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ABSTRACT

This paper identifies a paradigm shift that must take place in school networking. The ultimate goal is to retool the schools with a local technical infrastructure that gives teachers and students immediate access to communication systems and information resources, thereby supporting the implementation of advances in pedagogy and educational technology. The current notion of telecomputing cannot address the information requirements locally within the school and, ultimately, will fragment and inhibit any move toward universal access to information resources. A technology is needed that combines local and wide area networking (LAN and WAN), making access to remote resources part of the everyday work with school computers. This report contains the following sections: (1) The Problem: Combining Local and Wide Area Communication--facts about the current state of school networks and the dissociation of school LANs and WANs; (2) A Brief History of Network Technology; (3) A Convergence of School LAN's and WAN's--integrating and simplifying a school internetwork; (4) Current Models of School LAN-WAN Connectivity--a comparison of six models; and (5) Prospects for the Future. (Contains 10 notes and 34 references.) (Author/ALF)

CENTER FOR TECHNOLOGY IN EDUCATION

Local Infrastructures for School Networking: Current Models and Prospects

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Abstract

This paper identifies a paradigm shift that must take place in school networking. Our ultimate goal is to retool the schools with a local technical infrastructure that gives teachers and students immediate access to communication systems and information resources and, thereby, supports the implementation of advances in pedagogy and educational technology. On a more immediate level, we want to revise an overly narrow conception that many educators hold about network technology. In schools, the talk of "telecommunications" or "telecomputing" refers to the decades-old technology of connecting terminals to time-sharing computers. If this concept of networks persists, it will have a stultifying effect as schools attempt to use networks during this decade. The current notion of telecomputing cannot address the information requirements locally within the school and, ultimately, will fragment and inhibit any move toward universal access to information resources. A technology is needed that combines local and wide area networking, making access to remote resources part of the everyday work with school computers.

Summary of Recommendations[1]

Our analysis of the current state of school networking leads us to specific recommendations for a program of research and technology development. To take advantage of the existing and planned local infrastructures in schools and school districts and to assure the broadest possible implementation, four areas of technical development will be necessary:

- As an alternative to the pervasive terminal connections in school telecomputing, remote network connections (direct connections between school computers and a national educational network) must be supported and made easy-to-use.
- Before using the extensive networks already in place for school administrative functions, school network technologies designed for instruction and teacher support must address network security and management.
- To assure that network services are both affordable and appropriately tailored to schools, a

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network-server technology that can be distributed within schools, school districts, and regional networks must be developed.

- Within such a network of distributed servers, there is a need for special-purpose "client" software that simplifies students' and teachers' interactions with network services.

These developments must occur in the context of a program of research that will allow us to refine the design and application of advanced network technology for schools, which have their own requirements and organization. ■

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The Problem: Combining Local and Wide Area Communication

The research we report in this paper explored methods for using communication technology within the school to augment access to remote information resources. The problems we sought to address were in some ways more deeply rooted than we expected. Yet the opportunities for improving education remain a powerful incentive for developing a new paradigm for school networking.

Why Networking?

In spite of widespread publicity for telecomputing, communication technology of any sort is almost entirely absent from our schools. Even schools that have invested heavily in computers have surprisingly little in the way of telephones or computer networks available for instructional uses. Traditional educators may ask: Why should they? A set of textbooks for a classroom can effectively encode the required instructional content. Computer technologies can deliver effective exercises. Interactive multimedia can even engage students in motivating stories and visual presentations. What can communication technology add to this arsenal of instructional delivery methods?

The answer to the instructional delivery paradigm can be stated quite simply. Information required for productive citizenship is changing rapidly. It is now essential to present instructional content that is live, that comes from active information sources such as weather satellites, data collected by students in other locations, and responses from working scientists. School work must include primary information sources so that students are simultaneously learning the critical content while gaining firsthand experience with information sources themselves.

At the same time, information access technology is evolving rapidly and dropping in cost. Changes in the teachers' role from a dispenser of information to a coach who helps guide students' firsthand experience with the live sources of information will require support of teachers in finding and using these sources; in getting current information about technologies that may be helpful to them in the classroom; and in developing techniques for using these technologies in the classroom.

Why This Project?

The potential of communications technologies for opening schooling to information sources is recognized as one of the "Grand Challenges" of the High Performance Computing Act of 1991 (Office of Science and Technology Policy, 1991). In coordination with the National Research and Education Network (NREN) program,[1] the National Science Foundation (NSF) has initiated a program to develop the educational potential of computer communication networks (Hunter, 1992a). At the same time, many states, including Texas, Kentucky, New York, and California, have begun the development of statewide educational networks.

The NREN is expected to be shared not only by the higher education and scientific and research communities, but also by K-12 and related educational institutions and, indeed, by the larger public (e.g., see Melmed & Fisher, 1991). Given the national importance and opportunity of the NREN, we assume in this report that school networking and the technological infrastructure on which it is based must allow participation in the future NREN (see Hunter, 1992b).

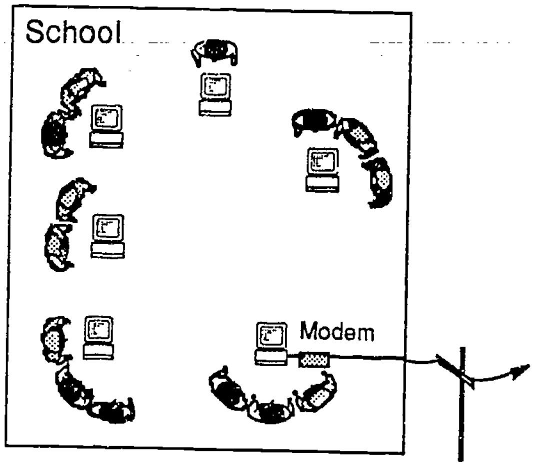
In the context of this identified opportunity to improve schools and these converging federal and state programs, we obtained funding from NSF to undertake an informal study of the local infrastructures in the schools and school districts that might support widespread, perhaps universal, access to a national school network as an extension of the NREN.

Some Facts About the Current State of School Networks

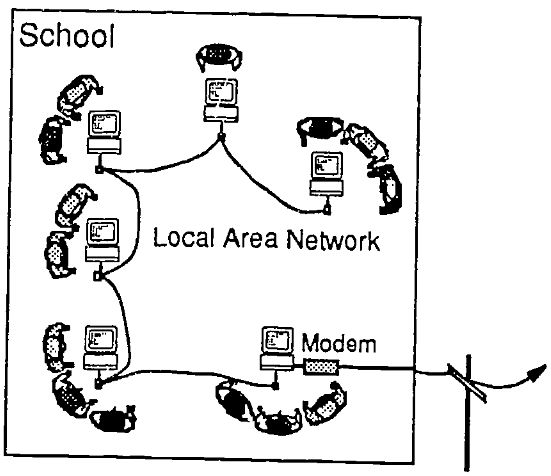
We were well aware in starting this work that most schools that use a telecommunications or wide area network (WAN) have a single computer with a modem attached to a phone line, perhaps in one of the classrooms or at the teacher's home.

It seemed obvious that this single resource would not be adequate for the whole school. At best, it could serve a handful of classes. Most teachers and students would have no firsthand experience with information sources outside the school.

We were also aware of a handful of examples where the school used a local area network (LAN), connecting either all the computers in a computer lab



or connecting computers distributed among classrooms, for communication within the school. In some rare cases, the local network was also used to broaden access to outside resources, providing a network connection for every classroom computer. This is the equivalent of every computer having its own modem and phone line. These LANs give many more students and teachers access to the WAN than is possible with just a single point of connection (and do so far more efficiently than would be possible by giving every classroom its own phone line and modem).



Our plan was to document such cases to provide models that other projects could emulate. A survey of California schools, conducted by the California Technology Project (1990), provided us with a glimpse of the current state of school networks. Their survey tabulated responses from 485 schools.[2] It included questions as to whether the school had a LAN and whether there was a modem or a wide area network connection available. For purposes of our report, we obtained an additional analysis of the data from CTP to find the intersection of responses on these questions, allowing us to construct the following matrix for the 407 schools for which appropriate data was available:

Local Area Network	Wide Area Network Connection: YES	Wide Area Network Connection: NO
YES	43 (10.6%)	24 (5.9%)
NO	140 (34.4%)	200 (49.1%)

While 16.5% of the schools have LANs and 45% have a wide area connection, only 10.6% have both. This 10.6% is a good place to start, since here we may find the schools most advanced in building on their LAN resources to make best use of their wide area connection. We were able to contact 30 of the 43 schools in this set. The striking outcome of this follow-up research was that none of these schools made use of their instructional LAN for distributing the data coming from the WAN.[3] In more than half the cases, the modem used in instruction was not even on a LAN computer.

The picture is a bit different if we look at administrative applications, such as reporting attendance records or administrative communication in the 30 schools. Twenty-one of the schools had a modem for administrative or management functions and 12 of those were connected to a LAN. In seven cases, the school administration office had a LAN of computers that served as terminals on a district database. In five cases, the modem was on an instructional LAN, but was used as a channel for the vendor to download new software versions and to perform troubleshooting. Clearly, the technology for connecting LANs to WANs exists in the schools, but it is not being applied outside of administrative functions. It is not available to teachers and students.

The Dissociation of School LANs and WANs

The almost complete absence of connections between instructional LANs and instructional uses of WAN connections is indicative of an ingrained conceptual dissociation between the two technologies.

On the one hand, LANs are used predominantly as a way to distribute software, as a means for sharing printers, or as a mechanism for managing instruction and saving records of student work.

On the other hand, telecommunications or "telecomputing" networks are a conceptually unrelated technology in which phone lines are used to connect a school computer to a community or information source outside the school.

Paradoxically, in business, research, and higher education, the primary use of LANs is for communication and sharing data. There, the technology for connecting LANs to WANs is well established. It is not easy, however, for a school to simply purchase systems designed for the business setting. Compared to office environments, schools are very large, complex, and volatile, with students changing grades and classes every year. While this puts a greater burden on system administration (e.g., creating and modifying student mailboxes, work group assignments), schools have fewer resources for full-time system operators than do other institutions. A network system for schools will require very high ease-of-use and a management system that integrates network services and student records.

The lack of LAN-WAN connections for teaching and learning in schools is not due merely to a lack of resources. Many LANs are in place. There are schools with wiring in place for their intercom systems that could serve adequately for a reasonably sophisticated LAN connecting all classrooms. Many school districts have WANs in place for administrative functions. However, the distinct functions of school LANs (as instructional management and delivery) and WANs (as communication and resource access) has resulted in a technological gap. Currently, none of the local area network vendors selling specifically to schools offer a product that is appropriate for connecting an instructional LAN to a wide area network. Vendors of administrative systems understand the connection between the local and the wide area networks but the concept has not been applied to instructional uses.

Problems to Address

Developing communications functions within schools is necessary if we are to avoid the following consequences of the current paradigm:

- *Lack of access.* Without any means of transmitting data, electronic mail, and documents around the school, the constraints of scheduling access to a single network terminal will limit the number of network projects that a school can engage in and the number of students and teachers who can have significant contact with the network resources.
- *Inequities.* Existing school infrastructures will favor the students who are already privileged. The limited access to network projects will likely favor students who are assigned to enrichment activities. In addition, inner-city schools are more likely to acquire local network systems providing basic skills lessons rather than communications or data sharing capabilities (Cole & Griffin, 1987; Sherry, 1990).
- *Marginal impact on the school.* A local infrastructure can multiply the impact of the wide area network on the school. The local intellectual community is the foundation on which to build activities that benefit from the network resources.

A serious development effort will be needed to fill the technological gap. More important, perhaps, a research and demonstration effort will be needed to articulate an alternative model. Few school systems are likely to take advantage of their installed local infrastructure for instruction or staff development unless there is a compelling pedagogical rationale. Giving teachers and students widespread, equitable access to the NREN resources could be a rationale for investing in the small additional costs of providing flexible and equitable access to all students and teachers.

In the next section of this paper, we present a brief history of network technology to locate the origin of the unusual dissociation of local and wide area networks in schools. We then outline some of the modes that we have found for schools to connect their local and wide area networks, with special attention to how schools may eventually move towards providing broad access to the NREN. Finally, we argue the case for eliminating the more commonly found telecomputing connection between school modems and outside resources in favor of a true network connection of the sort that is used in industry and in many school administrative networks—one that will provide the most appropriate access to the NREN. ■

A Brief History of Network Technology

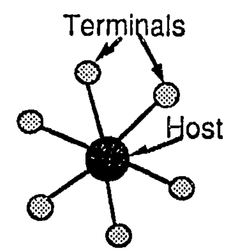
The dissociation of local and wide area networks has its roots in the historical introduction of the technologies in the schools. It might help to back up and take a look at the history of computer networks. This section serves as a tutorial on the technology that will help frame our subsequent discussion of school networks. Perhaps we can reduce some of the confusion of terminology that has made it difficult to understand concepts like "the NREN" and has gotten in the way of seeing the commonalties of local and wide area technology.

When educators talk about a "computer network," they are most often referring to a network service. This usage is reflected in several current surveys of school and educational networks (Kurshan, 1990a, 1990b, 1991; McAnge et al., 1990). For example, many teachers subscribe to CompuServe, America On-line, Prodigy, or AppleLink, which are information services offered via a dial-up connection. Similarly, classrooms subscribe to the National Geographic Kids Network or to the AT&T Learning Network, which are more structured products provided by similar services. Local or dial-up bulletin board systems (BBSs) are also sometimes called networks. At other times, "computer network" refers to a community of people who use access to a particular service as a means of communication. For example, the "superintendents' network" consists of a group of administrators who dial into a computer at the Merrimack Education Center in Massachusetts to communicate by electronic mail and share database resources. This common usage implicitly accepts an historically antiquated notion of computer communication because it assumes that there is a particular computer service or host computer that all the members of the community use. Their common connection to that host is what defines the community. To understand the history of networks, we have to get below the level of the services and communities that make use of networks and look at the networks as systems of hardware, software, and transmission media.

Centralized Computing

The first thing resembling a computer network was the terminal-to-host system used on timesharing computers. First developed in the sixties, the timesharing computer (which became known as a "host") allowed many people to access it simultaneously from terminals (desktop consoles) wired directly to the computer. In the late sixties and early seventies, the availability of modems, which turn digital into analog signals and vice versa, allowed the terminals to be located at the far end of ordinary voice phone lines. Those phone lines could be dedicated (i.e., leased from the phone company for exclusive use by the network owner) or switched (i.e., dial-up use of the public phone system). The host always managed the terminals and performed all computing.

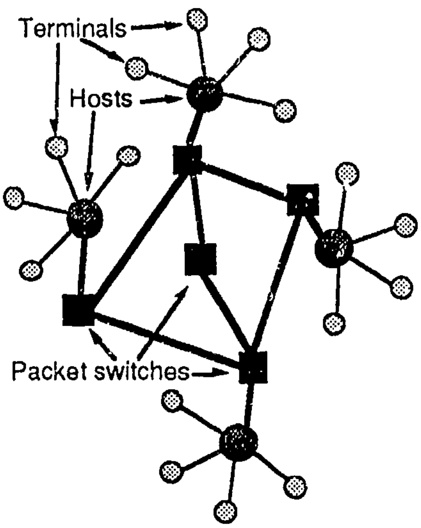
The model of centralized computing and dedicated terminal-to-host communications can be represented as a simple star-like figure.



When personal computers (PCs) became widespread a decade ago, "terminal emulation" programs were developed so that a PC could serve as a terminal. This paradigm was elaborated with protocols for sending files back and forth and with "user interface software" for PCs that let the PC present the menu options using its own graphical interface. But the essential feature of this paradigm is that the PC is connected as a terminal to one specific host.

Distributed Computing

While the terminal-host connection let remote users use a single host, it did little for hosts that wanted to communicate with other hosts. Packet switching was developed to solve the problem of inter-host communication. If a database were developed for one host, how could it be transferred to another host? How could a database administrator sitting at a terminal on one host get files from or send files to another host? How could a scientist working on one host run a program that was on a host at a distant university? The development of packet switching technology was given a big boost in the late sixties and seventies with the U.S. Defense Department-sponsored ARPANET, the predecessor of the NSFNET (Comer, 1990; Dern, 1989) and what is now commonly called the Internet. Packet switching was developed as an efficient way for many users to access and transfer data among many timesharing computers from different manufacturers, and for those computers to share expensive resources, that is, the long distance telephone lines[4] connecting them. ARPANET hosts were not physically connected directly to each other, but were connected to special-purpose computers called packet switches. We can represent this distributed computing and computer-to-computer communications as a complex mesh network with packet switches (squares) serving to get the packets from one host to another (dark circles). Conceptually, the hosts form a network of peers, each on an equal footing.



The ARPANET demonstrated how computing resources could be widely distributed on a reliable, shared, wide area infrastructure.[5] Each computer was a peer of the others; each had a network address and could send and receive messages.

Packets

The basis of packet switching is the concept of a *packet.* In the usual terminal-host connection, a stream of bits is transmitted between the terminal and host. Since the line between the terminal and host is dedicated to that connection (in the case of a dial-up, it is temporarily dedicated), there is no question as to where the bits are supposed to go. Anything from the terminal goes to the host and vice versa. In packet-switched networks, the bits from any one computer may want to go to any of the other computers, so there had to be a way to address the bits appropriately. Assembling a packet is simply like putting a group of bits in an envelope and addressing it to another computer. Each host has an address on the network. As the packets of data are sent out over the network, packet switches determine the most efficient route to the other computer.

In addition to the seminal ARPANET technology, several approaches to packet-oriented networking have emerged over the last decade and a half. For example:

- DECNet and SNA are the proprietary network architectures of Digital Equipment Corporation and IBM, respectively.
- X.25 is the international standard computer interface to packet switching networks and is used in all public data networks such as Telenet and Tymnet, as well as by private companies and organizations.
- OSI (Open Systems Interconnection) represents a set of international standards for interconnecting different manufacturers' systems worldwide (X.25 is part of the OSI scheme).
- TCP/IP[6] emerged out of the work on the ARPANET and is now the basis for the Internet (see discussion of internetworking below).

TCP/IP, X.25 and OSI are independent of specific computer manufacturers and their products, in contrast to SNA and DECNet. Irrespective of these distinctions, this heterogeneous collection of methods for addressing packets represents the real beginning of computer networks.

Store-and-forward networks

It is useful to distinguish a class of distributed networks commonly used in school telecommunications but not based on packet-switching technology. Instead, these networks use communications protocols for message transfer which are designed for "batch" file transfers rather than interactive traffic.

- FIDOnet, including the subset called K12net, consists of thousands of home and school microcomputers running electronic Bulletin Board System (BBS) software; the BBS messages and files are distributed ("echoed") from one to another micro (FIDOnet BBS) over dial-up phone lines when rates are lowest (generally at night); each BBS subscribes to a set of echoes or topics (Reilly, 1992).
- FrEdMail (Free Educational Electronic Mail) is similar in structure to FIDOnet, consisting of about 125 computers that exchange messages over dial-up lines on a scheduled basis. The computers are run by volunteers and offer discussions and collaborative projects for teachers and students.
- BITNET ("Because It's Time Network") is a college and university network of host computers (BITNET nodes) that transmit messages and files between each other using IBM protocols for "batch" submission of computer jobs (LaQuey, 1990).

These networks, generally called "store-and-forward," distribute the computing, but communications with end users are not interactive or "real-time" and are limited to the exchange of text files.

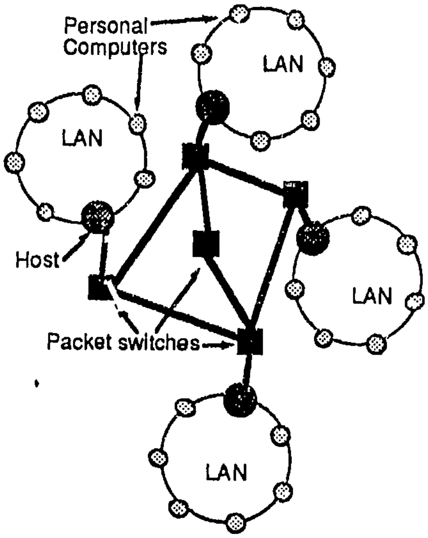
Value of Distributed Computing

The centralized computer approach could never have achieved what has happened with distributed, packet switching networks. A single, centralized computer could not have held all the computing and data resources of the ARPANET hosts. And connections to such a computer from all the people wishing to use the ARPANET would have been unmanageable. By distributing computing around the country and even around the world, the system as a whole is more reliable and robust, less expensive per user, easier to add users to, and can support many more applications and databases.

Packet switching made possible the development and subsequent astounding growth of electronic mail ("email"). The ability for people to communicate as peers using electronic messages was built on top of the analogous capabilities in the distributed computer network. Wide area communications began to signify *human* interchange, not merely computer data exchange.

Local Area Networks

In the early stages of the ARPANET, people were still using terminals to connect to their research center's host computer via a phone call or direct wire. The next major advance in computer networks occurred with local area networks connecting PCs within a building to printers and other resources, including host computers. By the early 1980s, local area networks (LANs) were becoming more commonplace on campuses and in corporations, as low-cost desktop systems (PCs) and sophisticated desktop workstations became available.



A large number of different LAN technologies now exist; for example, AppleTalk and Novell (NetWare) are widely used. Lower level LAN transmission schemes include the standardized Token Ring and Ethernet, and Apple's LocalTalk. Special purpose hardware (generally called a gateway) is used to connect different physical LANs that may be found in the same building; for example, LocalTalk and Ethernet. LANs are commonly wired out of coaxial cable or plain telephone wire or, more recently, optical fiber.

Like the wide area distributed networks, LANs also used addressed packets to transmit information from one PC to another. A local host could also be situated on a LAN. Now the connection between the desktop PC and the host was just part of the local packet network.

Internetworking

The development of different wide area network technologies (such as packet radio) and the need to interconnect multiple packet networks each using different protocols led to the growth of *internetworking*. Internetwork technology allows multiple diverse computers on different physical networks to communicate, using a standard set of communications conventions or protocols.

The internetworking research, sponsored by the U.S. government in the early 1980s, was a direct outgrowth of ARPANET technology. Internetwork packets were routed to their destinations by special-purpose computers called routers, which are a form of packet switch and serve similar functions in a network of networks. Using internet protocols, workstations (and, more recently, PCs) on LANs could communicate in exactly the same manner with each other, and with distant computers via wide area networks as they did with other computers on their own LANs.

Within the internetwork, all the computers (whether PCs or mainframe hosts) were equal in the sense that any computer could communicate with (i.e., address packets to) any other computer. Now, not only were more *remote* resources available more widely, the ability to make use of those resources *locally* (i.e., on the user's desktop computer) increased dramatically.

In addition to electronic mail, the most widely used network services that flourished with the development of distributed networks included remote login using terminal emulation, file transfer, and network news. The TCP/IP protocol suite includes protocols that support these services. SMTP (Simple Mail Transfer Protocol), Telnet (for remote login), FTP (File Transfer Protocol), and NNTP (Network News Transfer Protocol) are standard protocols. Telnet and FTP are also the names of application programs that users invoke, and have assumed the status of verbs (e.g., "to telnet to host A"; "to ftp the file"). Most Internet locations implement the distributed bulletin board system known as the USENET or netnews, and subscribe to *newsgroups*.[7] Research in internetworking and its widespread dissemination via distributed networks have led to many more network-based services in recent years.

What is now called "the Internet" (with a capital I) is an important development because it has extended this notion of internetworking internationally. The Internet consists of the global set of interconnected TCP/IP networks that share a common address space. Historically, the Internet has also been known as the ARPA or DARPA Internet (ARPANET was the first network in the Internet) and the TCP/IP Internet (see also Cerf, 1989). Today it consists of more than 5,000 networks, which link together hundreds of thousands of computers and millions of users throughout the world. The domestic, nonmilitary portion of the Internet includes NSFNET, which serves the U.S. scientific and engineering research community. NSFNET has a 3-tier structure composed of

- a "backbone" connecting the NSF-funded supercomputer centers. It consists of a series of packet switches (routers) and very high-speed links. Like an interstate highway, the backbone accepts traffic from any of the regional networks or supercomputer sites;
- mid-level or regional networks, such as THEnet (Texas Higher Education Network), NYSERNet (New York State Education and Research Network), NEARnet (New England Academic and Research Network), and CERFnet (California Education and Research Federation Network), which are autonomously administered;
- campus and corporate networks which connect to ("are members of") the regionals and which can be quite extensive themselves.

The Internet also includes statewide networks such as CSUnet (California State University's network) and other federally sponsored networks such as NASA Science Internet (NSI) and Energy Sciences Network (ESnet), and connects TCP/IP networks in many countries and regions of the world (see LaQuey, 1990). The high-speed National Research and Education Network (NREN) is projected to evolve from a part of the Internet containing portions of the current NSFNET, NSI, and ESnet.

Client-Server Systems

While all computers on a distributed network are equal in one sense, the notion that some computers could or should provide services to other computers emerged. The "client-server" technology combines some of the virtues of centralized computing[8] with the strengths of distributed networking (Wood & Mensch, 1991). Certain computers are dedicated as mailboxes (mail server) or for file storage (file server) or to maintain databases (database servers). Other computers, usually the PCs on people's desktops, are the "clients" in this paradigm.

Combined with internetworking, these client-server systems are now becoming commonplace in business and research settings. The desktop PC can be part of a world-wide Internet with servers in the same room or at a remote university. Routers on the LAN take care of sending packets out over the wide area connections. More significantly, in client-server computing, the person at the desktop PC is not personally interacting with the server. It is the client software embedded in the person's PC application that requests service from server software. The desktop PC is no longer doing terminal emulation. To the user, the communications involved in accessing mailboxes, files, or databases are invisible and nonintrusive. It is "as if" these mailboxes, files, or databases were on the user's desktop machine. The network pervades the person's interactions with the PC.

The convenience of client-server systems has recently appeared in the context of centralized terminal-host connections. CompuServe, for example, has a program called Information Manager that provides icons for each of the services. Rather than selecting from a menu presented by the host, the subscriber can click on an icon on the PC "desktop." Similarly, the National Geographic Kids Network provides a client program that makes the call, and sends and receives data without the teacher's having to select items from a host-based menu. The same program allows the students to display and analyze the data.

While making the work of interacting with the host much easier, these so-called "user-interface software" packages retain the weaknesses of the terminal-host paradigm. The fact that these programs are not based on packet-network technology may make little difference as long as the connection is restricted to those two computers. The centralized computing paradigm underlying the connection, however, makes it difficult to integrate a local area network or to flexibly address resources distributed on a wide area network. Client-server systems based on packet-network technology, on the other hand, have great promise for education since they simplify interactions with remote or local servers while retaining the flexibility and scaleability of internetworking.

Modes of Access to the Internet

A local area network is not required in order to attach a classroom computer to a wide area packet-switched network. For example, a standard called Serial Line Internet Protocol (SLIP)[9] makes it possible to connect a single computer with a modem and ordinary phone line directly to the Internet. These connections reportedly require some of the patience traditionally associated with telecommunications and are not therefore appropriate for unsupported, novice networkers. If school PCs *are* on a LAN, the work of connecting the LAN and its classroom computers to the Internet is done either by a dedicated router or by routing software on the local server.

Schools lag behind universities and industry in their use of Internet connectivity options. In almost all cases where teachers have "access to the Internet," they are still using a traditional terminal-host connection. Just as in universities and in industry before the installation of LANs, a terminal connection is made to a host located at a local university or other Internet member or maintained by a state education network such as Texas Education Network (TENET).

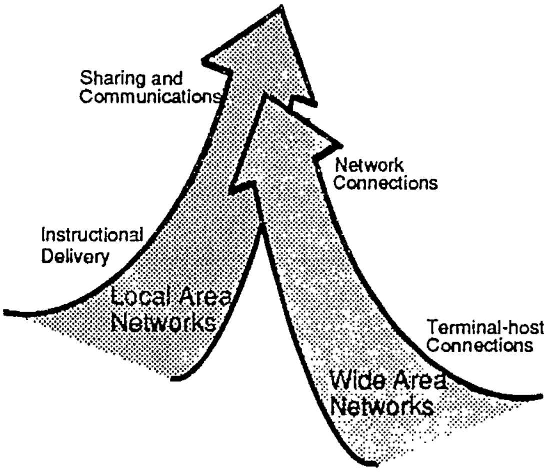
This host may provide bulletin boards, electronic mail, databases, and many other services to people with user accounts. Since this host is part of the Internet, the teacher may have permission to run programs on it to remotely log into any other computer on the Internet, transfer files to and from other Internet computers, send and receive mail, and so on. But it is the host computer that is performing these functions, not the computer on the teacher's desk. The teacher's PC is still just a terminal on the host.

So, for example, the teacher might request that a graphic file from the Magellan mission be transferred from the NASA computer (on the Internet) to the local host he is logged into. A few seconds later, the file is on the local host. Now, he must use the terminal software of his PC to "download" the file across the phone line. This two-step process contrasts with the scientist whose PC is on a LAN that is part of the Internet. In that case, she requests the NASA computer to transfer the file, and a few seconds later the file is on the disk *of her PC.*

Our simplified history of network technology has charted the substantial progress that has been made since the days of centralized, proprietary computing systems. Network technology is increasingly distributed, integrated, and based on open public standards. Local and wide area networks have become extensions of one another. ■

A Convergence of School LANs and WANs

School networks are now at an interesting juncture. Only a handful are doing true networking in the sense of having their school computers connected to a wide area packet-switched network. But school LANs are being used increasingly for communicating and sharing data locally, and the interest in the Internet as a vehicle for school networking suggests the potential for extending internetworking and client-server systems down to the student and teacher desktop computers.

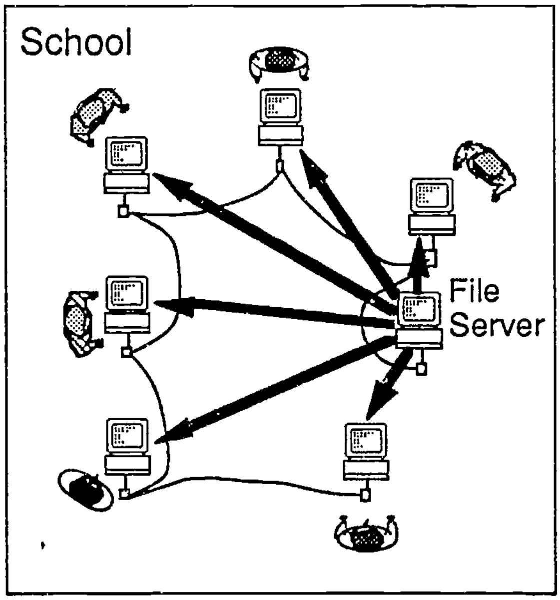


The convergence of LAN and WAN systems is at a very early stage. But we see critical elements in place that will support a new paradigm. In this section we describe the basis for the convergence and illustrate it with a hypothetical scenario.

The Elements: LANs, WANs and "DANs"

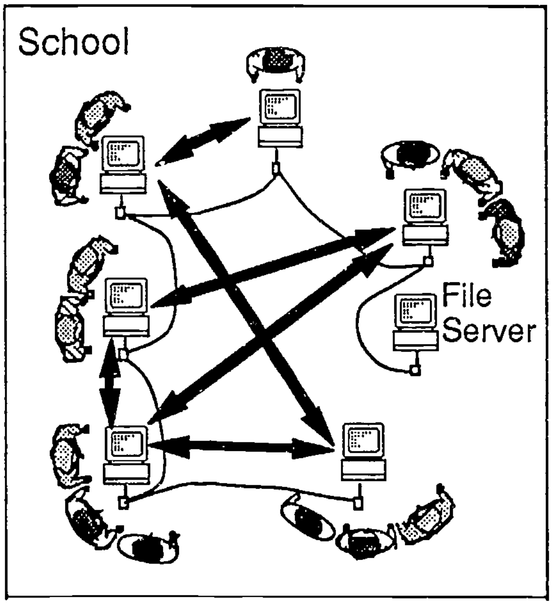
Local area networks

The original educational experiments with timesharing computers, such as the Plato system, were oriented to instructional delivery. This orientation has carried over to the so-called Integrated Learning Systems (ILSs) (see Sherry, 1990). Technically, many of the ILSs are LAN-based client-server systems and their evolution from terminal-host systems parallels the evolution in the rest of the computer industry.



Generally school LANs are seen as management tools that serve the purposes of teachers in charge of operating a computer lab, running a remedial program, and so on. Management systems, such as ICLAS for IBM PCs running on a Novell LAN or Aristotle for Apple IIs on an AppleTalk LAN, provide rudimentary client programs which simply display a menu of the software that the student at the computer is allowed to use in that session in the computer lab. This lets the teacher in charge easily control software usage while avoiding the annoyance of floppy disks.

While still few in number, some schools are beginning to use LANs to support tool-based student projects where the file server is used as a storage medium for project-related files and for communication among teachers (and occasionally among students). For example, in the Earth Lab project at New York City's Ralph Bunche School, students make extensive use of word processing, databases and electronic mail (Goldman & Newman, in press; Newman, in press; Newman, 1990; Newman, Goldman, Brienne, Jackson, & Magzamen, 1989; Newman & Reese, 1990). Each student, as well as each work group, has an electronic *laboratory* for the project-related text, data, and other files. The laboratories are folders (directories) on the file server that serve as group or individual workspaces.



The newspaper editorial group, for example, has a laboratory in which issues of the newspaper are assembled from stories and pictures contributed by students from various classrooms. Electronic mail is used among students for both personal and school-related projects. In this case, the LAN file server is no longer a centralized point of control but a mediator of communication among students and teachers. The use of school LANs for communication and information sharing may increase with the distribution of computers around the school rather than in computer labs, a direction in which some ILS vendors are moving (Mageau, 1990; Electronic Learning, 1992). As individual teachers tailor computer use to their own instructional units, taking advantage of continuous rather than episodic access to the computers, centralized management will become less important. With computers distributed around the school, the communication function of the LAN will become more salient and the potential for using the LAN as a mechanism for access to resources outside the classroom and outside the school will become more obvious.

Wide area networks

Since the late seventies, host computers have provided services to schools, classrooms, and communities of teachers (Kurshan, 1990a; Roberts, Blakeslee, Brown, & Lenk, 1990). The teacher or the school subscribes to the service, which may include conferencing with other teachers, weather reports, electronic mail student pen-pal communication, bibliographic data retrieval, and so on. Consumer services, such as CompuServe, America On-line, or Prodigy, charge a connect-time fee. Bulletin boards may offer similar services on a smaller scale and operate free of charge except for the phone call. All these services make use of a terminal-host connection with the classroom computer (or teacher's home computer).[10] Currently, it remains the case that practically all telecomputing projects use this kind of connection.

The recent interest in using the Internet as a vehicle for K-12 education is inviting a change in the telecomputing paradigm. Schools are beginning to take advantage of the distributed nature of the network to access data and services around the world. A few schools are now beginning to take advantage of the packet-switched nature of the Internet to make network connections between their PCs and the network. As LANs become increasingly used for communication and as the WANs of interest to schools are distributed packet-switched networks, the two technologies begin to converge, as we detail in the next section of this paper.

"District area networks"

The vertical integration of LANs and WANs also invites us to consider district networks, which currently are used extensively for administration (e.g., transferring attendance records to the district office). A district network, or what we might call a District

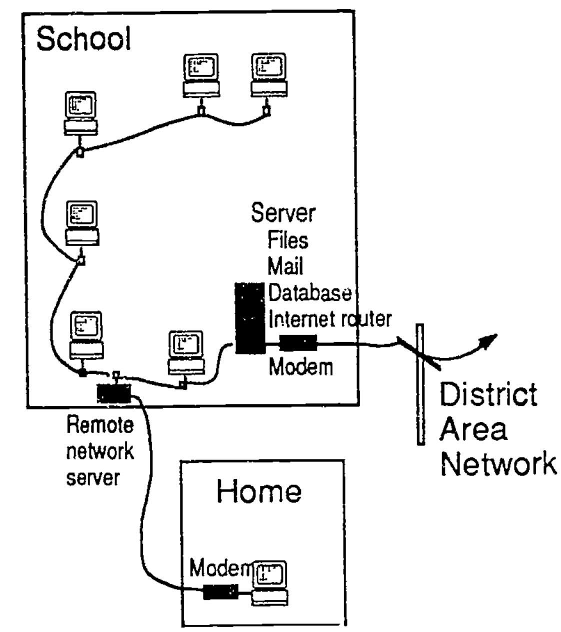
Area Network (DAN), can serve as intermediary between the school LANs and a state or national education network, such that connections between school and national communities piggyback on the connections required in any case for administration. The development of internetworking techniques, including the integration of IBM SNA technology, which is used extensively for district administration networks with Internet technology (Gurugé, 1992), lets us avoid costly duplication of administrative and instructional networks. With a packet-switched network, functions at different levels of educational organization (school, school district, county, state, and national) can be integrated into the same network. School LANs are an extension of this internetwork, reaching the teachers and students in the classrooms.

A Scenario

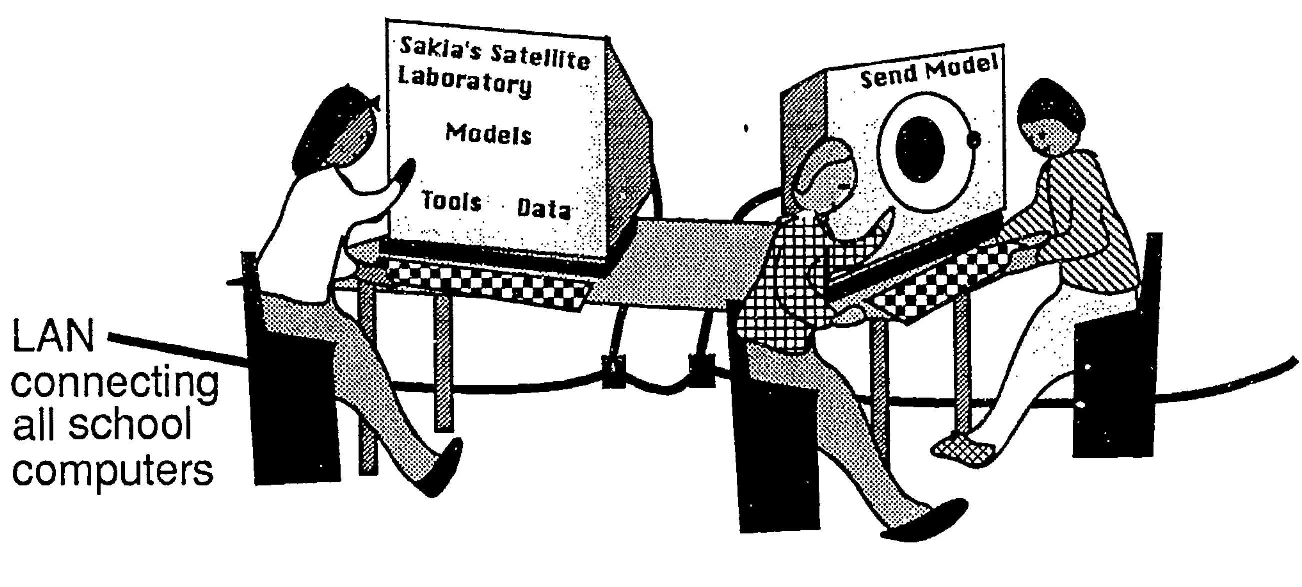
Here is a concrete picture of how this vertical integration of a LAN, DAN and WAN might work. We start in a hypothetical classroom with an individual student and a group of students working on their science investigations.

One student is making use of data stored on the school server, while a collaborating pair of students has performed an experiment on the velocity of a satellite in orbit and is about to send the results to a sister school in another state. The simulation program they are using sends the results, along with their text annotation, as mail to the other school's mail server via a series of routers at various levels in the system.

The next picture illustrates schematically the school's LAN, which connects all their desktop computers and servers. The server handles the students' communication locally as well as with schools around the world, serving as an Internet router as well as a file and database server. It stores the students' project data.



It also supports a management system that allows the school's computer coordinator to maintain these services for students and teachers in the school and to set privileges for network use, such as allowing these students to transmit experimental results to the sister



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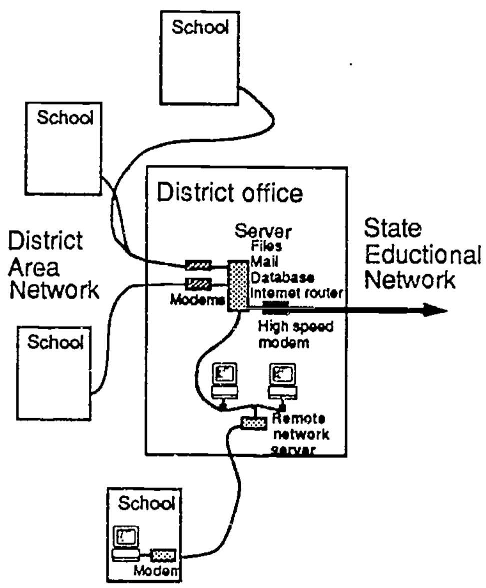
school and to access relevant Internet databases.

The school network has additional specialized modems serving as remote network servers, allowing teachers, students, or parents to communicate with the school. For example, the computer coordinator is able to manage the server remotely from home.

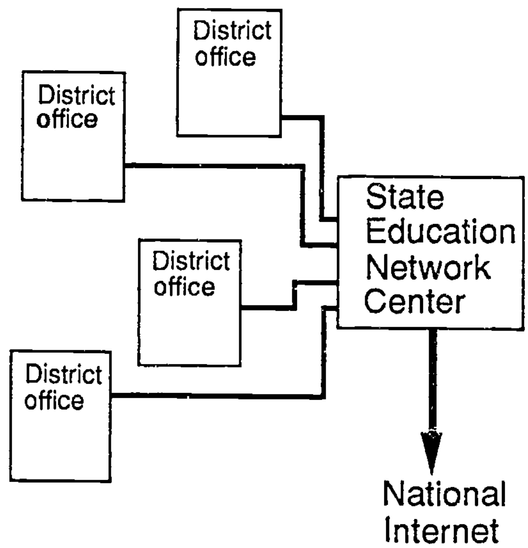
The connection between the school and the district office runs over an ordinary telephone line forming part of the district area network. The next picture shows that the same basic structure is replicated at the school district office. The district server continues to route the students' email to the state education network. The routing service at this level connects schools within a district to each other, as well as through the state educational network to other schools.



The district office also has a LAN providing communication within the office. The district server provides the same services as those found on the school server except here it contains aggregated data on students and other district administrative information. Not all the schools in the district have internal LANs yet. However, with an Internet router at the district office, they are still able to tap into the Internet from at least one computer.

The connection between the districts and the state education network center is shown in the next figure. The students' email message containing the results of their velocity experiment is one of very many kinds of communication going back and forth across that line. At this level the district has leased a line to obtain a continuous high speed connection that is sufficient to handle the level of communication being generated by all the schools.

The hierarchical nature of the Internet connectivity scenario depicted here provides a smooth path for upgrades in access and capacity. School districts are now in the situation that many colleges were in several years ago when Internet access was achieved through intermittent dial-up lines. A tremendous amount of information can be sent over an ordinary dial-up phone line.[11] As the schools begin making heavier use of multimedia documents or synchronous communication, capacity will have to be increased to avoid delays.



Integrating and Simplifying a School Internetwork

A major advantage of the distributed computing paradigm and the mechanisms for internetworking that have grown up around it is the capability of bringing multiple diverse networks into a single system. It may seem paradoxical, but in fact the centralized computing paradigm tends toward fragmentation. Each host is associated with a separate community, has its own way of interacting with its members, and often uses proprietary software. Internetworking, on the other hand, is built on explicitly open (nonproprietary) mechanisms in order to be able to handle the diversity of computer platforms that want to be connected.

Compared to a proprietary network service or well-run bulletin board, the Internet appears to many teachers as chaotic and intimidating. Some attempts have been made to make the resources more accessible through handbooks such as The NYSERNet New User's Guide (1991) (see also Kehoe, 1992; Martin, 1991), but even these require a fair level of sophistication. The comparison of the Internet to a network service is inappropriate because the current difficulties presented to the novice are a direct result of the distributed nature of the network that makes an ever-expanding number of resources available.

Ultimately, bringing all educational resources into a distributed network will tremendously increase the value of a connection to the network. But it will be necessary to develop for schools a client-server architecture in which the software running on the PC, not the person, knows how to interact with the remote resources. The problem will not be to create centralized services, but to continue the migration of computing from the host out to the PC.

The convergence of school LANs used for sharing information and packet-switched wide area distributed networks is opening up new possibilities that we believe are worth exploring. As long as educators view the Internet as just another (unfriendly) network service or (incoherent) network community, we will not succeed in tapping its potential, and the ways in which it invites connections to school LANs as part of an internetwork will not be fully appreciated.

In the next section, we describe current models for connecting LANs to wide area networks (not just to the Internet). The experiments now getting under way in schools can help to determine paths that schools can take from the current paradigms to full participation in the national network. ■

Current Models of School LAN-WAN Connectivity

Over the last year, our project conducted an informal international search for schools that had any kind of connection between their instructional LAN and instructional uses of wide area networks. In this section, we analyze the cases we found in terms of a matrix of six distinct models.

Recall that among the more than 400 schools in the California Technology Project survey, we were unable to find any instances of connections between instructional LANs and instructional uses of wide area networks. We sent messages out to a variety of network communities on the Internet, AppleLink, and FrEdMail. The Kidsnet mailing list on the Internet yielded a good set of candidates for follow-up interviews. We also asked all the major school LAN vendors[12] for candidates (yielding no results). And we made inquiries of several of the Internet regionals with somewhat better luck. In all, we talked to people at approximately 40 schools. We certainly did not talk to all schools with LAN-WAN connections, but our impression was that we had contacted a substantial portion of the schools with such connections. Our impression is also that the number is growing rapidly as many schools and school systems are making plans for Internet connections. Many schools we talked to considered their current set-up an interim solution and had plans for, or dreams of, upgrades. LAN-WAN connectivity in schools is clearly in its infancy.

The following discussion is not meant as a how-to manual nor will we address cost, an area of rapid change. Groups currently addressing these issues include the Internet Engineering Task Force working group on K-12 networks and the Consortium for School Networking (CoSN) (see, e.g., Solomon, 1992; St. George, 1992). Our goal is to determine paths for growth for schools and school systems as they move toward connections to the Internet. We expect to raise more questions than we answer, but we hope to lay out a framework from which schools can ask good questions and evaluate proposals by vendors, state agencies, district officials, and other interest groups.

A Matrix of LAN-WAN Connections

The table on the next page is a framework that allows us to usefully sort the cases that we found. "Type of connection" refers to whether the classroom PCs are terminals or are connected directly to a packet-switched network. The three columns refer to the local infrastructure. The lefthand column refers to stand-alone PCs, which, like the other columns, are connected to some remote services. The cases in the right two columns have put their LANs to work in connecting to the remote services. The cases in the far right column, in addition, have a local server on the LAN that is used in communicating with people and services outside the school.

maintained by the Board of Education. The bulletin board is in turn connected to the Internet through a leased line connection to NYSERNet, the New York State regional Internet network, but our interest here is in how *schools* are making their connection.

Type of Connection	Remote Services		
		Local Area Networks	
			Local Server
Terminal	"Telecomputing"	Network modem	"Portage"
Network	Remote network	Leased line to local campus	Local Internet server

Network modems

Not all schools with terminal connections are underutilizing their LANs. We found several schools using a device called a network modem on the LAN. They still establish a standard terminal connection, but the network modem and special system software running on the Macintosh computers let any Mac play the role of the terminal (one at a time) just as if the modem were connected to it directly.

For example, teachers and students at Jefferson Junior High in Oceanside, California, are active users of FrEdMail, CSUnet and other education services. They have 30 Macintosh computers on an AppleTalk network in a lab with a file server (AppleShare).

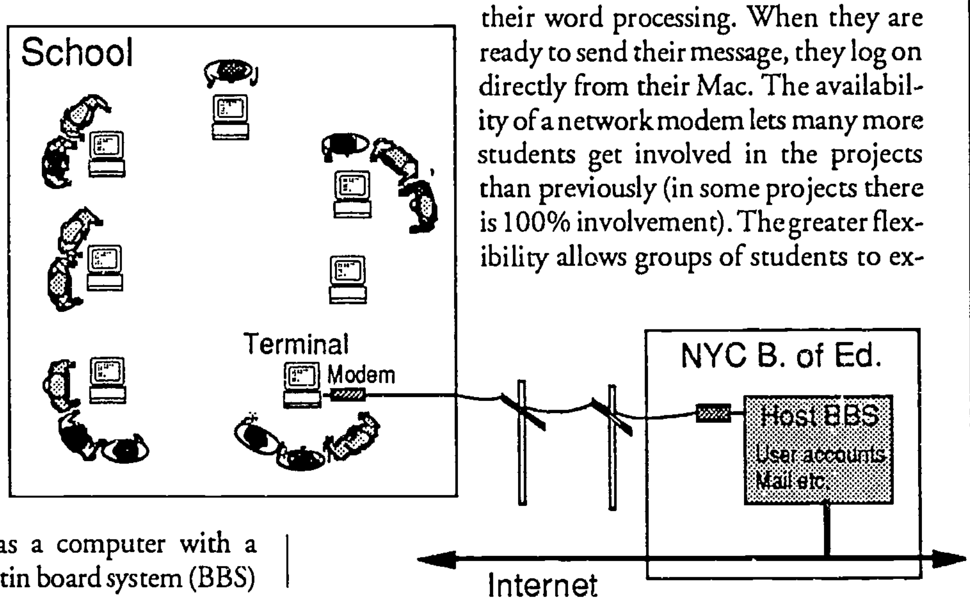
The school connects to the local FrEdMail node, which now has a gateway connection to the Internet via CERFnet, a regional network in southern California. It also connects to CSUnet through a local state college campus. Both are terminal connections. Students come into the lab and work on their word processing. When they are ready to send their message, they log on directly from their Mac. The availability of a network modem lets many more students get involved in the projects than previously (in some projects there is 100% involvement). The greater flexibility allows groups of students to ex-

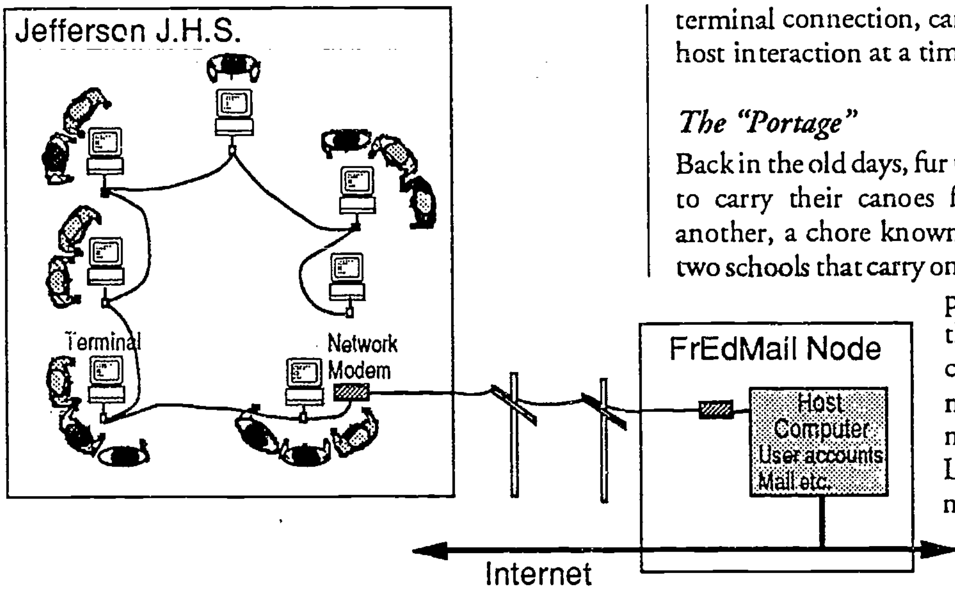
In this section, we describe cases of each model, beginning in the upper left of the matrix.

"Telecomputing"

In the upper left cell of the matrix are all the schools involved in telecomputing or telecommunications, including schools with access to the Internet, with the exception of the handful of schools that are of interest to this analysis. These schools use a terminal type of connection between their classroom (or other) PC and a host computer or remote service. Included in this cell are the schools with LANs but with no connection between the LAN and the wide area network (e.g., where the computer with the modem is not on the LAN, or is on the LAN but no use is made of that fact).

The diagram to the right shows a typical example. A school in New York City has a computer with a modem and calls into the bulletin board system (BBS)





terminal connection, can only support one terminal-host interaction at a time.

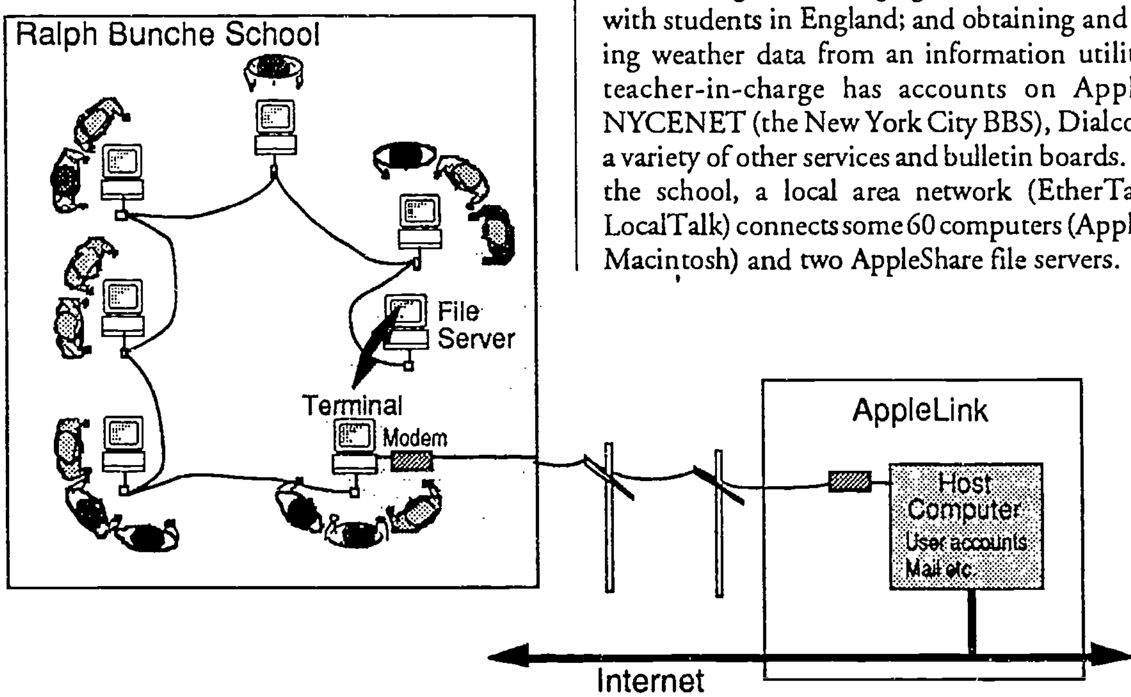
plore the network for appropriate projects, taking some of that burden off the teacher.

The network modem scheme adds great flexibility to the telecomputing paradigm because now any computer on the LAN can initiate communication. In cases where LAN computers are distributed around the school, the network modem would allow all the classrooms to share the very scarce resource of a telephone line. However, only one Mac at a time can be a terminal since the modem connection, like any terminal connection, can only support one terminal-host interaction at a time.

The "Portage"

Back in the old days, fur traders would frequently have to carry their canoes from one body of water to another, a chore known as a portage. We identified two schools that carry on an analogous labor-intensive process between the local and the wide area network. One computer is set up with the modem on it (or a network modem is installed on the LAN), and is used for communication with outside electronic mail services and database services. The teacher logs onto the outside service using ordinary terminal emulation software, and copies the mail and data to the local disk. The teacher then runs another program (e.g., a LAN mail system), retrieves the messages from the disk, and sends them over the LAN so that the internal community can have access to them.

In the Computer Mini-school of the Ralph Bunche School in New York City, students are engaged in a large number of projects, including collecting, sharing, and analyzing international data on changing sun shadow lengths; creating a guidebook which is shared with students in England; and obtaining and analyzing weather data from an information utility. The teacher-in-charge has accounts on AppleLink, NYCENET (the New York City BBS), Dialcom, and a variety of other services and bulletin boards. Within the school, a local area network (EtherTalk and LocalTalk) connects some 60 computers (Apple II and Macintosh) and two AppleShare file servers.



A local mail system (Bank Street Writer with email from Scholastic, originally designed by the Earth Lab project) operates from the file server. Students and teachers can access their own "laboratory" on the file server and can communica via the local email system from any of the school computers. For example, students in the Shadows project send messages to a "dummy" user called AGE (for Apple Global Education network), sometimes mentioning a particular addressee in the subject line. Once a day, the teacher checks the AGE account of the local mail system and transfers the messages to the appropriate recipients on AppleLink.

From the perspective of the students and teachers, their email is connected to the communities outside the school. Most are unaware of the behind-the-scenes work of the teacher-in-charge who transfers the local mail to their destinations on the various network services. A notable advantage of the portage is the opportunity for the teacher-in-charge to monitor the outgoing communication and to help direct incoming messages (e.g., those addressed to the larger AGE community) to appropriate student teams.

The previous three models were all variations on a terminal to host connection. We now move down to the second row of the matrix and consider the models that make use of network connections, beginning with a model involving a stand-alone PC.

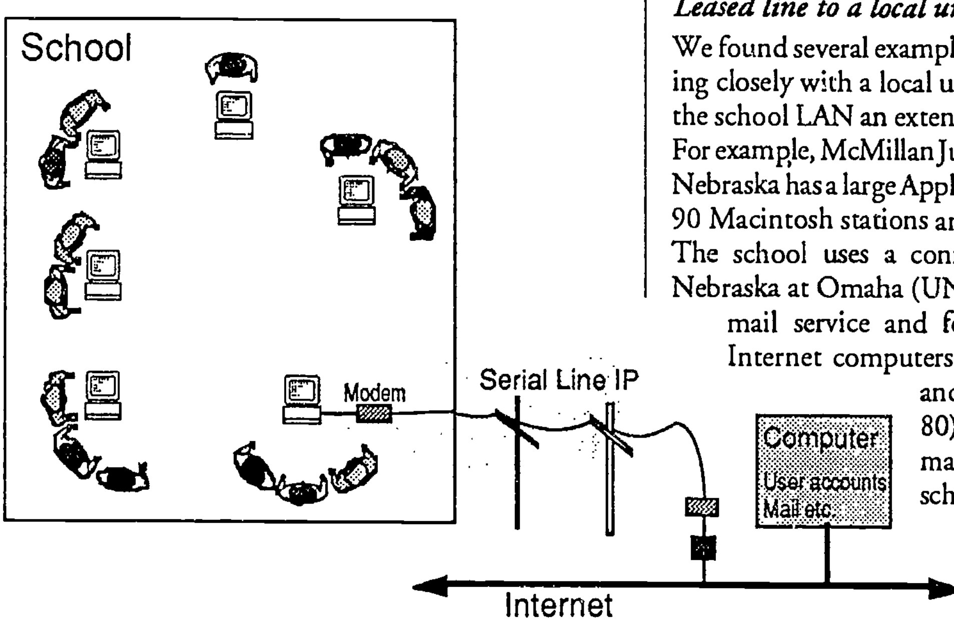
Remote network connections

A number of schools use SLIP software (described in an earlier section) to connect a single PC to their Internet regional. Once the connection is made, the PC is able directly to address any other computer on the Internet; for example, to retrieve electronic mail, transfer files, or log in and run programs remotely.

Another (relatively easy to use) version of remote network connections is AppleTalk Remote Access, a Macintosh System 7 extension that allows a remote computer to dial into an AppleTalk LAN and interact with other computers on that LAN as though it were connected directly (with the limitation of the much slower speed associated with modem connections over telephone lines compared to that of a LAN). For example, teachers at the Stratton School in Arlington, Massachusetts call up using a Macintosh LC equipped with a 9600 bps (bits per second) modem to a Macintosh on the LAN of a local corporation and are able to send and retrieve electronic mail via the corporate mail server. Since the connection is a network connection (transmitting AppleTalk packets across the phone line), the school's LC is able to run a mail client that makes it possible to use the Macintosh interface for all reading and writing of mail. Since the corporate LAN is connected to the Internet, the school LC (while the phone connection is open) is a full member of the Internet and can directly transfer files to or from any other Internet machine. A remote network connection can also be made from home to school. For example, the Ralph Bunche School teacher-in-charge uses a network modem (Shiva NetModem) at the school to call in from home to retrieve files or update records on the school file servers.

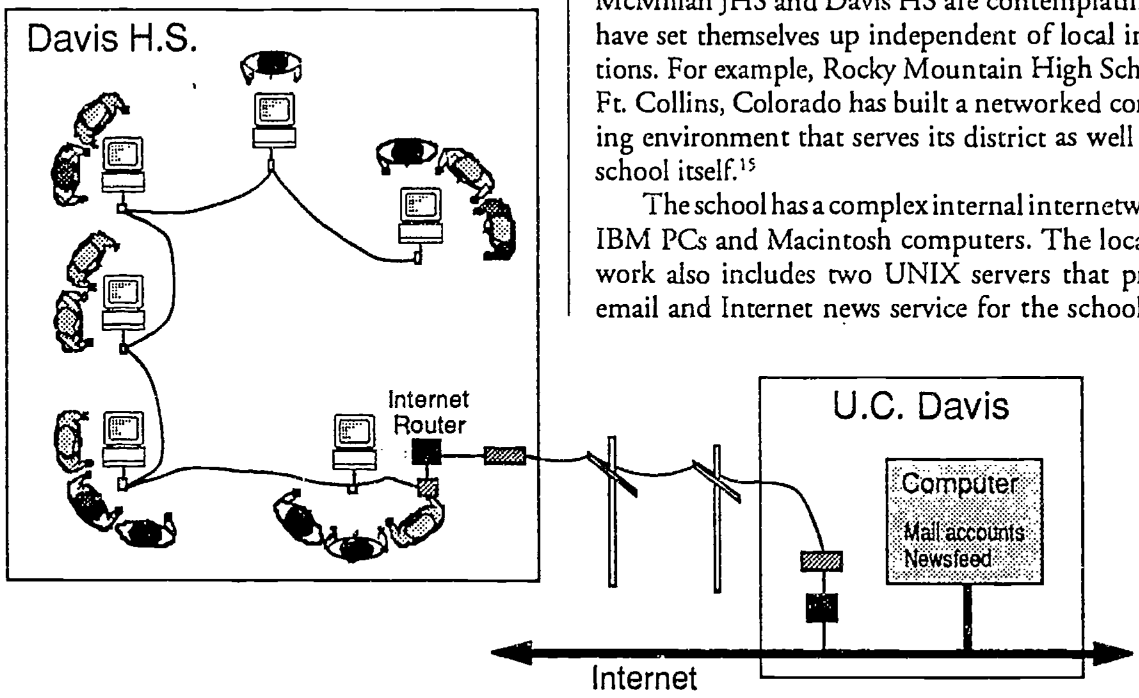
Leased line to a local university campus

We found several examples of schools that were working closely with a local university in a way that made the school LAN an extension of the campus network. For example, McMillan Junior High School in Omaha, Nebraska has a large Apple-Talk network serving 80 to 90 Macintosh stations and an AppleShare file server. The school uses a connection to a University of Nebraska at Omaha (UNO) computer for electronic mail service and for access to files on other Internet computers.[13] Fourteen or 15 students and about 20 staff (out of about 80) have accounts on the UNO machine. Macintosh users at the school run a Telnet program to establish virtual terminal connections to the UNO



machine. Once logged on, they can read and send email, and transfer files (using anonymous FTP) from other Internet systems.

Students and teachers are involved in several foreign language and social science projects. (One popular use of the network is to access Supreme Court decisions from a University of Maryland machine.) Since it appears that the UNO host is oversubscribed, recent discussions at the school have explored the possibilities of setting up a district server that would provide file, mail, and Internet routing service, but no decision has been made.



Another school set up as an extension of a local campus network is Davis High School in Davis, California, which has a similar relationship to University of California at Davis where about 150 of the students (out of 1200) and many of the staff have email accounts.[14] In addition to email, the campus server provides Internet news to the school. Projects involve foreign language communication, research on abortion rights (including accessing remote data on Supreme Court decisions and congressional voting records), a science and math exchange with Russia, and remote supercomputing. The teachers find that many more students can be involved given this direct connection to UCD than with the single computer with modem they used previously. Importantly, these high school students are better able to individualize their research projects, not having to stay lockstep with the class.

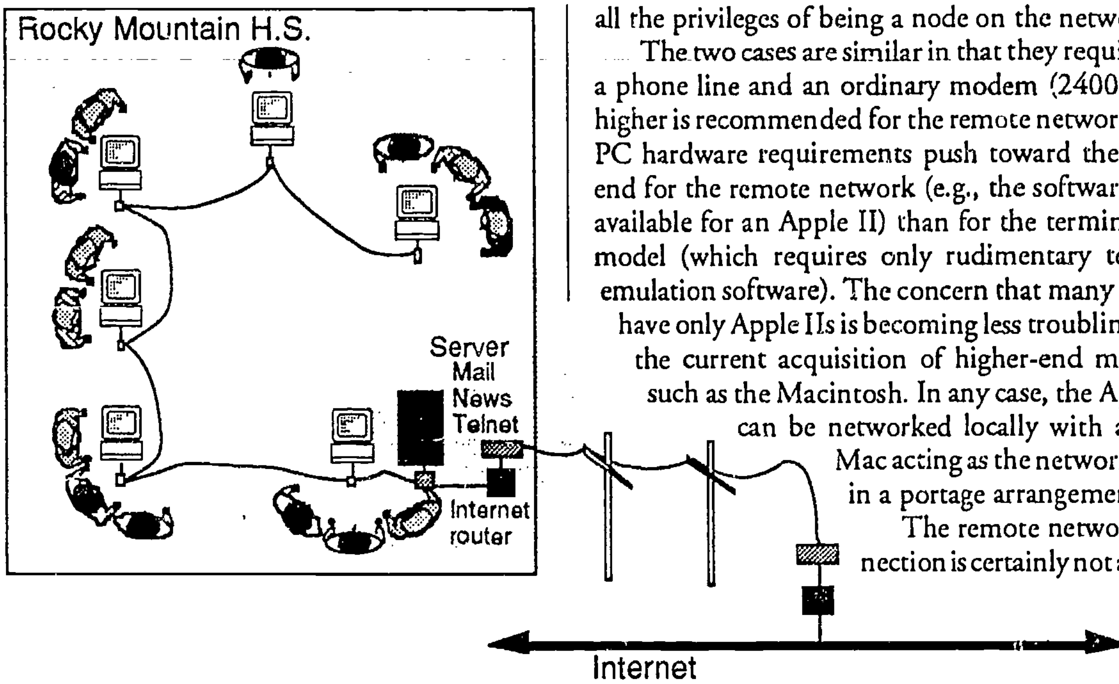
Shortly, the services provided by this remote machine (Internet mail and news) will be replaced by a local server (running on a UNIX workstation) at the school. UC Davis staff will manage this server remotely until the school staff are ready to take on this responsibility themselves.

Local Internet server

Several schools have already taken the step that McMillan JHS and Davis HS are contemplating and have set themselves up independent of local institutions. For example, Rocky Mountain High School in Ft. Collins, Colorado has built a networked computing environment that serves its district as well as the school itself.[15]

The school has a complex internal internetwork of IBM PCs and Macintosh computers. The local network also includes two UNIX servers that provide email and Internet news service for the school. Students are engaged in a variety of projects, especially in the area of envi. .nment studies, using space imagery. Individual email and Internet access for the students has opened the way for individualized projects as well as projects in which a collaborative group goes off to explore a new Internet resource.

About two thirds of the current email accounts on the UNIX servers belong to district users. The school expects the number of mail accounts and remote users to grow into the thousands as counselors, principals, other administrators, and other students find value in these services. Meanwhile, local students and staff can access resources on the Internet directly from their desktop machines.



all the privileges of being a node on the network.

The two cases are similar in that they require only a phone line and an ordinary modem (2400 bps or higher is recommended for the remote network). The PC hardware requirements push toward the higher end for the remote network (e.g., the software is not available for an Apple II) than for the terminal-host model (which requires only rudimentary terminal emulation software). The concern that many schools have only Apple IIs is becoming less troubling given the current acquisition of higher-end machines such as the Macintosh. In any case, the Apple IIs can be networked locally with a single Mac acting as the network server in a portage arrangement.

The remote network connection is certainly not as widespread as the terminal connection, but there is reason to believe that it will increase in use as more schools acquire access to the Internet. This type of "single user dial-up" service is offered by most, if not all, commercial Internet providers and regional networks today.

Another example of a local Internet server is at the Illinois Math and Science Academy, a public, residential school for talented students.[16] Students maintain a Sun workstation and other computers that provide email and other Internet services to the computer labs and resident halls. With full Internet access, students are involved in many projects and communicating with mentors at Argonne National Laboratory, Fermi National Accelerator Laboratory, and other scientific and research organizations. The IMSA campus network makes it possible for groups to collaborate on these projects without face-to-face meetings.

Comparing the Six Models

Setting up the models in a matrix makes it easier to compare features and decide what the various technologies are buying. As a way of understanding the value of the network connection, we can look at each column of the matrix in terms of the commonalties as well as the differences between terminal and network connections.

Type of Connection	Remote Services	Local Area Networks	Local Server
Terminal	"Telecomputing"	Network modem	"Portage"
Network	Remote network	Leased line to local campus	Local Internet server

The stand-alone classroom computer

In the first column, we have two models for connecting a single, non-LAN, PC to remote services. In the "telecom-puting" case, the PC becomes a terminal. In the remote network case, the telephone line becomes an extension of the packet network and the PC enjoys

LAN as access to the outside

The middle column represents cases in which the LAN is used as an effective mechanism for expanding access to the wide area connection. With the LAN in place, a student or teacher can sit down at any computer to call up a mail server or other remote resources, such as data on Supreme Court rulings. The immediately obvious advantage of the network connection over the terminal connection provided by the network modem is that many sessions can be carried on simultaneously. The function of the router at the school is to direct the appropriate packets off to the university campus network. The router does not care how many different computers on the LAN are generating the packets (i.e., up to the capacity of the phone line to carry the traffic). The network modem, on the other hand can only maintain a single terminal-host connection at a time.

Type of Connection	Remote Services	Local Area Networks	Local Server
Terminal	"Telecomputing"	Network modem	"Portage"
Network	Remote network	Leased line to local campus	Local Internet server

A common limitation in these middle cases is the number of email accounts the school has available. This is not a technical limitation. It results from the campus network administrator's not having the time or resources to create hundreds or perhaps thousands of email accounts for all the teachers and students in the neighboring school. In all the cases we observed where a school depended on a neighboring university or other organization, the helpful neighbor viewed the arrangement as temporary.[17] The plan was eventually to off-load the work of maintaining email accounts to a server administrator in the school or district. At least, in the network connection case, the direction of movement appears toward the matrix cell to the right.

We might characterize these cases as using the LAN to deliver the outside resources as illustrated in the diagram to the right.

In these cases we observed a differentiation between the functions internal to the LAN and the functions of external access. In one case, for example, computers were rebooted in order to operate over the WAN, at which point they could no longer access the local resources.

Supporting a local server

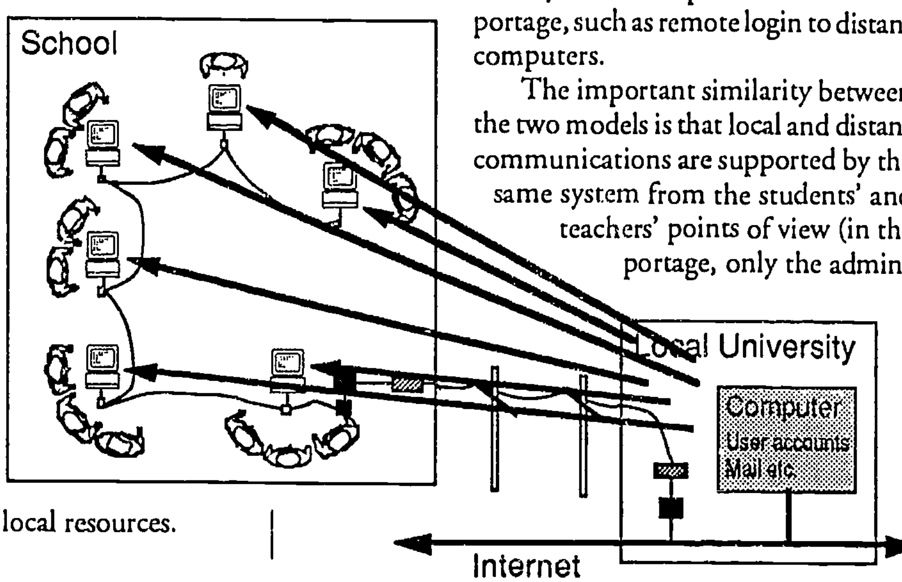
The right-hand column represents the few schools that maintain a server that supports communication within the school as well as between the school and the world outside.

Type of Connection	Remote Services	Local Area Networks	Local Server
Terminal	"Telecomputing"	Network modem	"Portage"
Network	Remote network	Leased line to local campus	Local Internet server

The portage model is a manual version of the functions served automatically by the Local Internet server. In the latter case, a common addressing scheme is used for messages sent either locally or to distant destinations.

The portage requires that the system administrator manually readdress messages going in either direction across the external connection. Similarly, for remote database access, the administrator has to download the information of interest and place it on the school server for local consumption. Besides avoiding the inconvenient portage, the network case, of course, allows much greater immediacy of access to local and wide area resources from any computer. It also permits activity that is not possible at all with a portage, such as remote login to distant computers.

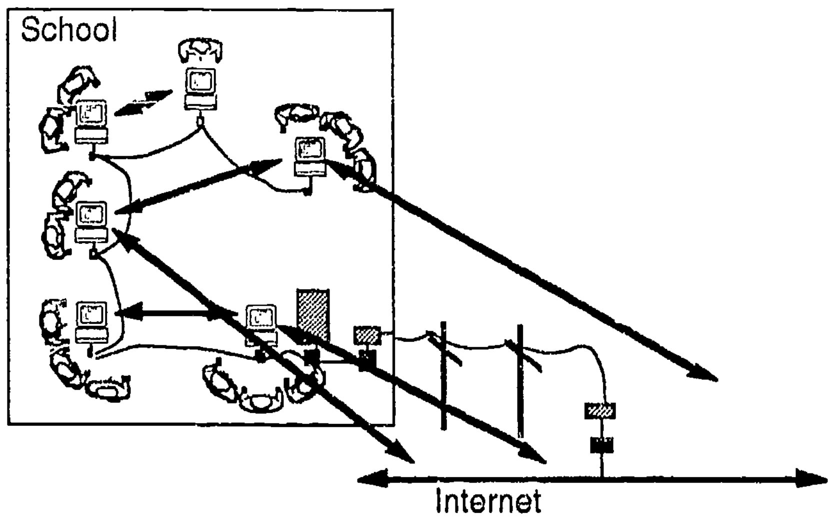
The important similarity between the two models is that local and distant communications are supported by the same system from the students' and teachers' points of view (in the portage, only the admin-



istrator sees two separate systems). The commitment of effort to administer local mail and other network services makes it possible to give all students and teachers an email account.

In these cases, we find local communications supporting local project groups that are accessing remote resources. Teachers use the local communications to coordinate their own work. The LAN is now a medium for supporting communication and sharing information among the local community, not just a means of access to the wide area resources.

The contrast between the middle column cases and the right column cases, which we attempt to capture in the two diagrams illustrating the flow of communication, is reminiscent of the difference we noted earlier between the instructional delivery and communicative uses of school LANs. The local server allows the school to go beyond using the LAN simply to provide access to the outside. The LAN can now serve an organizational function in the school, mediating the communication among students and teachers. ■

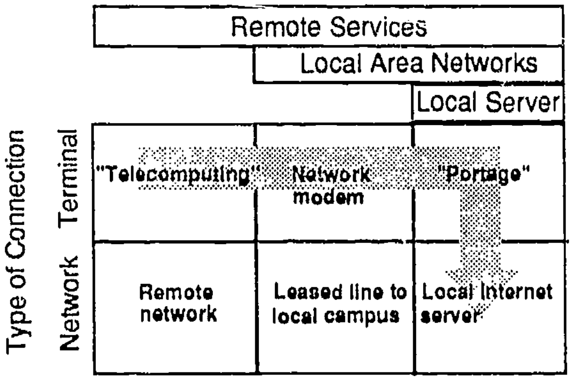


Prospects for the Future

How do we move from a situation in which only a minority of schools have even a terminal connection for a single classroom PC to a situation in which there is universal access to a national data network such as the NREN? We believe the prospects for universal access are very good as long as schools can make use of current and planned investments in local, district, and state education networks. We see the terminal-host paradigm as essentially a dead end. If the goal is to make resources available to all teachers and students, the centralized computing paradigm (the basis for the terminal-host connections) cannot handle the task. In this concluding section, we suggest the next steps that must be taken toward a school internetwork.

Build Remote Network Connections

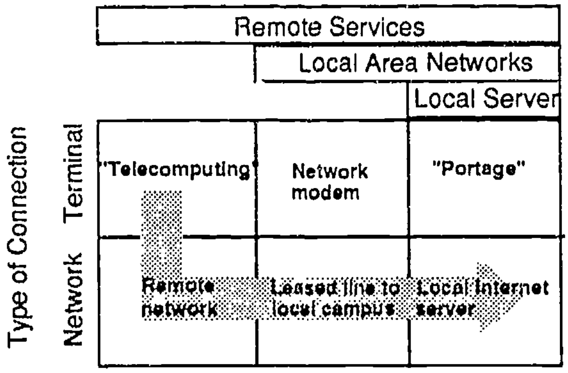
A number of paths might be recommended to get from the upper left cell of the matrix to the lower right cell. One path is the "high road" along the top row of the matrix. This path continues the terminal-host paradigm. When LANs are acquired, network modems are used to distribute access to the phone line and when local servers are used, material is portaged.



This route has major limitations because the remote and local systems remain essentially independent, requiring the manual portage of the material from one to the other. The transition from the portage to the Internet server requires considerable retooling, since PC software in use locally may not function on the wide area network.

Another path, shown above, is the "low road" along the bottom row of the matrix. In this case, we would begin by migrating from the upper left to the lower left; that is, not assume the initial availability of LANs, but begin developing the expertise and the software to support true network connections in schools with stand-alone computers.

This direction may be more workable. With the installation of a LAN and router, the same software, resources, and style of interaction that is familiar from



the single connected computer is simply extended to the other computers. An email client program, for example, that is used on the one networked machine can now be used on any of the machines on the LAN. With the later introduction of a local server, the same network interactions are simply brought closer and offered at a faster speed over the LAN.

This transition path argues for the aggressive migration from terminal connections to remote network connections in education. Some of the software for these connections, which are currently offered as a commercially available service, may require improvement for use by teachers who are new at networking. The migration path is worth developing, however, since it will open up to schools the kind of connection that can support standard forms of client software.

Address Security and Management Concerns

The open access that comes with internetworking raises concerns about how to keep administrative records secure and how to monitor student communication. Much of the existing state and district level network infrastructure (as well as many of the school LANs) supports administrative communication and databases of student records. The resistance that we have found in discussions of using existing administrative networks for instruction often revolves around fears of students breaking in and compromising those records. Instructional networks in the schools could also be prey to "hackers" intent on destroying or stealing data or planting viruses on school computers. Certainly such concerns have been addressed in military and business networks and by the Internet community (e.g, Holbrook & Reynolds, 1991), but school telecomputing has not made use of the level of technology available in other sectors. The design of a national educational network will have to incorporate adequate security mechanisms.

Educators also expressed concerns about managing communication from the school to the outside world or even communication within the school. Occasionally, the worry is that students or teachers will make use of the system for communication unrelated to instruction. For example, students may discuss socially sensitive issues or teachers may conduct union-related business. In business, research, and academic settings, extracurricular communication is seldom controlled. Provocative communication via email is dealt with as it would if expressed in other media. It is not clear that schools should be any different in this respect. There is a difference, however, in the case of communication with the outside world. Even teachers who are deeply committed to empowering students' self-expression question the wisdom of allowing unregulated student communication on national and international networks in terms of both the reputation of the school and the needs of the students for help with clarifying their communication. An advantage of the telecomputing model in which only the teacher has an account on the outside service is that all messages that cross the wire can be monitored. The teacher can work with children, who cannot be expected to know the rules of network discourse, to clean up their communication and appropriately distribute the incoming messages. While many teachers will feel comfortable giving many students unrestricted access, a communications system for schools, to be acceptable to the majority of teachers and administrators, will have to provide for the possibility of monitoring student messages.

Develop an Integrated Server

Currently, there is no server on the market, such as the one illustrated in the hypothetical scenario in the previous section, appropriate for helping schools and school districts connect to the Internet. A school server should integrate several commonly needed services and provide an adequate system for administering or managing these services. Such a server might be implemented on a relatively inexpensive computer, such as a 486 PC running a version of the UNIX operating system. Besides database, file, news, and mail services, the server should also provide a standard Internet routing service that allows anybody at a PC on the LAN to communicate over the entire Internet.

Most of the network services software that would be needed is readily available for integration on such a platform. A management system, based on a sophisticated database tool, could integrate the administration of these services and provide the kind of security and management of access privileges required in the school setting. The development of the management system in a way that takes advantage of existing administrative databases for the creation and updating of teacher, student, and other school accounts, that can be easily maintained as a part-time activity in the school, and that allows appropriate distribution of these tasks among coordinators and classroom teachers is perhaps the most critical component of a school server.

Develop Client Software

An important reason for moving quickly toward true network connections is that it will open the way for educational software developers to create network software that will be usable regardless of where in the internetwork the classroom PC finds itself. To allow the smooth scaling up from a single stand-alone computer with a modem in a school to the districtwide Internet, the fundamental relationship between the client software running on the classroom computer and the software running on the server must be the same regardless of whether the server is located in the computer lab next door or available by dialing up to the regional network center in another state.

There are near-term prospects for true networked systems coming into the schools as the commercial standards for client-server software interfaces are developed and adopted by manufacturers. Such "network-enabled" software, whether a word processor, a database interface, or a simulation, is able to communicate with resources anywhere on the Internet. In this way, a spreadsheet or a simulation can directly send or receive electronic mail, or a HyperCard stack can obtain and display data from a remote computer. A major advantage of network connections is the far greater ease of interaction with network services they afford. Using standard internetwork protocols makes it possible to have a completely open and general network-enabling strategy in which all educational software developers can participate.

The network paradigm will not be a lowest common denominator solution to school networking. We do not believe that there is a direct trade-off between cost of the technology and our ability to provide universal access. The lowest cost, short-term solution, a simple terminal-host system using very low speed dial-up lines, will not be able to take advantage of existing and planned investments in district-wide networks to lower costs, and will not be able to encompass multiple applications to raise the value of the investment. It is also far less likely that easy-to-use client software will develop for the terminal-host paradigm in the way it is already developing for networks.

The history of school LANs and WANs is different from that in other sectors. It is not simply that schools lag behind. The functions of the technology have been different, resulting in two distinct tracks; in other domains, LANs and WANs evolved together. Schools remain different functionally, organizationally, and in scale from business, research, military, and other environments in which networks have been deployed. Current solutions in these sectors will not necessarily be adequate for schools but schools can learn from them and borrow technology as needed. It may well be the case that future network solutions for schools will be borrowed by industry as we confront for the first time the issues of scale and ease of use and begin creating organizations in which people can learn through communication. ■

Notes

1. The National Research and Education Network (NREN) is a component of the High Performance Computing Act.

2. CTP mailed a 6-page questionnaire to a random sample of 1,000 school sites (of the over 9,000 school sites in California) in April 1989.

3. One case that approached such a use had a small single-purpose LAN that connected several terminals to a database in the state capitol. But this set-up was independent of the main LAN in the computer lab.

4. Packet switching was subsequently developed for many transmission types, including radio, satellite, and local area network technologies such as Ethernet.

5. The first packet switches that formed the ARPANET backbone connected computers at UCLA, the Stanford Research Institute, UC Santa Barbara, and the University of Utah. Before the military sites split off to form a separate network in 1983, over 100 ARPANET packet switches connected hundreds of computers at university campuses, research labs such as the Rand Corporation and Lincoln Labs, other companies engaged in research and development such as Xerox, DEC, and Bolt Beranek and Newman, and government sites, all of which had U.S. Government-sponsored projects.

6. The Internet technology, commonly referred to as TCP/IP, includes protocols that specify how computers and their applications communicate (notably, Transmission Control Protocol or TCP) and protocols that specify how data traffic can be routed over interconnected networks (notably Internet Protocol or IP).

7. K12net discussion groups can also be accessed as newsgroups.

8. For example, machines with large shared resources, such as disk space or databases, centralized management, and so on.

9. A more recent standard being implemented is the Point-to-Point Protocol (PPP).

10. This is the case, even when a public or commercial data network serves as an intermediary between the terminal and host. For example, when a teacher calls CompuServe or any of the other national "information utilities," he dials a local number of a specialized computer, which takes the incoming information. The information is turned into packets and sent out over a national network (usually an X.25 packet-switched network) to the host computer somewhere in the country. At the far end, the packets are disassembled into a stream of bits so that, from the point of

view of the classroom computer and the host, there is still just a terminal-host connection.

11. An important difference between a dial-up line and a leased line is the latency in response for highly interactive applications, since a dial-up connection would have to be established before communication takes place. Leased lines will be advantageous for synchronous interaction, remote computing, or where finer grained interactions with Internet services are desired. A leased digital line allows for much higher speeds of data transmission but may not be required immediately by schools. In a large state, multiple Internet connections will be desirable as traffic increases.

12. These include: Jostens Learning Corp.; Computer Curriculum Corp.; Computer Networking Specialists, Inc.; Wicat; Novell; IBM; Velan; Wasatch Education Systems; and Ideal Learning.

13. A gateway (Cayman's GatorBox) connects the LocalTalk network (the physical network supporting the Macintoshes) to the Ethernet interface of an internet router. The McMillan router is then linked to a router at UNO using a leased 56 Kbps line.

14. Davis High School students and staff use Macintoshes on a LocalTalk network, but run TCP/IP on their Macs and are connected to the Internet. One of the Macintoshes acts as a file server; it runs AppleShare, and students run Mac-based email (MacMH now, Eudora soon), terminal emulation (Telnet), and file transfer (FTP) applications from the server. In this way, incoming mail and files are stored directly on the server in one step. A gateway (Shiva FastPath IV) connects the LocalTalk network to the Ethernet interface of an Internet router (Proteon) in the school. The Davis High router is then linked to a router at the University of California (UC Davis) using a leased 56 Kbps line. A network services VAX host on the UC Davis campus network provides accounts for the exchange of mail between Davis High and the Internet. These are not accounts that allow people to log in; they only allow email exchange by the PC exchange protocol (POP).

15. Within the school, students and staff use Macintoshes and an AppleShare file server on a LocalTalk network, which is gatewayed to the school Ethernet (Cayman GatorBox). Users of the school's business lab work on PCs served by a Novell NetWare server, all of which are directly on the Ethernet. All networked Macintoshes and PCs have Internet terminal emulation (Telnet) capability. Two IBM RS/6000 AIX (UNIX) machines on the Ethernet provide email, selective Internet news feeds, and Telnet services to the school and to elementary, junior high, and administrative users in the larger district. This is made possible by two wide area connections. First, an Internet router (Cisco) on the Ethernet connects the school network via a 56 Kbps dedicated line to a regional Internet router at Colorado State University. Second, a dedicated line and some protocol converters allow terminal users of the district's VAX cluster (which does not support TCP/IP) to access the school's UNIX servers.

16. IMSA supports a heterogeneous local area network environment. Their network is connected to an Internet router at Argonne National Labs (an NSFNET high speed backbone node site) by means of a local Internet router (Cisco) and a leased 56 Kbps line. The IMSA network environment is built around two Ethernets (one educational, one administrative connected to each other by their router) and an extended LocalTalk network connected to the Ethernets by gateways. The Academy boasts a number of computing resources, several of which are used as servers. For example, there are two student and two administrative NetWare file servers. Servers are designated as either educational or administrative; administrators can access both types, but students and the rest of the Internet can only access the educational servers. IMSA students and staff use Macintoshes and PCs on the network, as well as a handful of UNIX workstations of various types; all support TCP and can reach any Internet host directly when necessary. A UNIX (Sun) server supports most of IMSA's electronic mail locally and all email to and from the Internet. It also provides a local bulletin board service ("notesfiles"). A variety of client mail programs, which communicate with the UNIX server, are used on the Macintoshes and PCs (QuickMail, Eudora, Pegasus); some users use terminal emulation (Telnet) to access their email directly on the mail server.

17. This view was echoed by many participants at a recent Boston workshop, "NEARnet and Grades K-12: Educational Innovation through Partnerships."

References

California Technology Project Assessment Team (1990). *An assessment of educational technology applications in California public schools.* Chico, CA: California State University.

Cerf, V. (1989). Requiem for the ARPANET. *ConneXions, 3*(10).

Cole, M., & Griffin, P. (1987). *Contextual factors in education: Improving science and mathematics education for minorities and women.* Madison, WI: Wisconsin Center for Educational Research.

Comer, D. (1990). *Internetworking with TCP/IP.* Englewood Cliffs, NJ: Prentice-Hall.

Dern, D. P. (1989). The ARPANET is twenty: What we have learned and the fun we had. *ConneXions, 3*(10), 2-10.

Dern, D. P. (1992, February). Applying the Internet. *BYTE,* 111-118.

Electronic Learning (1992, March). *The ILS Mac Pac. Electronic Learning* (Special Edition).

Goldman, S. V., & Newman, D. (in press). Electronic interactions: How students and teachers organize schooling over the wires. *Interactive Learning Environments.*

Gurugé, A. (1992, February). SNA and LAN internets: A long walk to the altar. *Network World, 9*(6).

Holbrook, P., & Reynolds J. (1991). Site Security Handbook. *Internet Request for Comments 1244,* FYI 8.

Hunter, B. (1992a). Linking for learning: Computer-and-communications network support for nationwide innovation in education. *Journal of Science Education and Technology, 1.*

Hunter, B. (1992b. April). *Internetworking: The coordinating technology for systemic change in education.* Presented to Subcommittee on Select Education, Committee on Education and Labor, U.S. House of Representatives, Congressional Staff Forum on "Designing an educational technology infrastructure: Defining the federal role in the dissemination of information."

Kehoe, B. P. (1992). *Zen and the art of the Internet: A beginner's guide to the Internet.*

Kurshan, B. (1990a). *Home market for educational online services* (Research Report). Educorp Consultants, 4940 Buckhorn Road, Roanoke, VA.

Kurshan, B. (1990b). *Statewide telecommunications networks: An overview of the current state and the growth potential* (Research Report). Educorp Consultants, 4940 Buckhorn Road, Roanoke, VA.

Kurshan, B., & Harrington, M. (1991). *Statewide education networks: Survey results.* Educorp Consultants, 4940 Buckhorn Road, Roanoke, VA.

Kurshan, B. (1992). *The global classroom—Changing the way we learn and teach.* Educorp Consultants, 4940 Buckhorn Road, Roanoke, VA.

LaQuey, T. L. (1990). *The user's directory of computer networks.* Bedford, MA: Digital Press.

McAnge, T., Harrington, M., & Pierson, M. E. (1990). *A survey of educational computer networks.* Blacksburg, VA: Virginia Polytechnic Institute and State University.

Mageau, T. (1990). ILS: Its new role in schools. *Electronic Learning, 10*(1), 22-32.

Martin, J. (1991). There's gold in them thar networks! *Internet Request for Comments 1290,* FYI 10.

Melmed, A., & Fisher, F. D. (1991). *Towards a national information infrastructure: Implications for selected social sectors and education.* New York: Center for Educational Technology and Economic Productivity, New York University.

Newman, D. (1990). Opportunities for research on the organizational impact of school computers. *Educational Researcher, 19*(3), 8-13.

Newman, D. (in press). Technology as support for school structure and school restructuring. *Phi Delta Kappan.*

Newman, D., Goldman, S.V., Brienne, D., Jackson, I., & Magzamen, S. (1989). Peer collaboration in computer-mediated science investigations. *Journal of Educational Computing Research, 5*(2), 151-166.

Newman, D., & Reese, P. (1990). Using a local area network for sharing data. In EPIE Institute (Eds.), *Report on integrated instructional systems.* Water Mill, NY: EPIE Institute.

NYSERNet, Inc. (1991). *New user's guide to useful and unique resources on the internet* (Version 2.0). Syracuse, NY: Author.

Office of Science and Technology Policy. (1991). *Grand challenges: High performance computing and communications.* A report by the Committee on Physical, Mathematical, and Engineering Sciences to supplement the President's FY 1992 Budget.

Reilly, R. (1992). *K12net: International educational network.*

Roberts, N., Blakeslee, G., Brown, M., & Lenk, C. (1990). *Integrating telecommunications into education.* Englewood Cliffs, NJ: Prentice Hall.

Sherry, M. (Ed.). (1990). *The integrated instructional systems report.* Water Mill, NY: EPIE Institute.

Solomon, G. (1992, March). The most complete guide ever to telecommunications. *Electronic Learning,* 18-28.

St. George, A. (1992). A voice for K–12 networking. *Research and Education Networking, 3*(1), 10-12.

Wood, R., & Mensch, H. (1991). *The Athena network services environment: An overview.* Presented at Uniforum.