wireless networking, and customized software, teachers can conduct field-based experiences in which students are physically distributed across an environment, yet linked together by shared data, collaborative discussion, and pedagogical guidance. Analyzing the technical, economic, and policy issues associated with this novel pedagogical strategy is a good way to illustrate the challenges and opportunities typical of emerging devices that empower distance education.

In classrooms with electronic walls, the notebook computer carried by each student group accepts pen-based data input and continuously updates the information collected by all groups. Results are displayed on multimedia databases, spreadsheets, and geographic information systems customized to that lesson’s structure and are simultaneously available to all participants. Walkie-talkies allow communication among groups separated by distance. Camcorders and digital cameras enable collecting visual data for documentation and analysis. A cellular phone and fax link the field-based team to both instructional resources and learners at a variety of sites. All this empowers collaborative groups of learners to collect data about authentic phenomena with guidance from a virtual community of peers, teachers, and subject experts. In the last several years, Apple Computer has conducted small-scale field trials that demonstrate the technical feasibility of this distributed learning approach (Cooper et al., 1994).

The capability to create these superimposable "classrooms with electronic walls" could be very useful in certain types of learning situations. As illustrations:

- Students in an economics class could gather consumer behavior data in different sections of a shopping mall.
- Social science students could go through historic preservation sites, like Monticello, gathering data about how people lived at different periods in history.
- Students evaluating health care delivery could disperse throughout a hospital to monitor simultaneously the progression of a patient and his paperwork, while tracking doctors, nurses, and others involved in treatment.
- Students studying technology could master descriptive modeling techniques while studying the interacting engineering infrastructure subsystems of a typical community (e.g. power plants, highways).
- Students in a course on education and culture could share simultaneous data about the cultural artifacts present in a school setting.
- Geography students could extend systematically in different directions to produce computer maps documenting zoning, traffic flows, concentrations of various types of businesses, pollution levels, soil types, cultural patterns within neighborhoods...
- Students studying ecology could spread through a canyon, simultaneously relaying data to each other on changes in different habitats with the passage of time.
- Students across a spectrum of disciplines could interpret a physical site from multiple intellectual perspectives (e.g. assessing the potential regional impacts of a planned industrial park).

- Disabled students could participate directly in field-based research through real-time data-sharing across distance.

Through this pedagogical approach, students learning any field can acquire overarching skills in inquiry, research methodology, statistics, and mathematical analysis. In addition, they can engage experts in real-time discussions of authentic phenomena.

At present, technical problems impede the ability of distance educators to utilize innovative approaches for learning such as classrooms with electronic walls. Wireless data communications are not currently designed for truly mobile usage; the slight interruption in the connection that occurs when moving into the geographic region of a new cellular host is unimportant in voice telephony, but wreaks havoc for data services (Harvey & Santalesa, 1994). Protocols such as MNP 10 from Microcom are designed to minimize these problems; but the current generation of PDAs (Personal Digital Assistants, described later in this study), such as Apple's Newton, do not incorporate this feature. As our society moves toward universal personal telecommunications (UPT), capabilities for truly mobile computing will increase (Lauer, 1994).

For example, an emerging technology termed cellular digital-packet data (CPDP) will provide a more robust solution for wireless mobility at higher bandwidth (19 Kbps), but requires special hardware in both the portable device and the transmitting/receiving base stations. To complicate matters, a competing technology, Ardis and RAM Mobile Data digital radio-frequency networks, is based on digital radio media rather than analog telephone signals. The challenges of choosing among these alternatives are comparably confusing to the wired-based infrastructure decisions described above, although the costs of retrofitting to redress a wrong initial choice are not as high.

This case study of classrooms with electronic walls is a good illustration of the technical, economic, and policy difficulties associated with new technologies for distributed learning. Which emerging mobile wireless technologies will prevail, when they will be robust enough for standard usage, and how much they will cost are unresolved technical and economic issues. Policy issues range from local concerns (Are students insured when they are on this type of field trip? What level of parental permission is needed? How far from a teacher can students physically move without violating regulations?) to national issues (Should the FCC give greater weight to educational applications of wireless technology in its frequency allocation decisions? Should the National Institutes of Health place higher priority on studies of exposure to wireless radiation?).

Further, the focus of federal agencies such as the National Science Foundation and the U.S. Department of Education—as well as corporate and private foundations—is more on specific content issues (e.g., how to improve arithmetic manipulation in the elementary grades) than on generic instructional innovations. As a result, these funders typically do not give research grants to explore the potential capabilities of innovative distance learning technologies such as classrooms with electronic walls. Due to all of these factors, the evolution of innovative distributed learning approaches is quite slow compared to the speed with which new technologies are used to automate traditional models of distance education.

Schools' Installed Base of Telecommunications

Even without considering new types of instructional applications on the emerging NII, teachers' and students' access to the educational services now appearing on the Internet is problematic, because few schools have information infrastructures capable of routing data to individual classrooms. Unlike higher education, K-12 institutions typically have neither host computers powerful enough to allow direct access to the Internet nor a web of telephones and modems that could enable individual Internet usage through dialing up a provider. Further, many schools do not have networks that transmit data around the entire building, and the networks in individual classrooms often have such low bandwidth (e.g., LocalTalk at 256 Kbps rather than Ethernet at 10 Mbps) that sending sophisticated data-objects from computer to computer is very slow.

Interconnecting different types of networks within a school or district is also a complex technical challenge (Smith, 1994). Some problems stem from challenges in physical interoperability; examples include running cables between devices that use different types of connectors, or porting software applications from one computer hardware architecture to another. Other barriers stem from the lack of general standards for semantic or object interoperability (e.g., often data files do not translate from one software format to another, even though the applications that use these alternative data structures support all the features needed for their utilization). Improvements in both types of interoperability are needed to support the full range of services learners and educators want on the NII.

Some districts are now passing bond issues to enable building-wide installation of higher bandwidth networks and the purchase of Internet servers with specially configured software to allow a non-specialist to serve as systems administrator, but this reconfiguration process is slow and expensive. Further, even bond issues do not provide ongoing support in yearly budgets for equipment depreciation, repair, professional development, and monthly telecommunications access costs—expenses for which American businesses routinely budget, but not typically part of school districts' fiscal planning. Until a sustainable shift in schools' telecommunications base occurs, students are blocked from accessing the power of even today's Internet, let alone the emerging National Information Infrastructure.

Simple innovations such as wireless networks for basic file exchange and printing provide an inexpensive means of beginning to address these challenges. In addition, point-to-multi-point broadcast technologies such as satellites, television, and ITFS offer proven, cost-effective ways to provide schools with some degree of interactivity. Too often, however, districts isolate the power of this distribution system to a single room in the school, a specially configured "distance education" place that teachers can visit when needed. However, as with desktop computers, the greatest benefits for learning are attained when technological delivery is seamlessly integrated into every classroom rather than limited to a computer labs or special distance education classrooms.

As schools expand their use of local area networks to access the NII, human resource development policies will be vital in preparing educators to manage local "social infrastructures" that tap the full power of new physical media. For example, schools will need systems operators, computer conferencing facilitators, and people adept enough in software programming to customize interfaces to each district's specific educational goals. As with the introduction of desktop computers into schools, if too much emphasis is placed on hardware acquisition without regard to corresponding professional development, the devices purchased will be underutilized.

High-Performance Computing

At both ends of telecommunications channels, high-performance computing technologies decode transmitted data into messages people can comprehend and utilize. The power of processing chips is increasing exponentially, with doubling times of two years or less at constant cost (Gazis, 1991). Comparable gains are occurring in the capacities of memory chips and storage mechanisms (Weiss, 1994). For example, the capacity of magnetic hard drives (a type of external mass storage device for computers) is increasing sixty percent per year at constant cost (Wallace, 1994). All types of low cost mass storage devices reduce the need for high bandwidth networking by enabling access to substantial archives at individual desktop computers.

CD-ROM (compact disc—read only memory) drives are an emerging standard for delivering information to personal computers, complementing current magnetic "floppy" disks. The costs for printing 650 Megabyte CD-ROM discs have dropped to several dollars each, once an original master disc is created, and the price of a low-end mastering system is now under ten thousand dollars. As a result, disseminating customized electronic information has become relatively inexpensive, opening a new means of educational publishing.

As another source of additional performance, most computers now utilize parallel processing techniques to handle multiple streams of data simultaneously (Hillis & Bailey, 1992). In addition, desktop computers on a "client/server" network can subdivide many types of tasks to accomplish work that previously required a large, expensive machine (Gabel, 1994). Supercomputers are also rapidly increasing in power while dropping in price (Bell, 1992); this is important for distance education because an enormous amount of "back-end" processing is required to provide high-bandwidth materials across the NII.

As a result of all these advances in performance, computing technology has progressed from crunching numbers through processing data into manipulating all types of symbols and even simulating virtual "worlds." Increased computational power potentially aids every aspect of distance education: More powerful computers can rapidly compress and decode more complex messages, thus increasing the effective bandwidth of existing networks to enable more effective distributed learning services. Also, greater processing speed empowers presenting sophisticated images to students, delivering the high video-production-values that the television generation has come to expect in educational applications (Cole, 1994).

Unfortunately, at present the installed base of computers in schools is old technology incapable of supplying the processing power necessary for new distance learning applications. The Apple II™ computers purchased by many schools even into the early 1990s are based on late-1970s technology. The other major type of desktop machines schools purchased during this period, MS-DOS™ computers with 80286 processors, is early- to mid-1980s technology. Today's PowerPC machines, developed around RISC rather than CISC processing technology, are the emerging standard for which current networking and productivity applications are written. These computers are literally hundreds to thousands of times more capable of processing information than the majority of the installed base now in K-12 schools. Without a shift to these more sophisticated devices, many of the most useful distance education services on the NII will be inaccessible to learners.

Merging and Shrinking Devices

As a capstone to these hardware advances, networking technologies, computing machines, and all other types of information devices are fusing together into a synthesis in which the whole (the NII) is more than the sum of its parts. Think of the information technologies as similar to a biological ecology, with each type of device a different species. First came the telegraph, then the telephone, the radio, television, videotape players, videodisc players... Now this ecology is incredibly crowded; every few months a new species appears, such as the Personal Digital Assistant. From their individual niches, a bewildering variety of species cooperate, compete, and become extinct, just as in nature’s ecological systems.

The National Information Infrastructure is different than prior evolutions of information technology because this century-old trend towards a crowded ecology of devices is dramatically reversing. Because all hardware is becoming digital, different species can fusing together; the radio, television, telephone, copier, fax, scanner, printer, and computer will eventually co-exist inside a single case. In two decades, the ecology of information technologies will have only a few super-species remaining (“teleputers?” “compuvisions?”) that synthesize the capabilities of all devices. Users will no longer wrestle with interconnecting many types of quasi-compatible technologies.

As hardware advances continue, information technologies will shrink in size until they vanish into everyday objects, such as pens, just as during the Industrial Revolution motors gradually disappeared from view inside the cases of machines. Eventually, the hardware portion of the NII will be largely invisible, universal within our everyday context. Ubiquitous computing empowers environments in which objects can teach users about their capabilities. For example, through "augmented reality" technology (discussed later in this study), on a user's request a copier could sequentially highlight the series of levers and gadgets to be manipulated when changing its toner, virtually depicting in which direction to twist or pull each object (Feiner, MacIntyre, & Seligmann, 1993).

When the National Information Infrastructure is fully developed and wireless technology becomes part of many school and work environments, our notebook computers can broadcast our presence to "smart objects" in the immediate environment. As we approach, electronic poster boards will change their messages to reflect our interests; incoming calls will automatically be transferred to the telephone nearest us. Because the NII will co-mingle the electronic and physical infrastructures, our artifacts and context can continuously adapt to our needs (Weiser, 1991).

In schools, smart objects for learning may first appear as intelligent manipulatives, providing individualized coaching for students. As one illustration, imagine a child stacking blocks in order of size from biggest to smallest to form a tower. When he picks up a block whose size is out of sequence, it could say, "not me," while the correct block lights up and says, "my turn." Researchers are now developing "building blocks" for children that go beyond creating structures, like a skyscraper, and mechanisms (such as elevators) to constructing behaviors (e.g., a robotic creature that seeks light) [Resnick, 1993]. This fusion of wireless technology and the miniaturization of hardware offers opportunities for new types of learning environments.

At present, an important intermediate step toward smart objects—as well as pedagogical strategies such as the classrooms with electronic walls discussed earlier—is the Personal Digital Assistant (PDA). These nomadic devices both contain many capabilities of desktop computers and offer a few of the "smart object" features described above. The first generation of PDAs (e.g., Apple's Newton™, Tandy/Casio's Zoomer™) are relatively expensive for the utility they provide. In the long run, however, PDAs will be as important as desktop machines in enabling distributed learning and in empowering access to all the benefits of the National Information Infrastructure.

Appendix B: Emerging Software Capabilities

Sophisticated software provides the instructions that enable hardware to process data into meaningful patterns and to accomplish tasks. New ideas about how to develop these sets of instructions (e.g., object-oriented programming, componentware, software engineering, microkernel-based operating system architectures, phased inspections) are creating emerging classes of software important to the functioning of the National Information Infrastructure. These include multimedia/hypermedia, data visualization, artificial intelligence, groupware, distributed simulation, and immersion interfaces. Each class of software makes possible new ways geographically separated users can collaborate and learn.

Despite the new approaches for software development listed above, the production of operating systems and applications is a major and growing bottleneck in realizing the full potential of computer hardware. While exponential growth characterizes the evolution of devices' power, software coding continues to plod along with only incremental improvements. The result is a widening duration between new hardware features and the software programs that allow users to routinely utilize those capabilities. How quickly various types of educational applications on the NII become routine for most American students will be determined more by the amount of time needed to build operating systems, pedagogical tools, and instructional programs based on distributed networking and multiprocessing than by the speed with which underlying hardware devices are deployed.

Multimedia/Hypermedia

One class of software applications important for distance education is distributed multimedia and hypermedia, ways of structuring information based on studies of how the mind assimilates ideas. Multimedia software displays data in multiple formats simultaneously (text, still images, animations, video, voices, sounds, music). This enables people with various learning and working styles (visual, auditory, symbolic) to peruse material formatted in their preferred mode of communication (Bly, Harrison, & Irwin, 1993). Also, multimedia is interactive; rather than passively viewing preprogrammed instruction, as in educational television, users can tailor presentations by selecting paths through the material customized to their interests (Fontana et al., 1993). In many training applications, multimedia has proven its ability to deliver high quality instruction at reasonable cost (Fletcher, 1990).

Hypermedia adds a further dimension to multimedia: associations among pieces of data (Dede & Palumbo, 1991). People can interrelate a wide range of ideas in part because human memory is associative; for example, the word "apple" conjures memories about the computer corporation, Snow White, Isaac Newton, the Beatles' record company, the Garden of Eden, orchards, and pies. Often, the interconnections among pieces of information are more important than individual bits of material; the route to knowledge is via comprehending patterns of relationships, not through storing isolated facts. Hypermedia software interrelates clusters of data; any node of material may have links to several other chunks of information, enabling learners to navigate through a non-linear web of associated ideas. Emerging standards, such as the Dexter model, are providing a principled basis for interchanging material among the plethora of hypermedia applications currently cluttering the educational scene (Leggett & Schnase, 1994).

Underlying progress in multimedia and hypermedia are two types of fundamental technical advances. First, information retrieval specialists are redefining the concept of "document" to include (1) user-defined groupings of information (rather than solely hierarchical structures) and (2) intrinsic code containing information about the document's origin and identity, as well as the capability to render, execute, or manipulate its contents (Reinhardt, 1994b). Because they provide "middleware" services for documents (multiplatform support, user administration, messaging transport, form views, database replication, data interchangability), applications such as Lotus Notes™ are gaining widespread distribution within business and higher education. As hardware servers and networks powerful enough to execute such programs are installed, middleware is beginning to appear in schools, providing a much needed means of integrating different types of distance learning resources.

Second, distributed multimedia applications such as the World-Wide Web (W3), based on HTML (an underlying language for hypermedia creation), are emerging as the standard archival storage and access mechanism on the Internet (Berners-Lee et al., 1994). The Mosaic browser, developed by the National Center for Supercomputing Applications, is the most popular means of navigating through W3 materials. Other client-server applications such as WAIS and Gopher are also widely used means of searching/retrieving networked archives, but lack the hypermedia capabilities of W3. To the amusement of many, tools such as Archie, Veronica, and Jughead are emerging standards for indexing and traversing these information spaces. From an educator's perspective, the important trends to note about all these developments in information creation and dissemination are:

—while still somewhat arcane, the interface applications students and teachers use for developing or accessing distributed learning materials are becoming easier, and

—the minimal hardware needed to run these multimedia/hypermedia tools is steadily rising in power, making the installed base in schools even more obsolete.

The spoken word, the written word, still images, and moving images each have their own types of rhetoric: formal structures for presenting material to aid rapid understanding. High-performance computing and communications have spawned multimedia and hypermedia as emerging styles of rhetoric, with multiple formats for presenting information, user selection of customized paths through material, and networks of interlinked ideas. To receive the greatest benefit from distance learning services on the National Information Infrastructure, both students and educators must master the new types of literacy associated with assimilating and creating communications in multimedia and hypermedia format.

Data Visualization

Data visualization is another emerging type of rhetoric; it enhances distributed learning by using the human visual system to find patterns in large amounts of information (Wolff & Yaeger, 1993). People have very powerful pattern recognition capabilities for images; much of our brain is "wetware" dedicated to this purpose. As a result, when tabulated data compiling variables such as temperature, pressure, and velocity are transfigured into graphical objects whose shape, texture, size, color, motion convey different values of each variable, increased insights are often attained.

As one illustration, graphical data visualizations that model thunderstorm-related phenomena (e.g., downbursts, air flows, cloud movements) are valuable in helping meteorologists and students understand the dynamics of these weather systems (Smarr & Catlett, 1992). For example, twisting, flowing, colored arrows can chart the passage of air through the thundercloud structure as a means of comprehending why tornadoes sometimes form. Visualization strategies go beyond scientific research; in business, analysts could use data visualization to display the relationship between advertising strategies and sales (Langworthy, 1991). If a breakthrough in financial visualization enables better stock market investment strategies, these techniques could become the "spreadsheet of the 1990s" in opening up the corporate market to a whole new class of user applications.

Psychologists are now studying the utility of adding auditory and haptic (texture, pressure, temperature) input to create multisensory pattern recognition (Erickson, 1993; Fuchs, Levoy, & Piser, 1989). This sort of "picture" might be worth a million words! As the National Information Infrastructure increasingly enables people to access large databases across distance, visualization tools can expand human perceptions so that we recognize underlying relationships that would otherwise be swamped in a sea of numbers. Literacy in understanding and creating data visualization images is an important emerging skill driven by the NII's real-time access to massive distributed learning resources.

Case Study: Learning Through Collaborative Visualization (CoVis)

Analyzing the technical, economic, and policy issues associated with collaborative, distributed visualization is a good way to illustrate the challenges and opportunities typical of emerging software that promotes distance learning. The Learning Through Collaborative Visualization (CoVis) Project is one of four NSF-funded National Networking Testbeds for Education. This work exemplifies how distributed learning via the Internet can make the teaching and learning of science in classrooms better resemble the practice of science by professionals (Pea, 1993).

Students in the CoVis project use a Weather Visualizer tool to examine current weather conditions throughout the United States, including:

- —Satellite images of the U.S. in the visible and infrared spectrum.
- —Customized weather maps displaying clouds, temperatures, pressures, dew points, weather symbols, visibilities, radar images, severe weather watches, fronts, isobars, isotherms, isodrosotherms, the locations of reporting stations, and wind directions and speeds at five different altitudes (850, 700 500, 300, and 200 mb). Via data visualization, learners can select any subset of these features to display on their weather maps and can view any region in the U.S. at any zoom factor.
- —Six-panel visualizations displaying temperature, pressure, wind speed, wind direction, dew point, and moisture convergence for the entire U.S., each in a separate image.
- —Textual information providing local conditions and forecasts for reporting stations.

All these features support collaboration among students, teachers, and remote experts to investigate weather nowcasting and forecasting as exemplary of general scientific principles and processes. In addition, the Weather Visualizer is supplemented by the Weather Graphics tool, which allows students to draw their own weather maps with traditional weather symbols. Thus, learners can construct their own visualizations, make predictions, and share their understanding of the weather with others.

CoVis is extending its investigations into historical analysis via the Climate Visualizer, which draws on archival data from the National Meteorological Center's Grid Point Data File Set. Learners use a Collaboratory Notebook that is implemented as a structured hypermedia database; this allows saving and linking multimedia images from the Visualizers. The notebook also incorporates some of the "groupware" features discussed in a later section of this study. In addition, students and teachers use standard Internet tools such as electronic mail, newsgroups, Gopher, Mosaic, and ftp. Remote experts are involved via telementoring relationships.

Through partnerships with Bellcore and Ameritech, the CoVis Project has developed a network architecture that provides high-speed data and desktop videoconferencing service over the public switched telephone network, using ISDN lines. (This type of telecommunications infrastructure will be available to 70% of the nation's customers by 1996). Students use workstations configured with videoconferencing units that include a camera, monitor, microphone, and speaker; these are connected to codecs (digital compression/decompression devices) capable of variable transmission rates between 64 kbps and 1.5 Mbps. The two high schools currently involved have internal Ethernet architectures (10 Mbps); the ISDN lines bridge these local area networks to the Internet and also carry 384 kbps videoconference calls between sites.

Video connections are established using an interface termed "Cruiser" developed at Bellcore that allows users to place calls to others by selecting their names from a menu (Fish et al., 1993).

These connections are instantiated by a network operating system also developed at Bellcore called Touring Machine (Bellcore Information Networking Research Laboratory, 1993). Using a Multipoint Control Unit owned by Ameritech as part of its switching infrastructure, Touring Machine is able to support multiparty calls; dynamically establish and terminate calls using heterogeneous network equipment; and maintain a database of all network devices, digital switches, and users' locations. Such a distance education infrastructure means that, through the public switched telephone network, an educator or student anywhere in the country can register with Touring Machine and engage in CoVis videoconferences.

Research issues raised by this work include: How does this type of learning experience affect student knowledge, skills, and attitudes? Do the visualization tools promote understanding complex datasets? Which types of students will benefit most from collaborative visualization experiences? Which types of communication, both direct and distanced, are most utilized and most useful in such learning settings? What minimum bandwidth is needed to support effective communication and learning across distance? What kinds of teacher support are needed to make this type of pedagogy practical and sustainable? How expensive, per student, would scaling up this type of educational approach be? How high is the quality of student products—could these supplement professional analyses of weather data?

The CoVis project needs drove Bellcore's first integration of the Touring Machine into an ISDN network. CoVis is also the first school-based integral application of ISDN desktop videoconferencing. Much of the time and effort spent the first year of this project has involved coupling all these devices and networks together to produce reliable functioning. Contrary to popular belief, distributed learning applications involve technical challenges as demanding as any in supercomputing, medicine, or entertainment. These difficulties are heightened by educators' continuing lack of awareness on the importance of physical infrastructure. The contrast between typical plans for new school buildings and new office buildings illustrates how education lags behind business in thinking about future needs for conduits and cabling.

Artificial Intelligence

Artificial intelligence (AI) programs impart to information technologies a semblance of people’s cognitive abilities. As one illustration, "expert systems" can solve narrow, but complex technical problems—such as differentially diagnosing various pulmonary diseases—but do not have common sense and the ability to learn characteristic of people's broad-based, evolving expertise. In a similar manner, “smart” neural networks enable machines to recognize speech or handwriting, converting people’s natural means of communication into digital code, but the computer does not comprehend the meaning of the messages it processes.

In the near term, the major impacts of artificial intelligence software on distance education will be (1) empowering people to flexibly interact with machines and (2) automating repetitive tasks. For example, specialized sensing devices and AI software allow users to input data in many ways (speech, handwriting, even gestures), eliminating the necessity of always using a keyboard (Rudnicky, Hauptmann, & Lee, 1994). Similarly, voice output frees users from continuously watching a monitor; this is valuable in mobile distance education situations, such as when driving an automobile. Within five years, about half the small personal computers sold will likely use pen and voice input technologies (Crane & Rtischev, 1993).

In addition, machine-based "agents" with artificial intelligence can perform many repetitive tasks for users: grouping incoming messages into categories; responding to standard classes of requests; even monitoring remote information systems to extract a stream of interesting material in pre-specified categories. A software agent is a simulated, limited intelligence that acts as a automated proxy for the user, constantly performing background, routine chores. Automating simple classification, reply, and retrieval tasks frees learners to focus on creative interpretation of educational services they are receiving and helps students to filter the massive archival information available on the NII. Work is proceeding rapidly on constructing different types of intelligent agents that aid work and reduce information overload (Maes, 1994).

In particular, information filters that enable the personalized delivery of multimedia information are important to the evolution of distributed learning, acting as a lifejacket to keep students and teachers from drowning in the sea of data that the Internet can deliver (Loeb, 1992). By using an agent with a particular point of view (e.g., a behaviorist perspective in an introductory psychology class), the resources potentially available on the global network can be rapidly and automatically filtered. Researchers are experimenting with designing intelligent agents so easy to customize that they can be programmed by children (Smith, Cypher, & Spohrer, 1994); this opens up the possibility of teaching software development through the personalized medium of agents rather than the dry syntax of traditional programming languages.

From an interpersonal perspective, the design of intelligent agents is challenging: Controlling an automated entity makes many people uncomfortable, privacy and reliability issues must be resolved, and users are likely to have unrealistic expectations about how smart their agent can be. On balance, however, this type of artificial intelligence technology is an important underpinning for the evolution of distance education on the NII.

Groupware

Artificial intelligence, multimedia/hypermedia, and data visualization are classes of software primarily targeted to enhancing an individual’s effectiveness; but we know that workplace environments increasingly emphasize teamwork and collaborative interaction. “Groupware” facilitates team performance; this type of software often draws on concepts from the field of computer-supported cooperative work (CSCW). At present, CSCW research focuses on computer-aided design, project management, group decision support, and conferencing applications (Muller

& Kuhn, 1993). Groupware tools embedded in the National Information Infrastructure will enable distributed learning experiences that involve sophisticated information sharing and task performance among students.

Effective teamwork requires building common conceptualizations by communicating each person’s ideas, structuring group dialogue and decision making, recording the rationales for choices, and facilitating collective activities. To accomplish this, groupware tools have several types of features not needed in software applications oriented to improving the performance of individuals. These include a window on the screen that presents the same information to all team members (a "What You See is What I See" interface). Any number of group participants can simultaneously input information into this common window, and all images of this shared data will be immediately updated. Also, any member of the team can maneuver a “telepointer” arrow to indicate an item, and all participants will have a common focus of attention.

Another useful groupware feature is the capability to automatically archive the material displayed on each participant's monitor. This provides an facile way for electronically capturing not only the final outcome of a group session, but also the stream of contributions each individual evolved during the meeting. CSCW research indicates that this rich record is much more valuable that the single set of minutes taken during a non-electronic meeting; a recorder's notes present only one person's perception of the group session and omit many potentially useful details.

Also, in meetings convened to accomplish structured outcomes (e.g. a debate), groupware can provide specialized information tools to aid each stage of the collective process. As one illustration, a convocation might be called to resolve an argument that group members are having; the team must either reach a majority decision or "agree to disagree." Such a session could be divided into three phases: describing different points of view; contrasting the merits and demerits of each stance, with an emphasis on topics of agreement and disagreement; and reaching a final resolution of what perspective the group should adopt. For this type of team session, special debating features developed by CSCW researchers facilitate each phase of the meeting. Without such software aid, personal biases, unstated assumptions, and concealed criteria can often cloud processes of cooperation, argumentation, and compromise.

Researchers are now developing a similar tool to aid geographically separated learners in constructing, comparing, and evaluating arguments for competing scientific theories (Cavalli-Sforza, Weiner, & Lesgold, in press). Also, "telementoring" is an alternative model of instruction based on CSCW features; a virtual apprenticeship under the tutelage of an expert can bridge the gap between abstract concepts presented in formal education and the specific competencies required in particular work settings (Riel, 1992; Means, Schlager, & Poirier, 1994). For example, the CoLab project discussed earlier uses telementoring to help learners interpret visualization images.

Overall, the challenges in designing effective groupware applications are complex (Sproull & Kiesler, 1991). Given the power of face-to-face collaborative learning, however, facilitating distributed sharing of concepts, skills, and social interactions is fundamental to the evolution of distance education. In particular, by increasing the diversity of human resources available in every American classroom, this is a powerful means of enhancing equity. Virtual interactions via groupware can complement alternative means of increasing classroom diversity, such as bussing, and can bring outside expertise into urban and rural settings without the specialist devoting time to commuting.

Distributed Simulation

Another software capability that enhances shared performance and collaborative learning is distributed simulation. The NII is not only a medium for transmitting messages, but also a communal virtual environment that students can enter and explore. Just as single-user simulations allow an individual to interact with a model of reality (e.g., flying a virtual airplane), distributed simulations enable many people at different locations to inhabit and shape a common synthetic environment.

The U.S. Department of Defense developed distributed simulation software as a means of creating virtual battlefields on which learners at remote sites could develop collective military skills (Orlansky & Thorp, 1991). The appearance and capabilities of graphically represented military equipment alter second-by-second as the virtual battle evolves. Through semantic interoperability, data that indicates changes in the state of the equipment is exchanged via a network interconnecting the training workstations ("dial-a-war"). On the NII, distributed simulation can empower a much broader range of educational uses (e.g., virtual factories, hospitals, cities). Defense conversion funding is now providing resources for translating military distributed simulation architectures into software systems that can run on today's desktop workstations, opening the educational and commercial market for applications of this technology.

In distributed synthetic environments, a user can interact not only with other people through videoconferencing, but also with simulated beings. These may be either “avatars” (computer graphics representations of other people in the simulation) or machine-based agents that use artificial intelligence to mimic human speech and action. In virtual environments, interpersonal dynamics are rather different than in typical face-to-face encounters (Dede, in press). For example, participants in a virtual world interacting via avatars tend to treat each other as imaginary beings. Prior communications media have dissolved social boundaries related to time and space; synthetic environments dissolve boundaries of identity as well, enabling communication about very personal things through the depersonalized mask of an avatar.

On the other hand, participants in distributed synthetic contexts often feel as if the machine-based agents they encounter (personality simulators) are real human beings. This is an illustration of the general principle that people tend to personalize objects (e.g., treating your car as if it had a personality). As a result, a machine-based agent in a virtual hospital environment can convincingly mimic many types of responses a typical patient might give, allowing medical students to practice skills in a simulated setting before tackling real-world situations.

The continual evolution of distributed simulations based on participants' collaborative interactions keeps these shared virtual environments from becoming boring and stale. In contrast to standard adventure games, in which you wander through someone else's fantasy, the ability to personalize an environment and receive recognition from others for a addition to the shared context is attractive to many people. Because of all these novel capabilities, distributed simulation on the National Information Infrastructure is creating a powerful new method of communication. Since it focuses on modeling effective actions for others, this class of software complements groupware applications, which center on sharing ideas.

Immersion Interfaces

As an extension of distributed simulation, advances in interface technology also are enabling physical immersion in “artificial realities.” This class of software application involves manipulating human sensory systems (especially the visual system) to enable the suspension of disbelief that one is surrounded by a virtual world. Using an immersion interface, the impression is that of being inside an artificial reality rather than looking through a computer monitor "window" into a synthetic environment: the equivalent of diving rather than riding in a glass-bottomed boat. At present, the hardware underlying immersion interfaces uses head-mounted, binocular displays and computerized clothing (e.g., gesture gloves) to sense users' actions.

A weak analog to immersion interfaces that many readers will have experienced is the IMAX motion picture theater, in which a two-story by three-story screen and high resolution images generate strong sensations of motion even though one is stationary, sitting in a chair. Adding stereoscopic images, highly directional and realistic sound, tactile force-feedback, a visual field even wider than IMAX, and the ability to interact with the virtual world through natural physical actions produces a profound sensation of "being there," as opposed to watching (Kalawski, 1993). The entertainment industry is devoting substantial resources to developing inexpensive immersion interface technologies that could sell into the large market for videogames. This provides a potential installed base of devices that could deliver educational applications, including immersive simulation in synthetic environments that model real world social, economic, and political issues.

One reason immersion interfaces are helpful is that they dissolve barriers between the user and the computer. Because common sense responses to physical stimuli work in artificial realities, participants quickly develop feelings of mastery, rather than the perception of helplessness and frustration typical when first attempting to use an unfamiliar computer interface or operating system. Also, being "inside" a synthetic environment is valuable for developing manipulation skills (e.g., surgery, device repair); in learning to navigate through unfamiliar places (surrogate travel); in recognizing complex patterns and configurations (for example, visualization of fluid flows or financial data); and in creating new types of objects (computer-aided design). Alternatively, as discussed earlier, "augmented reality" displays superimpose computer graphics on the surface of everyday objects, enabling a fusion of the real and virtual worlds.

Dede and Loftin (1994) have recently begun the design of ScienceSpace, a series of artificial realities that explore the potential utility of physical immersion to enhance science education. One objective of this project is researching whether physically immersive learning can remediate typical misconceptions in the mental models of reality held by many students. Another is studying whether mastery of traditionally difficult subjects (e.g., relativity, quantum mechanics, molecular-orbital chemical bonding) is enhanced by immersive, collaborative learning-by-doing.

Through distributed simulation approaches, this project supports shared interaction in a common virtual reality—even across today's moderate-bandwidth networks, such as the Internet—thus enabling "telepresence" and collaboration among learners' avatars. Designing the visual appearance of these avatars and what communications modes they use in order to maximize learning is an intriguing challenge. Young people like magical alternate realities; and the entertainment industry profits by providing amusement parks, videogames, movies, and television programs that build on this fascination. Educators too can profit, in a different way, by building eerily beautiful virtual environments that arouse curiosity and empower shared fantasy, leading to guided inquiry. If we forswear "edutainment," we risk losing the generation growing up with high-performance computing and communications to the mindless mercies of arcades—or consciousness altering drugs.

The emerging software capabilities underlying distributed learning on the NII include multimedia/hypermedia, data visualization, artificial intelligence, groupware, distributed simulation, and immersion interfaces. Features of these software applications that also satisfy the needs of the entertainment or business markets will be readily available to educators. However, software capabilities customized to educational uses have consistently lagged the advance of computing and communications hardware (Melmed, 1993); in the absence of policy interventions, this will also occur for the National Information Infrastructure.

Some of this lagging is inevitable; new and innovative uses of information technology will always be at the margin—first utilized by the wealthy, hobbyists, and business people reaching for a competitive edge—and only later becoming standard in resource-strapped educational settings.

The new software approaches hardest to implement are be those requiring changes in the installed base of computers and networks now in schools. Distributed multimedia applications that require a new PowerPC-level machine, an Ethernet port, and a CD-ROM drive will be slower to diffuse than e-mail enhancements that necessitate adding inexpensive random access memory to students' current machines. Vendors often deliberately limit the compatibility of emerging software and networking applications as a means of selling their latest hardware, forcing schools either into expensive upgrades or into limited access to powerful new educational services.

These issues particularly impact schools with limited financial resources located in communities with little opportunity to supply added dollars beyond state and federal funding. Thus, this situation widens gaps in equity; the more rapid the advance of the NII, the larger the distance between leaders and laggers in implementing new instructional technologies. Developing policies that mandate a "moving target" of minimum distributed learning services all schools must provide—without slowing the advance of new approaches while everyone catches up to this "floor" of required access—is very difficult.