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INFRASTRUCTURE: HARDWARE, NETWORKING, SOFTWARE, AND CONNECTIVITY

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INTRODUCTION

Education systems must help to build higher-order cognitive abilities, strengthen processes of inquiry, enable collaborative problem solving, and prepare people to compete in local and global markets and become productive members of society. Providing citizens with quality education is becoming ever more important with globalization and the increasingly dominant role information, knowledge, and digital technologies play in all economies. A new gap is arising between those who have access to and can use modern information and communication technology (ICT) systems and those who lack the access and ability to participate actively in the Information Age.

No single solution exists to address the immense challenges of providing quality education and bridging the ICT gap. One possibility is to develop and apply new approaches and strategies for teaching and learning that integrate computers, Internet-enabled collaborative learning, and related educational technologies with routine teaching and learning. When used effectively and integrated into education, computers and Internet technologies can improve teaching and learning, strengthen teacher professional development, support broad educational reform, enhance school-community partnerships, and improve school management (see chapter 3).[1]

The demand to realize these educational objectives by integrating computer and Internet technologies into education forces education planners, principals, teachers, and technology specialists to make many decisions about the technical, training, financial, pedagogical, and infrastructure requirements of school computerization programs. Some of the more challenging questions planners and educators must answer have to do with infrastructure issues. In this chapter, infrastructure includes what types of computer hardware to use, where and how computers should be distributed and networked in schools, if and how school computers can and should be connected to the Internet, and the software choices schools need to make. This chapter also touches on policies that can help to develop enabling environments to support school computerization and connectivity programs. There is no single *best* computer configuration[2] or single infrastructure solution to suit all situations. Rather, there are only optimum solutions for each school. Arriving at these optimum solutions is not simply a technical process but requires a careful consideration of educational goals and an understanding of the different costs and benefits, both economic and educational, of different technology options.

SCHOOL CONTEXT: ASSESSING OBJECTIVES, CONDITIONS, AND OPTIONS

Since infrastructural questions are dominated by a complex mix of technical factors, requirements, and options, decisions about infrastructure often are divorced from educational concerns and driven by technical matters and technology experts. In reality, infrastructure questions and decisions are coupled with educational needs, opportunities, and outcomes. Therefore, to achieve optimum educational results, each school or school system should base infrastructure decisions on an assessment of a mix of technical factors and educational needs and objectives. The results of such an assessment then must be compared to the costs and benefits of a variety of computer system configurations and infrastructure options. When carrying out an educational/infrastructure assessment, the following questions may need to be considered:

> *Educational goals:* What educational goals and learning objectives will be accomplished by using computers in schools? Different computer configurations have direct relationships to how computers and the Internet can and will be used by teachers and students to enhance education.

> *Professional development:* Will the computer system be used for teacher professional development and to supplement classroom teaching? Enhancing teacher professional development by training teachers both to use computer and Internet technologies and to integrate these technologies into education, along with improving subject matter competence and strengthening pedagogical skills, are often important objectives of school computer programs. Ensuring that such objectives are achieved often requires that teachers be provided with special access to computer and Internet technologies and a complex mix of initial and ongoing training and support. If online professional development is planned, suitable Internet connectivity and time to engage in online learning will be required.

> S*tudent-to-computer ratio:* What target ratio of students per computer is the school or school system aiming for? Most schools calculate this ratio by simply dividing the number of students in the school by the number of computers available to students. This simple calculation may not present an accurate picture of students' productive access to computers, however. In secondary schools, the issue is viewed more appropriately in terms of how much computer and Internet access, frequency, and duration students in different disciplines have.

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- *Community use:* Will a school's computer system be used by members of the community during nonschool hours? The high cost of investing in technology in public schools often can be justified partly by allowing the new computer facilities to be used by members of the school community. If this is a priority, then a lab or computers-on-wheels configuration (see below) may be needed, necessitating additional investments in staff and security.
- S*chool's electrical system:* What is the state of the school's electrical system? What is the availability and quality of electrical power and the type and distribution of electrical wiring in the school? Computers operate better and last longer when the electricity that powers them is continuous and of consistent voltage. Many schools, especially older ones, have an insufficient supply of electricity to withstand the additional demand made by the computers. Further, electrical cables may not be the correct gauge to withstand the additional load caused by computers being connected to the school's electrical system. Or the electrical cables may be composed of aluminum, which oxidizes over time and can become a fire hazard. Lack of electricity or poor wiring may require the school to refurbish the existing electrical system or add a whole new electrical supply system. This is one reason why many schools decide to install computers in labs, which reduces the amount of electrical wiring needed. Also, computers, especially those connected to a local area network (LAN), require a grounded electrical system to operate smoothly and trouble-free. Again, this is less costly if done to one or two computer labs or rooms, rather than to the entire school. The quality of electricity coming to a school also may be inconsistent and fluctuate between low and high voltages. These conditions can disrupt students' use of computers and result in premature and sudden failure of expensive computer equipment. These problems are often dealt with by installing line stabilizers to make the voltage constant and uninterruptible power supplies to provide a short-term (10 to 20 minutes) supply of electricity to the computer to allow work to be saved and equipment to be turned off safely when the electrical supply fails. Adding this equipment to a school computerization plan can increase costs significantly. When electricity is not available, it may be possible to install solar-powered systems for the computer equipment (see chapter 16). Solar equipment can be very expensive and is often best used with laptop computers, since they use less power and can use direct current (DC) electricity directly. Also, since laptops come with their own batteries, less money may need to be spent on a battery back-up system for the solar panels.
- *Other physical conditions:* What are the sizes and shapes of classrooms? What is the quality of natural or electrical lighting? Are telephone lines distributed throughout the schools? What types of desks, chairs, benches, and tables are available? As described below, one of the major questions about school computer systems focuses on whether to install computers in classrooms or computer labs. If classrooms are small and crowded and without lockable doors, it may be more appropriate to use labs. Creating optimum lighting conditions, especially where electrical light may be difficult to manage, often can be achieved most easily by modifying computer labs for skylights rather than trying to adjust the lighting in every room in a school. Often, as described below, the simplest way to connect computers to the Internet is through telephone lines and a dial-up connection to an Internet service provider (ISP). However without existing phone lines, it can prove difficult and expensive to provide wiring for telephone connections in more than just one or two computer labs.
- *Physical security:* How secure are the schools and the classrooms in which computers may be installed? Is the school located where the risk of theft is high? Providing sufficient security in the classroom and at the school to prevent theft of equipment, software, and supplies can be expensive and it is often only possible for one or two rooms in a school. When security plans are made, it is important to achieve a balance between protecting equipment from theft and allowing easy access to computers as often as possible. Fears of being blamed for damage to or loss of equipment can cause principals and teachers to make it very difficult for students to use computers, or for community members to benefit from investments in technology through after-school use.
- *Students per classroom:* What is the average number of students per classroom, and how large is the student population expected to grow over time? Schools with large numbers of students per classroom are likely to have limited space for permanently installed computers. Under such conditions, it may be best to install computers in one or more lab facilities where students can use the equipment. For smaller children, it is possible to have two to four students per computer. However, it is difficult and restrictive to have more than two older students per computer. To allow multiple students per computer requires sufficient space between computers with enough room left over to allow teachers to move among students to review work and offer support and feedback.
- *Technical support and management:* What strategies will be used to provide support, management, and maintenance of computer facilities? This concern, which has significant financial implications, is beyond the scope of

this chapter. But it cannot be stressed enough that the sustainability of any scheme to introduce computers into the educational process depends on careful attention to technical support and to equipment maintenance and renewal.

> *Financial resources:* How much money is available to purchase and install the equipment, buy software, train teachers, and support, maintain, and use the equipment? Is there a budget for ongoing maintenance, supplies, and technical support, and for replacing aging equipment and obtaining more computers? Technology budgets for initial installation of systems and ongoing support likely will be a decisive factor when deciding which configuration is best for a school or school system. As a result, budgets for ongoing equipment support, supply, repair, and replacement often are neglected or insufficient. Also, funds to purchase and install equipment and provide initial teacher training may come from national or state budgets. In contrast, local government and school budgets often will have to cover the purchase of consumables, pay for connectivity, and fund technical support and maintenance to keep the systems running. Without additional funds, these ongoing responsibilities and recurrent expenses often are not met. It may be necessary, therefore, for schools to devise special fund-raising schemes such as opening up the computer system to fee-based use during nonschool hours, reaching out to parent-teacher associations (PTAs), and soliciting the local business community for funding. In addition, where families have sufficient disposable income, some schools have charged an annual computer use fee to cover the cost of consumables and equipment maintenance. No matter what the solution, schools should develop and implement strategies immediately to guarantee sustainability of their computer systems.

> *Educator technology skills:* Do the teachers know how to use computers and, more important, do they have the skills to integrate computer and Internet use into routine teaching and learning? Only knowing how to use the technology will not enable teachers to use computer and Internet technologies to enhance learning significantly. Initial and ongoing teacher professional development focusing on using computers and effective pedagogy usually is required to enable schools to gain the greatest educational benefit from their investments in computers (see chapter 8). The configuration of computer facilities plays a major role in providing effective learning opportunities and professional development for teachers.

> *School routine:* Do students move from class to class throughout the day, or spend most of their time in one room? The answer affects decisions about using computer labs and/or placing computers in classrooms.

> S*pecial-needs or disabled students:* Will special-needs students use the computer system? Is physical access to computers by students in wheel chairs an important issue? If so, ramps, extra space between computers, and a few special desks will be needed. At another level, will there be need to install special software to make it easier for a visually impaired student to read the screen, or screen readers and headsets to allow blind students to listen to the screens being read? Learning-disabled students may need special keyboards with large keys and audio and tactile feedback to engage the technology effectively. Computer technologies have had some of their greatest impact in educating special-needs students. However, ignoring their special mobility and technological needs at the start of the planning and design process will guarantee that these benefits will be unrealized.

> *Temperature and air quality:* Will rooms with computers need to be air conditioned or protected from excessive dust? Modern computers and cathode ray tube monitors generate a great deal of heat. The lack of sufficient ventilation, especially in humid climates, can result in a very uncomfortable working environment for students and, occasionally, can even cause computers to overheat and malfunction. However, opening windows to improve air circulation can result in a damaging level of dust entering the computer room and increased risk of equipment theft. The combination of heat and dust often forces school computer programs to install expensive air conditioning units. Before committing to the purchase of air conditioning systems, programs should consult with architects, often as volunteers, about alternative strategies suitable for local environments to keep computer labs comfortable and free of excessive dust.

> *Connecting computers together:* Will the computers be installed as stand-alone systems or connected together to form a local area network (LAN)? Connecting computers together in a LAN, as described in greater detail below, can have significant educational benefits. At the same time, creating a LAN has financial and infrastructure effects that need to be weighed carefully against possible educational gains. LANs, if carefully planned, can be installed after the initial computer system is put in place if funding prohibits installation at the start. However, careful planning will be needed to avoid any duplication of effort and wasted investment.

> *Internet connectivity:* Will the computers be connected to the Internet? If so, what type of connection (intermittent use of normal phone lines, dedicated phone or cable connections, wireless links or satellite) is possible and affordable? Internet connectivity should be

dealt with at the very start of devising a school computer plan. Alternative approaches to connectivity are discussed below.

These questions are not equally important in all situations, so answers should be weighted according to the specific school's situation and requirements. One of the most difficult challenges, however, is balancing educational objectives with technical limitations and hard financial realities. Ultimately, the goal of assessing objectives, needs, conditions, and options is to determine the optimum configuration for integrating computers into education at a specific school.

There are many ways to describe different infrastructure needs and computer system configuration options and strategies. In this chapter, we use four organizing themes:

- physical configuration options,
- networking technology options,
- Internet access options, and
- software and operating system considerations.

PHYSICAL CONFIGURATION OPTIONS

Computers can be distributed in schools in three basic ways to meet educational goals. They can be provided to individual classrooms; installed in central computer labs, libraries, and teachers' planning rooms; or moved from room to room on mobile carts. Each of these options, and combinations of them, has associated benefits and costs that need to be considered carefully to select the options that best meet a school's needs. Some educational technology specialists argue that proximity and easy access to computers achieved by placing them in classrooms are crucial in achieving high rates of student and teacher use and, thus, educational benefits. Similarly, some people think installing computers in central computer rooms or labs is "old fashioned" and inhibits effective educational use. These are overly simplistic perspectives because the distribution of computers is only one factor in determining how teachers and students use them, and the Internet, to enhance teaching and learning.

Computers in Classrooms

One of the greatest potential benefits of distributing computers to individual classrooms is to provide teachers and students with easier access to these educational tools. More specifically, having computers in classrooms can:

- make it easier for teachers to integrate computer and Internet use into routine educational programs—but this cannot be guaranteed;
- allow for spontaneous use of these tools during instructional activities;
- permit teachers to organize students into a variety of learning activities, some using computers and others not; and
- make it easier to individualize instruction and strategically integrate computer and Internet technologies into project-based learning.

Achieving the multiple benefits of classroom-based computers demands significant financial investments to:

- purchase sufficient hardware and software so that all classes have equal access to computers;
- refurbish all classrooms so that there is sufficient room for the computers and a suitable electrical supply, security, networkability, and connectivity;
- provide each teacher with a high degree of computer technical and pedagogical skills since education technology specialists will not be available to help as they would in a computer lab; and
- supply ongoing technical and educational support.

Unfortunately, not all schools can afford enough computers to enable effective student access and use. As a result, some schools may decide to install only one or two computers per classroom, which likely will have little or no impact on learning. Experience also shows that when there is only a single computer in a classroom, it often becomes the "teacher's" computer and is rarely used by students.

Considerations for installing computers in classrooms include:

- *Teachers' skills:* Computers in classrooms usually require teachers to have a high degree of technical skill and the capacity to integrate computer use into their teaching.
- *Space and student numbers:* Placing clusters of computers in a classroom to enable effective student use requires enough space for both the computer systems and groups of two to three students to sit comfortably in front of the computers, circulation area for teachers and nontraditional student seating arrangements.
- *Quality and availability of electricity:* As mentioned above, computers demand a quality electrical supply. Remodeling classrooms to meet the electrical needs of computers is usually very expensive, especially if it needs to be done in many classrooms.
- *Security:* Maintaining sufficient security to prevent theft of equipment, software, and supplies, while also enabling open access to the classrooms to a variety of users, is usually impossible.
- *Availability of maintenance and support services:* Distributing computers throughout the classrooms in a school makes it more difficult, and more expensive, to provide effective maintenance and support services.

- *Internet access:* Providing even limited Internet access in each classroom via intermittent use of a single dial-up phone connection can be expensive, and high-speed access can become prohibitive.
- *Connecting computers within the classroom and the school:* Most schools require extensive remodeling to enable computers in classrooms and schools to be connected to form cabled networks. Also, creating classroom networks can require significant investments in additional hardware (servers, hubs, routers, etc.).
- *Community access to school-based computer systems:* Installing computers in classrooms can make it more difficult to provide community access to these costly resources. This difficulty is exacerbated if the number of computers per classroom is relatively low, since no single room may have a sufficient number of computers to meet community use and training needs. As a result, schools with classroom-based computers may not be able to generate enough revenue to cover the costs of consumables, maintenance, and replacement of systems through community access to their computers.

With sufficient funding, and under the right conditions, with highly skilled teachers, classroom-based computers can have a significant impact on the quality of teaching and learning (see Box 6.1). Classroom-based computer installations with low student-to-computer ratios also can provide unparalleled student access to computer use and enable teachers to integrate the use of computers and the Internet in ways that cannot be achieved by any other configuration. However, for most schools, especially those in developing countries and poor communities, it isn't possible to install computers routinely in classrooms. Under these more common conditions, alternative strategies must be considered.

BOX 6.1 • COMPUTERS IN THE CLASSROOM—A SUCCESS STORY!

Mrs. Barbara Bell teaches fifth grade in Montgomery County, Maryland. Over the last 15 years, she has accumulated a menagerie of 18 Apple computers, ranging from an "ancient" Apple II to a recent G3 powerhouse. Each of these machines is arranged in her classroom, filling each corner and empty space to afford optimum use and enable individualized and small-group learning. Many of these computers were scavenged from garbage piles behind schools at the end of the year and repaired and upgraded by her son and husband. An old large-screen TV is connected to several computers so she can switch the display to the TV for all students to see clearly. One system is connected to the Internet via a modem to enable e-mail communication and student research, often spontaneous and arising from class discussions. A special large-character keyboard and headset enable a student with Down's syndrome to be part of a "normal" classroom and participate in some class activities.

Along with her assortment of computers, Mrs. Bell has acquired a library of software, much of it purchased with her own money over the years. Some software titles are no longer published and are primitive by today's standards, with black and white graphics, no sound other than beeps and chirps, and no wildly interactive screens. Even without any essential multimedia elements, Mrs. Bell's students eagerly use these ancient software programs—often when a more modern version is available.

Maintaining her classic mix of computers, protecting and cataloging her rich collection of software, setting up the computers in a relatively small classroom with 32 students, and orchestrating the organized use of her computers in routine teaching and learning is not easy. So, why does Mrs. Bell continue to do this, year after year, without technical support from the school and when she is the only teacher with such an odd classroom?

The answer is easy: "It makes teaching and learning more effective, rewarding and fun!" According to Mrs. Bell, the routine and integrated use of computers in her classroom makes learning more effective and fun for her and for the students. It also makes it possible to individualize instruction at a level not possible without computers and allows Mrs. Bell to meet the learning needs of each student. It also enables planned and spontaneous peer-to-peer instruction among students. Mixing computer use with routine classroom activities allows for complex student-organized and -managed, project-based, and collaborative learning activities that often extend beyond curriculum themes.

When observing Mrs. Bell's class, one is struck by an apparent contradiction. The room is full of active, learning children, students working alone and in small teams, teaching each other, receiving focused instruction and tutoring from Mrs. Bell, researching answers to questions, struggling with problems, completing assignments, sharpening skills, and making seamless use of computers, blackboard, paper, books, and other learning tools. Yet, even with all this energy and activity, the room is surprisingly quiet; there are no arguments or disruptions, even from students diagnosed with attention deficient disorder; no one is goofing off, dozing, or eyeing the clock, eagerly awaiting the end of the day.

Computer Rooms or Labs

Establishing one or more computer rooms or labs is a popular way to provide equitable access to computers for the greatest number of users at the lowest possible cost. Computer labs enable schools to concentrate expensive resources in a common space that can be used for student educational activities, teacher professional development events, and community groups. When using computer labs, it is important to arrange computers along the walls of the room rather than in rows facing the front of the room, so teachers can view all the students' work from a common point and move quickly and easily from student to student, providing feedback, support, and guidance. This arrangement also can make it easier and less costly to provide electricity and network access for the computers. Some of the benefits and challenges of using computer labs are discussed below (see Box 6.2).

Benefits

> Establishing computers in a lab or dedicated room only requires schools to install quality electricity, network cabling and servers, Internet access, effective security, climate control systems, good lighting, and specialized furniture in one or two rooms in a school rather than in many different rooms.
> If designed effectively, a dedicated room ensures sufficient space to allow students to work in groups and move about to see each other's work, while also allowing teachers to move from group to group to provide input and guidance.
> Computer labs can be maintained by one or two staff members who also can provide technical and pedagogical support to teachers.
> Equipment and software can cost less for computer labs used by all classes than for classroom-based systems.
> Computer labs can optimize return on technology investments if their use is scheduled effectively.
> It can be easier and less costly to provide access to the Internet via computer labs than with classroom systems since many computers can use a common connection to the Internet.
> Computer labs can make it easier to encourage collaborative interdisciplinary projects among groups of teachers and students.
> Computer labs make it easier to provide community access to computer systems for public relations, and to generate revenue to cover the costs of consumables, Internet connectivity, and replacement of old equipment.

Challenges

> Computer labs can become oversubscribed quickly, and competition for use may make it difficult for teachers to engage their students in longer-term projects and activities.
> Scheduling conflicts can frustrate teachers and inhibit their use of computer labs.
> Once the novelty of using computers wears off, encouraging teachers to move their students to the lab may become more difficult.
> Spontaneous need to use computers for research, reference, word processing, etc., can be difficult or impossible to accommodate.
> In some schools, principals or lab coordinators may implement policies designed to keep the computers safe at the expense of using them.

Schools can overcome many of the challenges of using school computer labs by devising and implementing effective policies governing the use of the labs. A computer lab coordinator is a critical asset and can continue to promote use of the lab and help teachers deal with scheduling conflicts. Labs also can include one or two open- or free-access computers that can be used by students and teachers without scheduling.

Computers-on-Wheels (COWs)

Computers-on-Wheels (or COWs) systems are essentially rolling carts that hold one or more computers (often 10 to 20), usually laptops, often with a printer, and with the possibility to connect the cart to the school LAN via a single classroom network connection. COWs can be brought into a classroom, often by an educational technology specialist, when the teacher wants to use computers for a specific activity. Some of the benefits and challenges of using COWs are discussed below.

Benefits

> COWs make it possible to provide teachers access to computers in their classroom without having to remodel the room significantly, provide special furniture, or reserve space for dedicated computers.
> Working in small groups at their desks enables all students to have access to computers even in crowded classrooms.
> Using battery-powered laptops makes it possible to avoid providing special electrical power or installing additional power outlets.
> Using infrared printing and wireless networking cards enables the students to print their work and connect to each other and the school network for e-mail, electronic communication, and, possibly, Internet access without cables.
> COWs allow schools to optimize the use of expensive equipment by enabling teachers to request a cart of computers.

BOX 6.2 • COMPUTER LABS IN BRAZIL

Brazil's Ministry of Education officials were faced with a set of needs and constraints common to many education departments and ministries around the world. They wanted to provide as many public school students as possible with access to computer and Internet technologies, but they had limited financial resources. Also, few, if any, of Brazil's public state and municipal schools have the infrastructure to support computer installations without significant modifications and additions. Furthermore, most schools are used for two or three different school sessions during the day, thus making it impossible to install computers in individual classrooms. In addition, few public school teachers had the technical or pedagogical skills needed to integrate computer and Internet technologies into routine teaching and learning effectively, and there was no local, state, or national capacity to provide ongoing technical and pedagogical support to teachers who might use computers.

Faced with these and other constraints, Brazil's Ministry of Education, through the ProInfo program, decided to establish computer labs in refurbished existing rooms or in new rooms when existing space was either unsuitable or unavailable. Each lab holds 15 to 25 computers, often arranged along the walls of the room and connected together by a hub and server to form a LAN. Internet connectivity, where installed, consists of a single shared computer with a dial-up link to a local ISP or a dedicated 64Kbps line connected to the server so that all computers in the lab have shared access. Where needed, the labs, are powered by new or refurbished electrical systems and a combination of stabilizers and Uninterruptible Power Supplies (UPS) systems to protect the computers from potentially damaging electricity fluctuations. Special care was taken to provide a combination of quality natural and electric lighting while preventing excess glare and heat caused by strong tropical sunlight. Where needed, labs are air conditioned to provide comfort and limit dust. The labs are managed by teacher/lab coordinators who have had special technical and pedagogical training and who receive ongoing support to enable them to work with their fellow teachers to use the computer facilities and participate in interdisciplinary, project-based learning activities. Scheduling ensures equitable access to the computer labs throughout the day. Unfortunately, successful integration of computer use into regular teaching has resulted in teacher and student demands for access to labs that exceed available time.

A network of 229 computer resource and training centers across the country trains teachers from schools with labs to enable them to make effective use of computers, and provides them with ongoing professional development, pedagogical, and technical support.

- COWs may be more affordable than remodeling classrooms, building special computer labs, providing special electrical supplies, installing cabling to network all the computers, and buying special furniture.
- Since software only needs to be purchased for the computers on the carts, and not for dozens of computers in each classroom, the cost of software can be much less with COWs than with classroom-based installations.
- COWs can be stored in secure rooms when not in use.
- COWs can provide access to computers in situations where students have classes in different rooms.
- COWs can be customized to include expensive specialized equipment that normally would not be part of a classroom system.
- COWs often are brought to classrooms by an educational technology specialist who can help teachers to make effective use of the computers in teaching and provide immediate technical support.
- COWs can be used in teacher professional development programs.
- COWs can be used to support school-community computer programs because they can be brought to the room in the school used by community members.

Challenges

- The cost per computer to create a COW system with laptops and wireless networking capabilities is higher than for conventional desktop computer systems.
- There is a greater risk of equipment damage from accidents, hard use, or dropping.
- Dedicated staff is often needed to maintain COW systems, deliver them to teachers, and help teachers set up and use the equipment.
- Schools with multiple floors and no elevators have to have COWs for every floor or restrict their use to specific floors. The same is true for schools made up of different buildings.
- The difficulty of scheduling the use of a limited number of COWs may frustrate teachers and deter them from using these systems.
- COWs can perpetuate the belief that computers in education should be limited to "special" computer-aided activities.
- COWs, especially when used in secondary schools, can limit opportunities for interdisciplinary teaching and learning, since it can be more difficult to bring a mix of teachers and students together in a one-teacher classroom than in a common space.

For schools with few extra rooms for labs and no space or funds to build them, COWs offer a cost-effective way to provide teachers and students with access to computers and Internet connectivity. If COWs are used, effort should be made to promote the use of the COWs and to help teachers move beyond simple uses of computers in education. Without added educational inputs, COW systems can fall into disuse and rarely find their way into the classroom.

Computers in Libraries and Teachers' Rooms

When funding and staff resources are scarce, schools can optimize investments in computers and Internet access by installing a few computers in public spaces, such as the library or teachers' room. Giving teachers private access to computers and the Internet can encourage them to learn to use these technologies and integrate them into their daily routines.

Hybrid Options

Wherever possible, the greatest educational returns on technology investments can result by using combinations of the above configuration options. For schools with sufficient room, suitable infrastructure, and adequate funds and technical resources, distributing some computers to classrooms either as stationary systems or via COWs can be an effective means of easy and spontaneous access. Computer labs then can be used for whole class access and interdisciplinary use. Library computers can be used to focus on research activities, while special classrooms can be outfitted with computers, especially for special-needs students, creating benefits that are difficult to achieve from computer labs. The combination of these different options with one or more computer labs can create an ideal solution to providing students and teachers with access to these rich and powerful educational tools.

NETWORKING TECHNOLOGY OPTIONS

Connecting computers together to form a network, and connecting school, lab, and classroom networks to the Internet can multiply the educational value and impact of computers in schools. There are a variety of options for creating classroom, lab, and school computer LANs.

Peer-to-Peer Networking

As with all networked computers, users can share files and resources located on computers in the network. With peer-to-peer (see Figure 6.1) networking, however, there is no file server or central computer to manage network activity. One or more of the computers in a peer-to-peer network can provide centralized services such as printing and access to the Internet. Most desktop operating systems come with software to enable peer-to-peer networking once the computers are connected by some cable or wireless networking infrastructure.

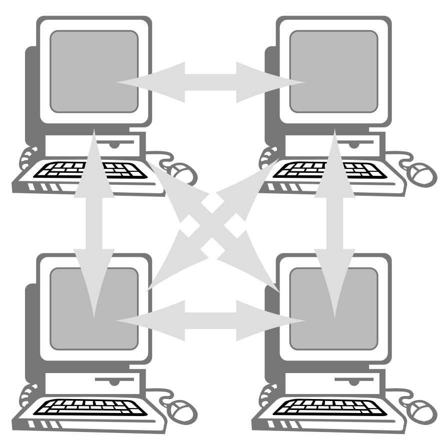
Peer-to-peer networking is good for small networks where a centralized file server is not needed and network security is not a major issue. This type of networking is less expensive to set up since the only additional expense is in the cables and networking hardware (one or two hubs). Most common computer operating systems (Mac OS and Windows 95/92/Me/2000/XP) come with software to establish a peer-to-peer network, so it may not be necessary to purchase, install, and configure special network operating system software such as Windows NT, Novell Netware, or Linux.

Client/Server Networking

As a computer network grows in size and complexity, it may be necessary to shift to a client/server style of network using more advanced network operating software. In these networks, as seen in Figure 6.2, one computer centralizes such functions as storing common files, operating network e-mail delivery, and providing access to applications and peripherals such as printers.

One of the advantages of client/server networks is that they are scalable: more clients and servers can be added to the system without changing the network significantly. These centralized networks are easier to manage, administer, and secure than peer-to-peer networks. These benefits come with some disadvantages, however. Because of the need to have a central "dedicated" server, initial costs are higher. Also, they are more complex to set up and maintain than stand-alone computers and peer-to-peer networks, often requiring schools to hire a technician to oversee the network. Also, if the server fails, all network functions fail.

FIGURE 6.1 • PEER-TO-PEER NETWORK[3]



Resources are shared among equals in a peer-to-peer nework.

Thin-Client/Server Networking

A thin-client/server network is similar to a traditional client/server network except that the client is not a free-standing computer capable of operating on its own. In contrast, thin clients are desktop appliances or network devices that link the keyboard, monitor, and mouse to a server where all applications and data are stored, maintained, and processed. The server, often called an application server, is built to provide all networking services and computer calculations. Since all network and computer services are centralized, all maintenance and upgrading is done at the server; there is no need to service the clients.

Proponents of thin-client/server networks emphasize that even though initial purchase costs are usually higher than with traditional PC/server networks, lifetime costs or total cost of ownership can be significantly less. For example, a recent "survey of 25 [business] sites using thin-client technologies conducted earlier this year by Datapro concluded that on average, deploying thin-client devices cut support [lifetime] costs by more than 80 percent."[4] A low cost of ownership in this case is achieved primarily through a reduced cost of centralized management, which can be from centralized remote sites, and from less costly software and applications upgrades. Thin-client/server networks are also easier to install than traditional client/server networks. In addition, since the client appliances cannot function without the server, there is little risk of theft. Thin-client systems are very efficient at providing access to the Internet, and, because the client appliances have few moving parts and limited functions, thin-client/server networks are more reliable and stable than traditional network systems.

A major disadvantage of some thin-client/server networks is that little educational software is written to run on thin-client servers running a version of UNIX. Most of these servers come with special emulation software, but this is usually an incomplete solution: software often runs slower and some applications fail to function. Since many thin-client/server networks are based on a type of UNIX operating system, skills with UNIX are needed to set up and administer. However, if schools have no staff with these skills, but do have access to the Internet, it is possible to have a technician at some remote site administer and maintain the network. This enables a school district to have one highly skilled technician manage thin-client/server networks in several schools, thus reducing management costs further.

Even though thin-client/server network systems are relatively uncommon in K-12 educational environments, they are a viable alternative to traditional client/server network systems. A careful assessment of total cost of ownership and the availability of technical skills at a school or school system can help planners decide if the thin-client/server network is best for their needs.

Connecting Computers

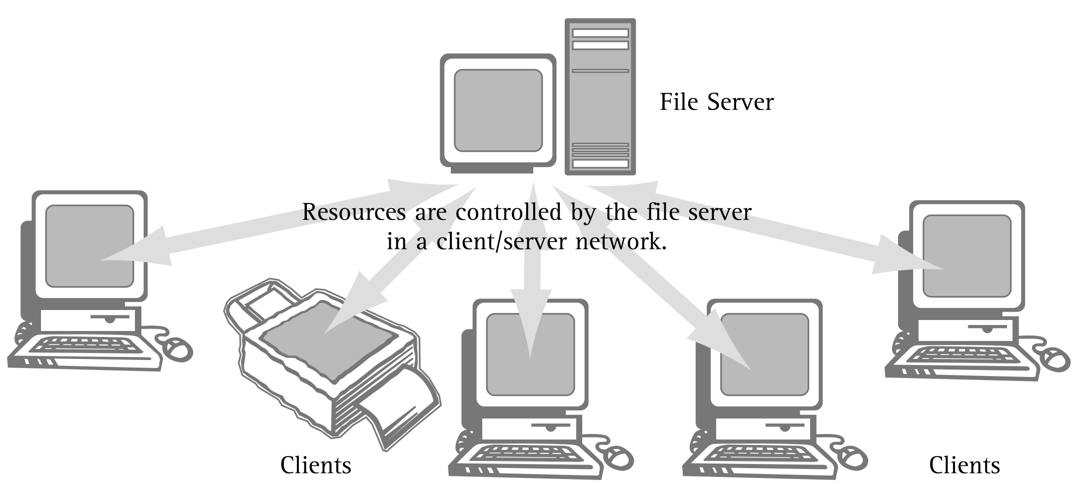
There are essentially three ways to connect computers to form LANs: cables, wireless, and power line systems.

Cabled LANs

Installing cabling in older buildings or in schools with thick walls built of brick and cement can be expensive, difficult, and time-consuming. To provide a sufficient number of individual connections for each computer, and to allow for flexible arrangement of computers in a room, many ports and cables must be installed.

Each cable connected to a computer must be connected as well to a network hub, an electronic device that controls

FIGURE 6.2 • CLIENT/SERVER NETWORK



the flow of network traffic between individual computers and the system's server, usually in clusters of 20 to 30 cables. Several hubs can be connected together to allow larger numbers of computers to be networked together. Hubs usually are housed in shielded and locked network closets to protect the hubs and prevent people from accidentally rearranging the network cables. Cabled networks provide reliable, high-speed—up to 100 Mb per second—transmission of network traffic. Because cable systems are more common than the other two options, it is usually possible to find firms and technicians with the skills needed to install quality cable LAN systems.

Wireless LANs

An increasingly popular alternative to cabled LANs is wireless networks. This type of system does not require cables to connect computers to each other and to the server and shared peripherals. Instead, wireless network adapters (receivers) are installed in all computers that will be part of the network (either as an internal network card or as a device that plugs into the computer's universal serial bus [USB] port). One or more wireless network hubs/transmitters are connected to the server, usually by a cable (several wireless network hubs can be connected to each other in a daisy chain). Network traffic is then transmitted by the hub to each computer and to and from the server. Wireless LANs have many advantages:

> They can be installed and configured in a very short time, since limited or no construction is needed.
> They allow for a high degree of flexibility. Computers, especially laptops, can be moved around a room or building, within the range of the network signal, without losing their connection to the LAN.
> They can be less costly to install and use than conventional cabled systems.
> They allow schools to create customized LAN systems covering single rooms or whole sections of the school. They also can be mixed with cabled systems to create greater flexibility.

Wireless LANs are not a perfect solution for all environments. The speed of network traffic depends on how many computers are using the hub's bandwidth simultaneously. Distance from the hub and thickness and character of walls between the transmitter and receiver can affect the speed and quality of the network signal significantly.

Because of the benefits of wireless LANs and their growing popularity, the technology is improving rapidly, and new standards with higher transmission rates are emerging.[5] Over the next few years, the speed and range of transmission will increase, and reliability and security will improve. Wireless LANs will become an increasingly desirable LAN solution for school computer systems.

Power Line LANs

Another alternative to installing special network cables that recently has become a reliable technology for some situations is to use the existing power lines in the school to carry the network traffic. Power line networking (PLN) currently is capable of providing reliable network communication speeds between 250Kbps and 500Kbps for six to 20 network access points. Higher-speed systems, ranging from two to 12 Mbps, are also available. Equipment costs are higher than conventional and wireless networking technologies, but these are expected to fall as technical improvements are made and larger-scale systems become available. In some situations, the costs of using PLN can be less than installing cable or wireless systems.

INTERNET ACCESS OPTIONS

By accessing the Internet, computers can become powerful communication devices with many educational applications. A variety of options and technologies should be considered when deciding whether and how to access the Internet.

Simulated Internet. If direct connection to the Internet is not possible, for economic or technical reasons, students and teachers can still gain simulated access to a selection of Internet resources by copying valuable Websites to CD-ROMs. Then they can use the CDs to access these sites, thus simulating the Internet. For example, the Rio de Janeiro municipal school system provides schools that cannot access the Internet directly with a CD containing a selection of more than 100 Portuguese-language educational Websites. The CDs, which are updated periodically, use the same browsers that are used with the Internet, so that when Internet access becomes available, teachers and students will have no difficulty using this technology. The "Internet" CDs also can make it easier for teachers to prepare structured educational activities using Websites since they can preview the resources quickly before the class session. In addition, this approach can focus student inquiry because students can explore the CD's resources but cannot surf freely beyond the scope of the activity or become distracted by noneducational Websites. Also, since these Internet resources are stored locally, no time is spent waiting for Websites to load. Even if Internet access is available, a CD with copied Websites can make it easier for students to access Internet resources rather than relying on a slow, congested connection.

Dial-up Connection. The simplest and lowest-cost connection to the Internet is through dial-up access using a single standard phone line. A dial-up connection can provide Internet access to a single computer (for example, in a lab, classroom, teachers' room, or library) or, by using software on a server, networked computers can share this single connection. However, with a shared connection, access can become very slow, since the total available bandwidth (the total amount of data that can be moved through the network per unit of time) is divided among all the computers sharing the same Internet connection.

If two or three phone lines are available, these lines can be combined using an analog router to enable multiple phone line access to an ISP, thus increasing available bandwidth.

Dedicated Connection and Other Connectivity Options. Schools can get faster and more reliable Internet access by using permanent "dedicated" high-speed connections where they are available and affordable. A variety of dedicated high-bandwidth options may be available to schools, including integrated services digital network (ISDN), digital subscriber line (DSL), terrestrial wireless, digital cable, radio modem, and satellite access, as described below.

Several new technologies offer the potential for developing countries to leapfrog earlier generations of equipment to provide connectivity. Terrestrial wireless and satellite technologies offer many advantages because they do not require installation of wireline networks. Satellite facilities also can be installed where communication is needed, even in remote and isolated areas, rather than waiting for terrestrial networks to be extended from the cities.

Terrestrial Wireless

Cellular: Cellular telephony has become the first and only telephone service for many people in developing countries, where it may be available much sooner than fixed-line service. In countries such as Côte d'Ivoire, Gabon, Rwanda, Tanzania, Uganda, Cambodia, and the Philippines, there are now more cellular telephones than fixed lines.

If no fixed lines are available, but there is cellular service, a cell phone with a cellular modem can be used to allow access to the Internet. For example, the community telecenter in Buwama, Uganda, about 60 km from Kampala, connects to the Internet via cellular modem. However, cellular access is often quite costly, and bandwidth is limited. It is likely to be more practical for short bursts of use for e-mail communication than for surfing the Web.

Wireless local loop: Wireless local loop systems can be used to extend local telephone services to rural schools without laying cable or stringing copper wire. Thus, instead of a fixed-line connection, schools would have a wireless link to the telecommunications network. Wireless local loop costs have decreased, making it competitive with copper. Wireless systems enable faster extension to new users than extending wire or cable; they also have a lower ratio of fixed to incremental costs than copper, making it easy to add more customers and serve transient populations. Wireless is also less vulnerable than copper wire or cable to accidental damage or vandalism. Countries with wireless local loop projects include Bolivia, Czech Republic, Hungary, Indonesia, South Africa, and Sri Lanka.[6]

Point-to-point wireless systems: If the telephone company does not provide wireless local loop, schools may be able to install or lease their own wireless links to the Internet. Point-to-point fixed wireless, such as microwave systems, can provide high-speed Internet access by connecting to an ISP's point of presence (POP). These fixed wireless links may be the least expensive means of getting high-speed Internet access if wireline services are not available.

Cordless: Short-range cordless extensions can provide the link from wireless outstations to subscriber premises; the DECT (digital European cordless telephone) technology standard also can allow the base station to act as a wireless private branch exchange (PBX) and reduce costs further.[7] For example, DECT has been used in South Africa to provide links to rural pay telephones and telecenters. However, DECT has very limited bandwidth, making it unsuitable for accessing the World Wide Web.

Wireless access protocol: This wireless protocol has been developed to make it possible to transmit Web pages and other data to cellular phones. It can be adapted for wireless services in developing countries so that Internet information can be transmitted to low-bandwidth wireless systems. However, the variety of Web content accessible through devices enabled by this protocol is still very limited.

Third-generation mobile services: Third-generation mobile networks are beginning to be introduced in some industrialized countries, and eventually may be made widely available in developing regions. They offer greatly increased bandwidth over existing mobile networks, with the possibility of Internet access to handheld devices such as portable phones, personal digital assistants, and small personal computers. However, the capital cost of upgrading existing networks is very high, and the price of access for Internet applications may be greater than for other options.

Satellite Technologies

Very small aperture terminals (VSATS): Small satellite earth stations operating with geosynchronous satellites can be used for interactive voice and data as well as for broadcast reception. For example, banks in remote areas of Brazil are linked via VSATs, and the National Stock Exchange in India links brokers with rooftop VSATs. VSATs for television reception (known as TVRO—television receive only) deliver broadcasting signals to viewers in many developing regions, particularly in Asia and Latin America.

Internet via satellite: Internet gateways can be accessed via geostationary satellites. For example, MagicNet, an ISP in Mongolia, and some African ISPs access the Internet in the United States via the PanAmSat global satellite system, and residents of the Canadian Arctic use Canada's Anik satellite system, while Alaskan villagers use U.S. domestic satellites. However, these systems are not optimized for Internet use, so they may be quite expensive. Also, there is a half-second delay in transmission via geosynchronous satellites, although it is a more obvious hindrance for voice than data.

> *High-speed downlink:* A system designed by Hughes, known as DirecPC, uses a satellite to deliver high-bandwidth Internet content downstream to a VSAT from an ISP. Upstream connectivity is provided over existing phone lines. This approach is designed for rural areas with telephone service, but where bandwidth is very limited. Some rural schools in the United States are using DirecPC for Internet access.

> *Interactive access via VSAT:* Several companies offer fully interactive Internet access via satellite; examples include Gilat, Hughes Gateway, and Tachyon. Systems typically are designed for small-business or home office use, but could be a solution for schools with no other communication options. For example, schools in Alaska and the Canadian Arctic access the Internet via satellite.[8] The price of Internet access is likely to decline as new protocols are developed to make more efficient use of bandwidth and, thus, lower transmission costs for users.

Data broadcasting by satellite: Geosynchronous satellites designed for interactive voice and data can be used for data broadcasting as well. For example, the WorldSpace satellite system delivers digital audio directly to small radios. While one market for these products is people who can afford to subscribe to digital music channels, the systems also can be used to transmit educational programs in a variety of languages for individual reception or community redistribution. It can also be used to deliver Internet content; schools or telecenters can identify which Websites they want to view regularly, and WorldSpace broadcasts the data for reception via an addressable modem attached to the radio. WorldSpace has donated equipment and satellite time for pilot projects at schools and telecenters in Africa.[9]

Global mobile personal communications systems: Using low earth-orbiting satellites, these systems provide voice and low-speed (typically 2400 to 9600 bps) data virtually anywhere, using handheld transceivers. However, the price per minute for these services is typically much higher than national terrestrial services, and the first generation of low earth-orbiting satellites (from Iridium and Globalstar) has very limited bandwidth.

Store-and-forward messaging: Volunteers in Technical Assistance (VITA) has developed a satellite-based system, called VITAsat, capable of delivering sustainable, low-cost communications and information services to remote communities. The system uses simple, reliable, store-and-forward e-mail messages relayed to the Internet via low earth-orbiting satellites. Using compression technology and software that allows access to Web pages using e-mail, VITAsat can make the Internet accessible virtually anywhere. VITA's two current satellite systems have the capacity to serve about 2,500 remote rural terminals that could be installed in schools, clinics, community centers, and NGOs. VITA plans to include local skill and organizational capacity building and development of targeted information content and services designed specifically to meet the needs of small businesses, local NGOs, educators, health workers, and other relief and development workers.[10]

Bandwidth on demand: Future satellite systems are being planned to provide bandwidth on demand. Constellations of low earth-orbiting satellites such as Teledesic and new generations of geosynchronous satellites such as Loral's Cyberstar and Hughes's Spaceway will be designed to offer bandwidth on demand for Internet access, videoconferencing, and distance education.

Wireline Technologies

Innovations in wireline technology make it possible to provide high-speed Internet access over telephone lines, rather than having to upgrade existing copper networks.[11] These technologies may be used in urban areas where basic telephone service is available.

Integrated services digital network (ISDN): Regular twisted-pair copper telephone lines can carry two 64 kbps channels plus one 16 kbps signaling channel. One channel can be used for voice and one for fax or Internet access, or two can be combined for videoconferencing or higher-speed Internet access. Developed in Europe, ISDN may be available from telephone companies in some urban and suburban areas of developing countries.

Digital subscriber line (DSL): Several variations of DSL technology have been developed that provide data rates from 384 kbps or more downstream over existing telephone lines. This technology is replacing ISDN in industrialized countries because of its greater bandwidth. It can be used in urban areas where copper wire is already installed, but its range is limited to about 1 km from a telephone exchange.

Cable modems: Some cable television systems can also be used for high-speed Internet access via cable modems. Like DSL, cable offers much higher bandwidth than dial-up telephone lines. However, a high volume of users may result in congestion of a shared cable network, and older networks may not be converted easily for two-way connectivity.

Optical fiber: Telephone companies upgrading their networks may install optical fiber for institutional customers such as hospitals, schools, and businesses. The advantage of fiber is its enormous bandwidth, which can be used for high-speed Internet accessing or other services such as videoconferencing. However, the price of access may be prohibitive. Some schools have managed to gain free or heavily discounted access to so-called "dark fiber," excess capacity that has been installed but is not yet in use.

Hybrid fiber/coax: A combination of optical fiber and coaxial cable can provide broadband services such as TV and high-speed Internet access as well as telephony; this combination is cheaper than installing fiber all the way to the customer premises. Unlike most cable systems, this hybrid allows two-way communication. The fiber runs from a central telephone switch to a neighborhood node; coaxial cable links the node to the end user such as a school. Developing countries with such projects include Chile, China, India, and Malaysia.[12]

Other Technologies

Other technological innovations that can be used for educational communication in developing regions include:

Internet telephony (voice over IP): Packetized voice communication can be transmitted very inexpensively over the Internet. Schools with Internet access may be able to use their networks for voice communications as well (regulations vary by country). Using Internet protocols for voice and data is much less expensive than using regular telephone networks.

Community radio: Small community radio broadcasting stations can be important news sources for the community and can be used to broadcast educational radio programs for listening in school, at home, or in community centers.[13] Some school and telecenter projects are combining computer facilities with community radio stations, so that information received via the Internet can be communicated more widely. Portable windup or solar-powered radio receivers are practical for school and community use.[14]

Selecting an Internet Service Provider (ISP)

In addition to choosing a means of connecting to the Internet, it also will be necessary to choose an Internet service provider (some ISPs bundle connectivity with services). Factors to consider include:

Distance to point-of-presence (POP): Ideally, the ISP should provide local connectivity so that long distance calling charges are not incurred. However, in many rural and developing regions, local access is not available. In such cases, it will be important to consider the price charged by telecommunications operators to reach the POP, and whether there are any toll-free or flat-rate options.

Speed and reliability of access to the Internet: The speed of access to the Internet depends not only on the bandwidth available to reach the ISP, but also the number of ports at the ISP and the bandwidth it has available to reach an Internet gateway. In addition to asking the ISP for such information, it is useful to check with other customers to determine whether they experience outages or delays, and whether they have noticed any improvement or degradation in access over time.

Batched and compressed e-mail accounts: Users can save money in telecommunications charges if they can compose messages offline and send and receive e-mail in batches to the Internet service provider (ISP). A batched e-mail service using the compressed UUCP (UNIX to UNIX copy) transfer protocol is four to eight times faster than the standard TCP-IP/POP (post office protocol) used by most e-mail clients.[15]

Web hosting: The ISP should provide Web-hosting capability if another Web-hosting site is not already available in the country. Alternatively, schools can use one of the free Web-hosting services made available by some U.S., European, or Australian sites.[16]

SOFTWARE AND OPERATING SYSTEM CONSIDERATIONS

Software, an essential component of computer systems, enables the hardware to do useful work for users. In this section, the discussion about software for educational computer systems is organized into the following four broad categories:

- operating system (OS) software for client and server computers;

- basic computer application software, including software for word processing, spreadsheets, presentations, and graphics;
- educational software applications; and
- Internet-related and -delivered software, including browsers, Java applications, and interactive tools on Websites.

Operating System Software

Decisions about what operating system software to use on client or end-user computers are usually based on the type of hardware purchased. If Apple computers are purchased, then Apple's OS, which comes with the computer, will likely be used on client computers. If computers with Intel or Intel-compatible CPUs are purchased, the computers likely will come with a version of the Microsoft Windows OS. In contrast, decisions about what software should be used to operate networked computers are not as easy or predetermined as they are with client system software. Basic Apple and Windows operating system software comes with the capability to enable computers to be connected together to manage small networks. However, larger and more robust networks that may need to be managed securely will require special network operating system software installed on the network's server to manage the functions of the network, including links to printers and other peripherals, e-mail, file sharing, security functions, and communication among linked computers. There are different options for network operating system software. For Apple computer systems, two main options are available: Apple's own network operating system and Linux.[17] For Intel-based computers, the three main options are Microsoft NT, Novel Netware, and Linux.

It is beyond the scope of this chapter to present a detailed comparison of these network operating system software options. However, there are several important questions that should be addressed when deciding which network operating system to use, including:

- Is technical support available and what does it cost for the different options?
- What types of network operating system software are most common in schools, businesses, and government agencies in your country or locality?
- What types of network operating system software are used already?
- How much money is available in project and school budgets to cover the costs of installing, maintaining, and upgrading network operating system software?
- Are there local user communities (face-to-face or Web-based) that can be used to access local technical support for different network operating system software systems?
- Is the network operating system software available in a language version to match languages commonly spoken by technicians and users?

Open Source Software (OSS)

One of the most hotly debated topics in educational technology today deals with the question of whether it is better for school systems to use open source software (OSS) or commercial software products for client and server operating systems. There are no simple answers to this question since they involve policy, commercial, technical, and educational concerns. For education systems, the education functions that need to be supported and the needs of students and teachers are the most important factors in making technology decisions. If the software and hardware solutions do not ultimately serve the teaching and learning process, then even "inexpensive" or "free" options can be very costly educationally. If key educational software programs cannot be used on computer systems with "free" OS software, then the "free" solution could become very expensive. Similarly, educational uses and needs for computers are often quite different from corporate needs—and decision making about technology choices for schools needs to reflect these differences.

Linux, part of the family of UNIX-based operating systems, is one of the most popular open source software products used for computer operating system software. Linux has become popular primarily because it is available free of charge and has a large development and user community. Linux is also the first or second most popular operating system software for Internet servers—accounting for about 30% of all Web servers in the world today. It is used only rarely as a client operating system (on the end terminal or PC at the user's desk), however, mainly because few software applications, such as word processing, can be used on computers running Linux. The exception is WordPerfect's and Sun's StarOffice's application suite (the latter is now called OpenOffice, since it was released as an OSS application).

Questions of Benefits of OSS

The technical benefits of operating system and network operating system software generally are discussed in terms of the software's reliability, performance, scalability, security, and cost. A variety of comparisons have shown that servers running Linux crash less often and perform better than commercial and other OSS software. Also, Linux can be used on a wider range of computer platforms than any other operating system and is more secure than commercial OSS. Finally, studies have shown that Linux and other open source software usually have significantly lower initial costs than commercial operating system software.[18]

When Is Free Software the More Expensive Choice?

Proponents of using Linux in educational computer environments often emphasize the fact that Linux is "free," and that the money saved from not having to purchase operating system or network operating system software is a sufficient reason to use it. Unfortunately, this argument is seriously flawed. Operating system and network operating system software only account for about 5% to 8% of the total cost of buying a client computer system. In contrast, the ongoing costs to train teachers to integrate technology into teaching and learning, and to support and keep computer systems running from year to year, can be many times greater than the original purchase cost of the computer and the operating system or network operating system software. In many cases, school systems will spend as much in two years for operating school computers as was spent initially to purchase and install a system that is expected to last five years. Therefore, it is more important to consider the total cost of ownership carefully—acquiring, installing, configuring, supporting, maintaining, training users in, using, and upgrading the software—when evaluating the real costs of using different types of operating or network operating system software. It is also important to emphasize that total cost of ownership studies carried out for corporations cannot and should not be used to justify purchase decisions for educational systems. There are special and critical differences between the needs and uses of computers in education and corporations.

The most important factor in realizing the potential educational benefits of technology is how teachers and students use computers and the Internet in learning activities. Consequently, the most important cost factors in total cost of ownership studies of technology in education are linked to the use of technology and its integration into teaching and learning. Therefore, when evaluating the use of OSS in education, it is essential to assess how different software decisions will affect how teachers and students use technology and how easy or difficult it may be for them to integrate it into routine teaching and learning.

Human capacity development considerations: In Brazil's ProInfo[19] program, for example, more than 40% of the budget was dedicated to initial teacher professional development and training, both pedagogical and technical. ProInfo staff also made significant and continual investments in building teachers' confidence to use computers and the Internet in their teaching, and in developing successful project-based learning strategies that make effective use of computers and the Internet. The value of these investments is several hundred times greater than the initial cost of the computers and several thousand times greater than the cost of the operating system software used on these computers. If the government of Brazil were to develop a total cost of ownership model to evaluate the costs of switching from a Microsoft Windows operating system for client, end-user computers that are currently used in schools to OSS such as Linux, it would have to include the costs of rebuilding the skills and confidence of thousands of teachers across the country to use computers over several years, and the opportunity cost of not having students use computers during those years.

Technical support considerations: Anther lesson from Brazil's ProInfo program is that technical support to keep school computer systems running, and to help teachers implement their learning projects with technology, is essential. A shift from Windows to OSS options would require states, municipalities, and schools to spend thousands of dollars and years rebuilding the technical support capacity essential to making effective use of computers in education. Some countries, such as Namibia, may have greater technical capacity to manage UNIX and Linux operating systems than Microsoft NT, so using Linux could be a more cost-effective decision for them.

Matching skills to needs: Windows is the operating system used on 80% to 90% of all client computers in business, government, and the nonprofit sectors of the economy. If students were to use computers in schools with OSS, some likely would not gain the needed skills and experience with Windows that prospective employers would demand. Therefore, total cost of ownership calculations for education systems considering OSS would need to consider the costs that students and companies would likely incur to train workers to use Windows.

Educational software applications: The lack of educational software applications that can operate on OSS, and the loss of current investment in Windows applications that could not be used on OSS, without using emulation software[20], would need to be considered as well in total cost of ownership calculations. Furthermore, many schools, especially those in developing countries, have very small budgets to purchase additional software for their computer systems. A shift to OSS would make some current investments useless, and replacing the software with versions to run on OSS, if they were available, would drain scarce resources. Also, some critical applications, such as software used in special-needs education, are not available for the OSS operating system, and a shift to OSS could prevent some students and schools from using their computers.

Optimizing Investments

When considering the technical specifications of educational computer systems, especially regarding the use of open source software, it is critical that the primary goals and objectives of such systems—significantly improving the quality and equity of teaching and learning—remain the principal focus of decision making. If decisions to use OSS are made for short-term or immediate cost savings, it is possible that the long-term costs, both financially and educationally, may become excessive. As described above, the development of total cost of ownership models to assist decision making must reflect unique local realities and include the significant hidden costs associated with building the capacity of educators to integrate the use of computers and the Internet effectively into routine teaching and learning.

Basic Computer Application Software

All computers in schools require a basic set of software applications to be useful for computer literacy programs and to be integrated effectively into routine education programs. These applications generally include software for word processing and manipulating numeric data such as spreadsheets, presentation software, and graphics software, and the increasingly important software to create Websites and HTML documents. As with operating system software, commercial and public domain options are available. Major commercial applications often are purchased because they are the types of software used in businesses and government offices, and it is often important to prepare students to use computers and applications that are common in the workforce.

Where funding is a constraint, schools have the option of using Sun Microsystems public domain software application suite, called OpenOffice. It includes an integrated graphical interface similar to MS-Office and WordPerfect and comprises word processing, spreadsheet, and presentation applications. StarOffice also has support for AutoPilot Web page design software, 3D graphics, diagrams, HTML editing, and calendar, newsgroup, browser, e-mail and scheduler, photo editing, and other applications. This software is also available in a variety of languages and can be downloaded for free from the Internet.[21] There are versions of StarOffice for Windows and Linux operating systems.

Educational Software Applications

Thousands of software applications have been developed over the years, many for free, to meet specific educational objectives, including:

> strengthening subject matter competence;
> providing drill and practice activities for different subjects;
> enhancing logical thinking and problem-solving skills;
> enriching research and writing activities;
> simulating complex or dangerous processes that enable students to change variables and visualize how processes are changed; and
> providing opportunities for students to extend learning beyond the scope of classroom activities.

As with all uses of computers to enhance and improve teaching and learning, the key to success is not the type of educational software that is used, but how teachers use the software and integrate it into their teaching programs. For example, research has shown that when drill and practice software is used without active teacher participation, performance on standardized math tests can go down. In contrast, when this type of software is integrated into a comprehensive set of activities and actively facilitated by teachers, performance on standardized tests can improve.

It is commonly believed that the best educational return on investments in computer systems in schools comes from using specialized educational software. This assumption is not valid. Significant benefits to teaching and learning can be achieved without using any specialized educational software. However, when used effectively by teachers, many excellent educational software applications can enhance the use of computers in education. Achieving these benefits is not guaranteed, and the costs of purchasing often very expensive software must be considered carefully. Selecting software should not be done based on the publishers' promotional materials. Rather, schools and teachers should seek out evaluations of software from other educators to learn the benefits of and possible problems with the software. Numerous Websites can provide evaluations of educational software. Also, publishers often will provide evaluation copies of software that teachers can use to test the products before the school decides to purchase them. When evaluating educational software, teachers and schools need to develop evaluation criteria so that purchase decisions are based on objective and subjective measures of educational quality.

Internet-Related and Delivered Software

One of the most important benefits of Internet- and Web-related software is that most of it can be used regardless of the hardware and software installed at schools. The "platform independence" of the Internet reduces the costs involved in using the Internet in education and enhances its benefits. One key area of Internet use is access to a variety of Internet and Web-based software applications, much of it freely available in different languages that can be used by teachers and students in a variety of ways, including:

> browser and search software that enables students to carry out research on the Internet and engage in

enquiry-based learning activities using the millions of Websites on the Internet;

- e-mail software that allows users to send and receive communication from other learners and Websites;
- listserv or e-mail distribution software that allows groups of users to form and communicate easily by e-mail;
- Web-based discussion forum software that allows users to engage in ongoing dialogues in which the topics or themes are linked to form discussion threads;
- interactive Web-based publishing tools that allow students and teachers to publish their thoughts, comments, experiences, pictures, suggestions, etc., instantly on Web pages;
- Internet- and Web-based chat and instant messaging software that allows users to engage in live text-based discussions;
- easy-to-use Web page construction and publishing tools;
- voice and video software applications that allow teachers and students to participate in synchronous audio- and videoconferencing, if sufficient bandwidth is available; and
- file storage and retrieval software that allows users to share digital files easily, including documents, presentations, images, data, and music, with other users.

The existence of these online or Web-based software applications that enable users to communicate at a distance has given rise to opportunities for collaborative and project-based learning that were not possible before the Internet. Since learning is very much a social activity, the ability to link students and teachers together to form learning communities can significantly enhance learning outcomes and opportunities to develop lifelong learning skills.

Another important category of Internet-related software includes applications, many of which are freely available, that enable teachers and students to construct and publish Web pages and HTML documents on the Internet. In addition, the Internet's "platform independence" helped give rise to a variety of software applications, including JAVA, FLASH, and Shockwave, which can be used to create learning applications that simulate simple and complex processes and concepts. These programming languages can be used by teachers, students, and mediated learning specialists to create simulations that can accelerate understanding of complex concepts and demonstrate scientific activities that normally would need to be carried out in expensive labs. (For a full description of these authoring tools, see chapter 7.)

CONCLUSION

As mentioned at the beginning of this chapter, no "off-the-shelf" configuration solutions meet the diversity of needs and conditions of different schools around the world. Carrying out an assessment of needs, physical conditions, constraints and opportunities, and weighting factors, according to their importance, will contribute greatly to deciding which type of configuration optimizes resources against needs. It is also important to examine the capacity of local markets to support different options, especially new, innovative, state-of-the-art technologies. Throughout the information-gathering and decision-making process, it is important to evaluate options and alternatives against the ultimate objective of all school computer systems—to enhance teaching and learning.

ENDNOTES

[1] This chapter does not address the use of computers and Internet technologies in school management or in building school community partnerships.
[2] In this chapter, computer configurations refer to how computer systems are distributed, arranged, connected, and used in a school, and the supporting infrastructure needed to power school computers systems and link them to the Internet. The chapter does not discuss the technical configuration of how software is installed or how individual computers are prepared for use.
[3] From *An Educators' Guide to School Networks* (1997-1999). Florida Center for Instructional Technology, College of Education, University of South Florida. Available at: *http://fcit.coedu.usf.edu/network/*.
[4] Molta, D. (June 28, 1999). For Client/Server, Think Thin. IT Papers.Com. Available at: *http://www.itpapers.com/cgi/PSummaryIT.pl? paperid=13855&scid=154*.
[5] The most common standard for wireless LANs today is 802.11b, which transmits data up to 11 Mbps (the rate of transmission is affected by distance, walls, and radio frequency interference) 30 to 500 meters. A more recent standard, 802.11a, can transmit data up to 33 Mbps.
[6] International Telecommunication Union (1998). *World Telecommunication Development Report*. Geneva: ITU, p. 53.
[7] Kayani, R., & Dymond, A. (1997). *Options for Rural Telecommunications Development*. Washington: World Bank, p. 48.
[8] See, for example: *www.schoolaccess.net*.
[9] See: *www.worldspace.com*.
[10] See: *www.vita.org*.
[11] It should be noted that copper wire is prone to theft in some countries: Telkom South Africa reported more than 4,000 incidents of cable theft in 1996, at an estimated cost of R 230 million (about US$50 million).
[12] ITU, op cit., p. 57.
[13] See, for example, Latchem, C., & Walker, D. (eds.) (2001). *Telecentres: Case Studies and Key Issues*. Vancouver: Commonwealth of Learning.
[14] See, for example, Freeplay Energy at: *www.freeplay.net*.
[15] Jensen, M., & Walker, D. Telecentre Technology in Latchem and Walker, op cit.
[16] See, for example: *www.geocities.yahoo.com* or *www.tripod.lycos.com*.
[17] Linux is a public domain operating system software based on UNIX. Linux can be downloaded from the Internet free of charge.
[18] See: *http://www.dwheeler.com/oss_fs_why.html*.
[19] Started in 1997, ProInfo is a national program in Brazil that works in partnership with state and local authorities to establish a network of teacher training and technology resource centers across the country, build computer labs in public primary and secondary schools in all states, and train thousands of trainers and teachers to integrate technology into all aspects of the curriculum.
[20] Emulation software enables Windows applications to operate on computers running the Linux OS. Unfortunately, not all Windows applications will run under emulations software, and, when emulations software works, the application will run more slowly.
[21] StarOffice can be downloaded from the Sun Microsystems Website at: *http://www.sun.com/software/star/staroffice/5.2/index.html*.