Expanding Access with Satellite-enabled Distance Education

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ABSTRACT

Education and training became increasingly critical for citizens of every nation during the last century, and that paradigm will be no less true, throughout the 21st Century. As the world progresses fully into an information society, access to information and to a knowledge-based work force is a precondition for any country to remain competitive. Education, and increasingly distant education (DE), plays a vital role in turning human resources into knowledge workers. Information and communications technologies (ICT) have provided new ways to educate and to disseminate information that is crucial for creating these competitive, knowledge-based work forces. Modern DE, enabled by ICT-based networks and the Internet tools, offers great advantages that are leveling the global playing field, in terms of providing access and opportunities for specialized training and education. Using satellite technology in DE may be imperative to developing countries, where the majority of their populations are scattered in rural and remote areas. Where the traditional brick and mortar classrooms cannot easily reach, satellite-powered DE systems can. Through literature review and rational analysis, this paper examines how satellite-assisted DE systems expand education access.

Keywords: distance education, education access, information and communication technologies, satellite technology, developing countries, knowledge-based work force, information society, digital divide.

INTRODUCTION

The digital revolution, powered by the engines of ICT, has restructured the means by which the world handles economic functions, conducts business activities, and runs governments. Moreover, it has formed new ways to create knowledge, educate people, and disseminate information. Access to information and knowledge is essential in an information society where knowledge is a prime source of social dynamism and education is the most assured means for human, community, and national development (Daniel, 2003).

While the digital revolution has eliminated physical and national boundaries across the global village, access and adoption has not been uniform. The majority of the world remains detached and little affected by this unfolding phenomenon. With the ever-widening chasm between knowledge-based commercial acumen and ignorance, the economic development gap between the rich and the poor—both among and within countries—has increased considerably. According to Bell (1999), human capital is a strategic resource while information and knowledge are the transforming resources in the emergence and formation of an information society. Education plays a vital role in turning human capital into a knowledge-based work force, which may be defined as one with the knowledge, skills, competence, and other attributes embodied in individuals that are relevant to modern economic activity (OECD, 1998). As experiences by such countries as China and India show, a large population does not make a nation wealthy. Such immense human resources must be transformed into human capital through adequate training and education, in order to be productive in the information society (Wang & Wang, 2004). Thus, to narrow its digital divide and economic development gap, a nation must provide necessary and timely education to its population so that citizens are empowered with the essential means to live and function in this new digital era.

Daniel (2003) contends that an eternal triangle of education exists, which consists of three vectors: access, cost, and quality. Modern DE, assisted by the Internet and other ICT-driven systems, offers great advantages concerning education *access*. Using satellite technology in DE may be especially instrumental to developing countries, where the majority of their populations are scattered in rural and remote areas. Where the traditional brick and mortar classrooms cannot reach easily, satellite-powered DE systems can. Indeed, using satellite technology may put a nation in the economic fast lane by providing education-for-all services to its citizens at an affordable *cost.* The third vector, *quality* of instruction is easier to attain when the target audience is large numbers in rural and remote areas, who are at the base level of knowledge. In this learning environment, instruction must necessarily be rudimentary and highly standardized. The following sections provide a review of distinctive features and technical attributes of satellite communications, illustrate specific educational activities that can be optimally supported by satellite services, cite successful cases of satellite applications in education from both developed and developing countries, and make pertinent recommendations.

SATELLITE TECHNOLOGY FUNDAMENTALS

A robust infrastructure of high-quality educational resources, centers of excellence, leading experts, and lively peer groups is a pre-requisite for the efficacious development of DE and eLearning programs. While quality education is the goal, regardless of subject under study or a student's location, access ultimately depends upon the speed, reliability, maintenance, and costs associated with satellite-based computer networks. Satellite communication will continue to hold great promise in accommodating DE and eLearning networks. Vanbuel (2001) asserts that important innovations are taking place throughout the satellite industry and they have made possible low cost, two-way satellite services which bypass the need for expensive surface cabling. Such services can offer near instantaneous high-quality access to digital information. However, much needs to be done and understood about these kinds of services, before they can optimally play a role in global education environments. Issues of signal and terminal availability, broad and persistent reach, tailored network designs, service costs, and usage authorizations all have to be addressed in an educational context. It is important that all aspects of satellite and Internet-based communication technologies are understood in order to leverage them; and by so doing, fundamentally change the ways in which future education will create knowledge-based work forces.

According to Littman (2002), communications satellites are Earth-orbiting spacecraft that use microwave technology in the super-high and extremely-high radio frequency (RF) bands of the electromagnetic spectrum to transfer voice, data, video, and other media-rich contents to locations that cannot be easily served by terrestrial facilities.

1. *Satellite Communications Basics*—Dean (2002) asserts that early satellites circle the earth approximately 22,300 miles above the equator in a geosynchronous orbit. As a result, at every point in their orbit, the satellites maintain a constant distance from a point on the earth's equator. Satellites operate as radio relay stations in space. Through an *uplink*, information is transmitted from an earth station to the satellite. At the satellite, a *transponder* (a typical satellite contains 24 to 32 transponders) receives the uplink, amplifies and translates it to a different frequency, then transmits the signal to another earth-based station in a *downlink*. Each satellite uses unique frequencies for its downlink. In the United States, these frequencies and the satellite orbit locations are assigned and regulated by the Federal Communications Commission (FCC). The signal quality depends largely on the condition of the uplink and downlink. To reduce the effects of signal attenuation, the downlink usually operates at a lower frequency level than the uplink. Back on earth, the downlink is picked up by a dish-shaped antenna. Such a shape concentrates the signal weakened by traveling over 22,000 miles, so that it can be interpreted by a receiver. Littman (2002) states that conventional antennas used in wide area television broadcasting are omni-directional (half-duplex). By contrast, directional antennas utilize spot beam technology to support full-duplex point-to-point transmissions. With spot-beam technology, an antenna system can divide a single *footprint* (coverage) into sub-footprints to support lower power transmission to and from multiple subscriber sites. Antenna shape and size are determined by the wavelength of radio waves that are transmitted or received.

2. *Satellite System Configuration*—Littman (2002) affirms that satellite configurations include three segments: space (satellites), ground (earth stations), and control. Control segments consist of low-cost Very Small Aperture Terminals (VSATs) that are linked to relatively simple and inexpensive end-user equipment and to more complex and costly equipment that tracks the accuracy of satellite operations. Satellites and their transmitting and receiving earth station components make up a basic three-node network system used extensively to facilitate long-haul and transoceanic information distribution. Because satellite signals cannot pass through the Earth surface, its transmissions travel in straight line-of-sight paths from one location to the other. Hence, landline links, such as coaxial copper and optical fiber cable, are used in conjunction with satellite systems to connect corporate, government, educational, and residential networks. By this means, integrated satellite network architecture is created. Hybrid network configurations can be tailored to provide high-speed access to bandwidth-intensive resources and to time-critical data.

3. *Satellite Communications Protocols*—Lin (2002) maintains that primary protocols governing satellite transmissions include Time-Division Multiple Access (TDMA) and Code-Division Multiple Access (CDMA). TDMA assigns each individual earth station a specific time slot to uplink and downlink its signals. These time slots are arranged in sequential order for all earth stations involved. Since the sequential order of time allotment is repeated over time, all stations will be able to complete their signal transmission using the same frequency. CDMA, on the other hand, utilizes the spread spectrum transmission method to optimize bandwidth utilization and provide better signal security, as it alternates the frequency at which a signal is transmitted and hence allows multiple signals to be transmitted at different frequencies at different times.

SATELLITE FIXED BROADBAND WIRELESS

Ciampa (2002) states that satellite usage falls into three broad categories: (a) acquiring scientific data and performing research in space; (b) looking at earth from space, such as weather and military satellites; and (c) reflectors used to bounce or relay signals from one point on earth to another point; an example of which is communications satellites that reflect telephone and data transmissions, broadcast satellites that reflect television signals, and navigational satellites. Broadband wireless communications modes that are most conducive to DE use this third category of satellites. That is, as objects to bounce signals from one point on earth to another. Satellite systems serving this purpose include satellites of low earth orbiting (LEO), medium earth orbiting (MEO), and geosynchronous earth orbiting (GEO). Their differences in orbits present both advantages and disadvantages.

1. *LEO Satellites*—orbit the earth at a low altitude of 200 to 900 miles. Because they are close to the earth, they travel at 17,000 miles per hour, circling the earth in about 90 minutes. Their low orbit is the direct cause for their small global footprint. Hence, many satellites (225) are needed to provide total earth coverage. LEO constellations are arranged in orbit in such a way that from any point on the surface at any time at least one satellite is in a reception line of sight. LEO systems have a low latency (delays caused by signals traveling over a long distance) and therefore accommodate low-power terrestrial devices. It takes only 20 to 40 milliseconds (ms) for a signal to bounce from an earth station to a LEO and back to an earth station again. LEOs are in demand for three markets: rural telephone service, global mobile digital cellular service, and international broadband service. The speed for wireless access with LEO satellites is expected to exceed 100 Mbps.

2. *MEO Satellites*—orbit the earth at altitudes between 1,500 and 10,000 miles. Since MEO satellites are farther from the earth, they have two advantages over LEOs. First, they do not need to travel as fast; a MEO can circle the earth in 12 hours. Second, MEOs have a bigger footprint. Thus, a constellation of several MEO satellites with properly coordinated orbits can provide global

coverage. However, the higher orbit also increases the latency. A MEO signal takes 50 to 150 ms to make the round trip.

3. *GEO Satellites*—are stationed at an altitude of 22,282 miles. A GEO satellite orbit matches the rotation of the earth and moves with the earth. This means that it remains “fixed” over a specific location on the earth. Given its high altitude, only a few GEO satellites are needed to provide continuous service to cover the entire earth. Yet the high altitude also causes high latency of about 250 ms and requires high-powered terrestrial devices. GEO satellites are used for world-wide communications. Broadcast satellites like AfriStar, Intelsat, PanAmSat, Eutelsat, and ASTRA are in this category.

SATELLITE SERVICES AND FREQUENCY BANDS

Satellites are best suited to services that must travel long distances. In addition, they are used by organizations that simply want to avoid wire line transmission either because they cannot afford to build a secure cable infrastructure or because the wire line cannot reach enough intended users. Dean (2002) cites the following services that make use of satellite transmissions: (a) analog and digital broadcasting of television and radio signals via GEOs; (b) voice communications especially transoceanic telephone calls; (c) videoconferencing via LEOs and MEOs; (d) mobile wireless services via LEOs and GEOs; (e) tracking and monitoring; (f) global positioning service; (g) low-cost and high-bandwidth Internet access via LEOs and GEOs; and (h) wide area networks to carry data, voice and video traffic.

Most satellites typically transmit and receive signals in any of five frequency bands. These are the L-band (1.5—2.7 GHz), S-band (2.7—3.5GHz), C-band (3.7—6.5 GHz), Ku-band (10.7—18 GHz), and Ka-band (18—31 GHz). The higher the frequency, the farther the distance for provided coverage. But higher frequency also means that more power is required to generate transmission and that the signal is more susceptible to environmental interference (e.g., rain or snow). The satellite transmission bands that are of interest to education application are the C-, Ku- and Ka-bands. According to Vanbuel (2001), the selection of the band is chosen by large satellite operators based on the following factors:

Availability: C-band is still the most widely available worldwide. Ku-band is becoming more available recently in regions which were less covered in the past (South America, Asia, Africa)

- C-band is more prone to interference from other transmission services that share the same frequencies (adjacent satellites or terrestrial transmissions) than the higher bands
- While the C-band technology is cheaper in itself, it requires larger dishes (1 to 3 m) than Ku- and Ka-band (0.6 to 1.8 m) and therefore imposes relatively higher (installation) costs on the end-user
- Ku- and especially Ka-band make better use of satellite capacity
- Higher frequency bands (Ku- and especially Ka-) suffer significantly more from signal deterioration caused by rainfall. To ensure availability in bad weather conditions, the signal has to be much stronger. Note that 0.1% of unavailability means in fact that the service will be interrupted for almost 9 hours over a 1-year period. 1% unavailability represents 90 hours or almost 4 full days

SATELLITE SUPPORTED EDUCATION APPLICATIONS

Effective content delivery has always been one of the primary goals in education. Creating content is of no use if the creator cannot convey the message one way or another to his or her target audience. The type of technology that is right for the message depends upon many different aspects of the content and of the audience. Understanding different types of deliverable education content, learner preference for accessing content by differing means, and learner-content interaction enabled by ICT will help educators and administrators better select ICT-based DE solutions that match a pedagogical model to the appropriate content.

1. *Common Types of Deliverable Education Content*—include materials that are in the form of audio, text, still image, and moving visual (Alessi & Trollip, 2001). The audio information can be human voice, a conversation, a discussion, music, a speech, a lecture, or a play. Such auditory information can be recorded and transmitted. The text information can exist in written form of a handwritten note, a letter, a newspaper, a magazine, a book, a course, course notes, or a written assessment. The still image information can be a drawing (e.g., a drawing on the blackboard), a sketch, a map, a graph, an image, or a photograph. The moving visual information can contain a demonstration, a show, a film, a video, or a computer animation. These resources are sometimes static and the content does not change once the resource is created, for instance, a digital library with a complete collection of Shakespeare works. In other cases the content is dynamic and the resource can be changed interactively by all their users at all times, for example, the contents of an online discussion forum. A less obvious type of content is data itself, although they have to be structured in some kind of a database to be usable and useful. For example, student records must be accumulated, to show progress towards graduation. Another form of content is a procedure or a program which can be in the form of a software or description. The most evolved form of content is a combination of all elements, where different types are blended in such a way that they make an effective and balanced mix. For example, blended learning combines a technology-based delivery mode (e.g., videoconferences with CD-ROMs) with classroom teaching and learning. Web sites with a collection of web files on a particular subject can be considered the ultimate way of converging different types of content. These web files can consist of text, audio, image and video; all of which can be configured into interactive elements. Examples are software applications and games, virtual reality applications, and simulations.

2. *Learner Preference for Content Access*—refers to content delivery modes that a learner chooses to receive, and by which to send information. According to Vanbuel (2001), there are three types of delivery modes: unicast, broadcast, and multicast. *Unicast* is

limited to individual communication only. It applies to personal letters, phone calls, emails, and the retrieval of information from web sites. For example, when one performs a specific search in Google, it will return with a customized response. Although unicast communication is still the most important communication mode, it is mainly used to communicate rather than to distribute or generate information. *Broadcast* means that the signal is sent out in all directions at the same time. A radio or television broadcast for example, is a program that is transmitted over the airwaves for public reception by anyone with a receiver tuned in. When used in relation to email it means distribution of a message to all members of a group such as a department or enterprise. Broadcast mode is a typical way of sharing information with as many people as possible. *Multicast* occurs when a single sender communicate with a specific group of receivers, where the sender transmits a specific content set to a specific target group. Pay TV, where people subscribe to certain programs on TV, is a good example. Although the signals are transmitted all over the area, only people that are allowed to decrypt the content can effectively view the content. In Internet terms, multicasting is used to send content to certain well-defined IP addresses, or to a specific range of addresses. In general, wireless and radio networks are better suited for broadcasting activities such as radio and TV.

3. *Interaction Supported by ICT*— refers to certain forms of interaction between a learner and content, which are facilitated by communication technologies. Such interaction has three dimensions which are referred to as topology (the actors between which the interaction takes place), time, and symmetry (Vanbuel, 2001). *Topology-related* interaction can happen between a human being and a machine: for example, between someone sitting at a computer and the application on that computer. Computer-based training programs, such as simulations and CD-ROM-based learning applications, fall within this category. Interaction also happens between human beings, such as classroom lectures, discussions, and dialogues. When selecting an ICT to support one or the other interaction topology, there are several obvious choices that can be made. In the case of DE when one person wants to address many people at the same time and who are dispersed over a large geographic area, broadcasting via radio or television may be the most effective means. *Time-related* interaction is the element of synchronicity. In some cases it is necessary to communicate directly and without any delay between parties involved in the exchanges. Videoconferencing and radio and TV broadcasts are synchronous examples, in which the opportunity to receive is lost if the receiving individuals in the target audience are not watching, listening, or recording the program that is being transmitted. Email is a typical asynchronous person-to-person communication system. Email may approach the speed of light, but it does not require the receiver to be present at the other side of the communication channel at the moment the message is sent. *Symmetry/asymmetry-related* interaction refers to the balance of exchange or transfer of information. A normal conversation between two people is symmetric as both parties have an equal say. However, in a teacher-centered classroom, with one teacher lecturing to a hundred students, it is obvious that the communication is not evenly distributed; as the information flow from professor to students will normally be many times larger than the other way round. The same principle applies to technology-enhanced communication. Depending on the symmetry of the communication flow, it will be necessary to opt for the appropriate communications services. In general, videoconferencing and email offer symmetric flow of communication in the sense that all subscribers have equal possibilities to contribute. Radio, television, and web browsing are asymmetric; as the content flowing from the transmitting party towards the receivers is much larger and of much higher quality than the communication that listeners or viewers will be able to return.

4. *Education Applications Supported by Satellite Technology*—include (a) one-way broadcasting radio and television; (b) interactive television; such as video-on-demand, or one-way broadcast with asymmetric return (viewers watching a broadcast program interact with those in the studio via telephone, Internet chat, email messages or a videoconferencing link); (c) data broadcasting and multicasting (e.g., video files, website contents, software updates); (d) Internet access; as colleges, universities, and educational providers seek to reach new learners, satellite-enabled Internet access is often the only way such services can be extended; (e) one and two-way connectivity to support virtual classrooms (synchronous online chat or asynchronous online discussion forum) and resource-base learning, when the teacher and students are in the same location and are using the satellite service to access resources when needed; and (f) VSAT networks with both synchronous and asynchronous configurations which provide the flexibility to control the educational environment. The following table presents the types of educational activities that can be supported by satellite services and where such services are most suitable.

SUCCESSFUL CASES OF SATELLITE TECHNOLOGY INITIATIVES IN EDUCATION

The previous section has illustrated various applications of satellite technology in education and described some broad categories in which such use could be considered. This section cites successful implementations of satellite-based education services from both developed and developing countries. These cases may serve as models for countries seeking satellite-enabled DE solutions.

1. *Mexico Telesecundaria*—is a satellite application of broadcasting type. Telesecundaria broadcast educational programs via the Satélite Solidaridad II, a government-owned satellite managed by the Ministry of Communications and Transportation. Telesecundaria was launched in 1968 as a means to extend lower secondary school learning with television support to remote and small communities at a lower cost. It is the oldest project of its kind in Latin America. In recent years, Telesecundaria has been renovated and extended to primary school and technical teaching as well, through

the dedicated Satellite Network for Educational Television (Red Edusat) which transmits educational programs through 16 video channels and 24 audio channels. Three institutions collaborate to produce the televised programs: the Telesecundaria Unit (responsible for content materials), the Educational Television Unit (in charge of producing televised components), and the Latin American Institute for Educational Communications (broadcasting the program). Centrally-produced television programs – covering the same secondary school curriculum offered in traditional school – are broadcast via satellite throughout the country on a scheduled daily basis in two shifts (8 am to 2 pm and 2 pm to 8 pm). Each hour focuses on a different subject area and children follow the same routine of 15-minute television, then book-led and teacher-led activities. Because the program is better-conceived and better-managed, it is widely perceived as equivalent, if not superior, in quality to its traditional brick and mortar counterparts (Creed & Perraton, 2001).

2. *Chinese Education TV*—is an application of interactive television type with one-way video broadcast and return via a variety of media. China's vast populations live in remote areas that the conventional site-based school systems cannot reach. Capacity expansion into these areas is both costly and time-consuming. In addition, given China's phenomenal economic growth in the recent years, improving its population literacy and strengthening its labor force skills is vital in sustaining such economic growth. Satellite-empowered DE has proved to be instrumental. According to Creed and Perraton (2001), China Central Radio and Television University (CCRTVU) was established in 1978 with 28 Provincial Autonomous Regional and Municipal Television Universities (PRTVUs) to accommodate the vast population needs for higher education. Between 1986 and 1997, DE alone produced 2 million new primary and secondary teachers and assisted 4.82 million to upgrade their qualifications to the prescribed standards. CCRTVU's scale and reach is extensive. It offers 529 courses in 55 disciplines and 9 fields through three satellite channels serving 49 hours of educational programs per day. The enabling satellite system, known as SinaSat-1, is provided by Sino Satellite Communications Company Limited. According to Cernet (2001), a new grand project is underway which intends to modernize the existing national DE network (computer and satellite-based analog one-way video transmission) through integrating ICT (Internet and broadband) into the system to achieve the goal of being multimedia, multifunctional, and multi-standard. The project calls for upgrading China's current satellite education network and transforming C-band frequency to Ku-band frequency. The communications services shall be provided by Xinnuo Satellite Communication Co. Ltd.

3. *Austria AVD Project*—is an example of data broadcasting via satellite using the SkyMultimedia system. Vanbuel (2001) affirms that SkyMultimedia is an interactive satellite-based system which enables the transmission of IP-based content between server and client. It uses the satellite for down-stream (from the central office to the clients) and any medium (dial-up modem, ISDN, satellite, leased line, GSM) for up-stream (from the clients to the central office). Because of the use of DVB/MPEG2 standard, the signal can be received from any current DVB-home-receiver (integrated receiver/decoder). The information is only available for authorized receivers. The satellite used is called Eurobird. The AVD project involves 89 schools, which are connected via satellite and provided with broadband access to the Internet. The AVD project ran during the school year 2002-2003 in Austrian schools and was co-coordinated by Education Highway in cooperation with the Federal Ministry of Education, Science and Culture and Telekom Austria. The aim of the project was the creation of a satellite-based broadcasting system for media-on-demand solutions and interactive tele-learning in schools. All participating schools received equipment, which was used for downloading videos via satellite and streaming interactive tele-learning through live lectures, chat, web browsing, and virtual network computing. All courses have been recorded and archived so that participating schools can access the courses anytime and anywhere.

4. *US Boston College Mobile Satellite Van*—represents two-way Internet access via mobile satellite unit with wireless access for the local network. Boston College, together with Satweb, Tachyon and ABK Ltd, developed a wireless network with satellite Internet access to deliver mobile training. The underlying aim of the project is to bring online ICT training to rural and deprived areas of south and east Lincolnshire. The Internet and online training is provided via satellite connected to a wireless network using a bridging unit to extend the range. The van can be parked outside the chosen venue and there are no trailing wires between the van and the venue. In this way the number of learners accommodated is limited only by the size of the venue, the number of laptops carried and the number of learners the staff can support. The wireless equipment can potentially support up to 250 users. The unit provides laptop computers that are set up in each venue. These are totally portable and space saving to pack in and out of the vehicle. The van carries up to 20 portables initially with space for more if required. In 2000, the units visited well over 30 different communities (the majority are small rural villages) in the College's catchment's area and over 500 individual learners engaged with the mobile training units (Vanbuel, 2001).

5. *The World Bank Global Development Learning Network (GDLN)*—is an example of a VSAT network being used in an educational context. Based on the GDLN (2004), the network uses a mix of satellites covering Africa, the Americas, Eastern Europe and Asia. GDLN, established by the World Bank, is a partnership of public, private and non-governmental organizations and provides a fully interactive, multi-channel network with a mandate to serve the developing world. GDLN partner organizations work together to take advantage of the most modern technology, for building local capacity, sharing learning and knowledge, and developing a global community dedicated to reducing poverty. Network connectivity is achieved through a VSAT satellite transmission system for voice, video and data. A total of three satellites

provide coverage to Africa, the Americas, Eastern Europe, and Asia. Assisted with a technology known as Demand Assigned Multiple Access, GDLN uses Intelsat over the Atlantic to cover Africa and Latin America; Orion to cover Europe and parts of Central Asia; an IOR (Indian Ocean Region) satellite from an uplink in Perth to cover South Asia and East Asia. GDLN connects with Perth via fiber from Washington. In this way, the whole system is one satellite hop. The GDLN network involves a growing consortium of facilities with high-quality interactive video conferencing and Internet capacity which is currently linking more than 50 countries in Europe, Africa, Asia, Latin America and North America. Course topics include: Political Economy of the Environment for Journalists, Economic Growth and Poverty Reduction, Procurement, Urban and City Management, Analytical and Policy Issues in Macroeconomic Management, Controlling Corruption: an Integrated Strategy, Capital Flows Volatility and Financial Crises, Health Sector Reform and Sustainable Financing, Gender Health and Poverty, Social Safety Nets and Rural Development.

CONCLUSION

Education and training for all has become more critical than ever with the emergence of the Information Society. To remain economically competitive and to prosper in today's global and knowledge-driven economy, countries cannot afford to have large sectors of their population excluded from education, or to remain at the lower level of the educational spectrum. Yet educational systems, to differing degrees worldwide, are struggling to afford educational opportunities for all. They are neither adequately preparing citizens for lifelong learning, nor providing younger generations with the necessary knowledge and skills to match evolving marketplaces and the jobs of the future. To meet these challenges, countries must focus on expanding access, promoting quality education, and improving delivery efficiency through economy of scales. As the successful cases cited in the paper demonstrate, satellite-based DE systems can adequately address all three critical elements of education (access, cost, and quality). In addition, DE systems are sufficiently adaptive now to be tailored to different levels within a nation's education hierarchy (e.g., Mexico's Telesecundaria for secondary education, and China's CCRTVU for higher education); and adequately flexible to accommodate small and nomadic communities (e.g., Boston College Mobile Satellite Van for rural population).

Whether instruction is unicast, to serve unique and individualized student needs, or whether it is broadcast to serve all who may receive it uniformly, satellite and Internet technology will always make DE an integral part of any learning strategy. Countries of large population should view the initially high capital cost of satellite-enabled DE system as worthwhile and necessary investments in their future. Indeed, it can be the biggest-bang-for-the-buck means to quickly provide large percentages of citizens with easy access to instructional materials of uniformly high quality. Expanding access to education is a matter of both economic development and social justices. Without doubt, satellite-based DE systems will serve this aim well.

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