skills and abilities. For example, in the case of problem solving, one can easily measure how often a user attempts a given problem. Attempt frequency (especially if each attempt is different) correlates highly to improved problem solving. Similarly, by monitoring users' keystrokes while they navigate search engine results, we can distinguish between hypothesis-driven searches and random searches, another key indicator of advanced problem-solving skills.

Sustainability

The last major hurdle in expanding the use of game-based learning is arriving at sustainable business models. Academic game development, which depends on living from one grant to the next, is inherently unsustainable. However, if funders could lay the foundations in an initial grant, the same learning materials could transition to profit-generating models that could be used to expand the material's reach after small-scale academic development is completed. These models could include corporate sponsorship, dual pay (free to some, but a fee for others) or sliding-scale fee models, subscriptions, site licensing, and the sale of virtual goods (e.g., virtual clothing to be worn by the player's in-game character, downloadable wallpapers, electronic books that give game hints). Other business models could include leader sales to countries with nationalized education systems and hence centralized buying power, partnerships with commercial game distributors, and microcredits for microknowledge (a far-future economic concept wherein a user would pay, say, $0.99 to learn the Pythagorean theorem via a small educational module, in exchange for a math mini-credit that could aggregate with other mini-credits toward a degree). To my knowledge, none of these methods has yet been used to sustainably support academically developed games, with the possible exception of corporate sponsorship, which has supported the growth of academically developed but for-profit–operated Whyville.

Summary

Although the field is still in its embryonic stages, game-based learning has the potential to deliver science and math education to millions of users simultaneously. Unlike other mass-media experiments in education (e.g., TV, Webinars), games are a highly interactive medium with many key attributes shared with sophisticated pedagogical approaches. Large-scale adoption, however, still awaits key infrastructural developments to improve quantity (of users), quality (of product), and sustainability (of business models).

References and Notes

1. *NSF Science and Engineering Indicators 2008*, NSB 08=01, 08-01A (National Science Board, Arlington, VA, 2008), appendix table 2-27.
2. www.worldofwarcraft.com (United Nations World Food Programme, Rome, Italy).
3. B. S. Woodcock, MMOGCHART.COM **23.0** (2008), available at www.mmogchart.com.
4. www.food-force.com (United Nations World Food Programme, Rome, Italy, 2005).
5. United Nations World Food Programme, various press releases, available at www.food-force.com/index.php/press/releases/undefined.
6. www.whyville.net (Numedeon, Pasadena, CA).
7. J. Bower, paper presented at the Grantmakers for Education Annual Meeting, Baltimore, MD, 20 to 22 October 2008.
8. Subsequent personal communication from J. Bower detailed the exact percentage of female Whyville users, at 68%.
9. http://fas.org/immuneattack/ (Federation of American Scientists, Washington, DC, 2007).
10. B. D. Coller, paper presented at the Serious Games Summit, Washington, DC, 30 to 31 October 2006; available at www.ceet.niu.edu/faculty/coller/research.htm.
11. Also, for more detailed information on concept map results, see B. D. Coller's related work at www.ceet.niu.edu/faculty/coller/images/handsOnPreprint.pdf.
12. http://muve.gse.harvard.edu/rivercityproject/ (Harvard Univ., Cambridge, MA, 2007).
13. D. J. Ketelhut, C. Dede, J. Clarke, B. Nelson, paper presented at the 2006 AERA Annual Meeting, San Francisco, CA, 7 to 11 April 2006; available at http://muve.gse.harvard.edu/rivercityproject/documents/rivercitysympinq1.pdf.
14. R. T. Hays, "The Effectiveness of Instructional Games: A Literature Review and Discussion" (Technical Report 2005-004, Naval Air Warfare Center Training Systems Division, Orlando, FL, 2005).
15. J. J. Vogel *et al*., *J. Educ. Comput. Res.* **34**, 229 (2006).
16. J. P. Gee, *What Video Games Have to Teach Us About Learning and Literacy* (Palgrave MacMillan, New York, 2003).
17. D. G. Oblinger, *J. Interact. Media Educ.* **2004**, 8 (2004); available at www-jime.open.ac.uk/2004/8/.
18. M. Begg, D. Dewhurst, H. McLeod, *Innovate: J. Online Educ.* **1,** issue 6 (2005); available at http://innovateonline.info/?view=article&id=176.
19. J. Willinsky, *Science* **323**, 39 (2009).
20. A. C. Peck, D. Detweiler, *Hum. Factors* **42**, 379 (2000).
21. S. Barab, M. Thomas, T. Dodge, R. Darteaux, H. Tuzun, *Ed. Tech. Res. Dev.* **53**, 86 (2005).
22. S. Barab *et al*., *Sci. Educ.* **91**, 750 (2007).
23. A. C. Graesser, N. K. Person, *Am. Educ. Res. J.* **31**, 104 (1994).
24. D. Druckman, R. A. Bork, Eds., *Learning*, *Remembering*, *Believing: Enhancing Human Performance* (National Academy, Washington, DC, 1994).
25. R. M. Ryan, C. S. Rigby, A. Przybylski, *Motiv. Emot.* **30**, 344 (2006).
26. B. S. Bloom, Ed., *Taxonomy of Educational Objectives* (Susan Fauer Company, Chicago, 1956).
27. J. D. Bransford, A. L. Brown, R. R. Cocking, Eds., *How People Learn: Brain*, *Mind*, *Experience*, *and School* (National Academy, Washington, DC, 2000).
28. D. W. Johnson, G. Maruyuma, R. Johnson, D. Nelson, L. Skon, *Psychol. Bull.* **89**, 47 (1981).
29. L. J. Sax, J. A. Lindholm, A. W. Astin, W. S. Korn, K. M. Mahoney, *The American Freshman: National Norms for Fall 2001* (Higher Education Research Institute, Los Angeles, CA, 2001).
30. E. Seymour, N. Hewett, *Talking About Leaving* (Westview, Boulder, CO, 1997).
31. R. R. Hake, *Am. J. Phys.* **66**, 64 (1998).
32. www.collada.org (Khronos Group, Beaverton, OR, 2006).
33. www.web3d.org/x3d/ (Web 3D Consortium, Menlo Park, CA).
34. www.kauffman.org (Ewing Marion Kauffman Foundation, Kansas City, MO, 2008).
35. D. Hutchison, *Br. J. Ed. Tech.* **38**, 977 (2007).
36. D. E. Powers, J. Burstein, M. Chodorow, M. E. Fowles, K. Kukich, *Comparing the Validity of Automated and Human Essay Scoring (GRE No. 98-08a*, *ETS RR-00-10)* (Educational Testing Service, Princeton, NJ, 2000).
37. M. Kebritchi, thesis, University of Central Florida, Orlando, FL (2008).
38. M. Kebritchi, A. Hirumi, H. Bai, "The Effects of Modern Math Computer Games on Learners' Math Achievement and Math Course Motivation in a Public High School Setting," available at www.dimensionm.com/docs/UCFResearch_Brief_June_202008.pdf.
39. Reference (*37*) is the basis for (*38*).
40. P. McClean, B. Saini-Eidukat, D. Schwert, B. Slator, A. White, in *Selected Papers from the 12th International Conference on College Teaching and Learning*, J. A. Chambers, Ed. (Center for the Advancement of Teaching and Learning, Jacksonville, FL, 2001), pp. 111–118.
41. K. Squire, M. Barnett, J. M. Grant, T. Higginbotham, in *Proceedings of the 6th International Conference on Learning Sciences*, Y. B. Kafai, W. A. Sandoval, N. Enyedy, A. S. Nixon, F. Herrera, Eds. (UCLA Press, Los Angeles, CA, 2004), pp. 513–520.

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PERSPECTIVE

Laptop Programs for Students

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With the continuing decline in costs of technology, programs are proliferating worldwide to put networked laptop computers into the hands of millions of students on a routine basis. The reasons policy-makers support these programs are based on economic arguments, equity concerns, and widespread interest in education reform. Studies of laptop programs in schools report that they increase students' engagement in school, improve technology skills, and have positive effects on students' writing. However, evidence of the effectiveness of large-scale laptop programs in other learning domains is scarce. Research in many nations suggests that laptop programs will be most successful as part of balanced, comprehensive initiatives that address changes in education goals, curricula, teacher training, and assessment.

Interest in providing laptops to schoolchildren has been growing for more than a decade, with a school in Australia beginning what may have been the first such program in 1990 (*1*). Traditional manufacturers now offer many laptop models costing under US$900. In addition, less-expensive laptops especially designed for children and schools have become available, including the XO computer designed and distributed by One Laptop Per Child [a spinoff of the Massachusetts Institute of Technology (MIT) Media Lab] and the Intel Classmate personal computer (PC). Ultra-low-cost computers such as these typically include flash memory instead of a spinning hard drive, smaller screens, and fewer external ports. At the same time, they and others like them may offer features of particular interest to schools in developing nations, such as low power consumption, a free or low-cost operating system, and the capability to establish a mesh network with other computers.

With declining unit costs, policy-makers around the world are investing large sums of money in laptop computers for students and teachers in elementary and secondary schools. In the United States, the state of Maine provided every middle-grade student (ages 13 to 14 years old) with a laptop beginning in 2002, on loan from schools like a textbook. Pennsylvania's Classrooms for the Future program is providing classroom sets of laptops to more than 500,000 high school students. Uruguay has recently distributed 120,000 laptops and plans to buy 300,000 more. Portugal announced it will provide 500,000 computers to students, and Venezuela has ordered 1 million laptops for children, which will be assembled in Portugal based on the Intel Classmate PC design. Australia, Chile, Columbia, Libya, Mongolia, Nigeria, and South Africa are among the many other nations supporting at least pilot programs with laptops.

The reasons given by policy-makers for investing in these programs vary. There are economic arguments, based on improving students' technology skills, creating a better educated work force, and attracting new jobs; equity concerns, to support students from low-income families whose access to technology and information is otherwise restricted; and education reform issues, as policy-makers try to make schools more effective and provide students an education that prepares them for life in the 21st century.

The growth of laptop programs globally has been fueled by widespread discontent with the status quo in elementary and secondary education. Computers and globalization have changed skill requirements. Schools are being asked to increase the quality of education, notably by providing more students than in the past with advanced skills and the ability to be flexible thinkers and problem-solvers. At the same time, in many developing countries there is a demand for deep reforms in education to help create a more democratic, participatory, and responsible society, which calls for substantial changes in the schools (*2*, *3*). Those countries, which are only now beginning to move away from traditional education systems, often see technology as one of the keys to transforming their education systems.

Programs to provide students with laptops and related technologies use various devices and differing usage or ownership models. In almost all cases, the laptops are wireless and provide students with access to the Internet and a local school network. Programs providing students with personal laptops to use during the school year are often called one-to-one (1:1) computing. Some 1:1 programs allow students to take their computer home; others do not. A few 1:1 programs (such as in Henrico County, Virginia, involving more than 25,000 laptops) subsidize home access to the Internet for low-income families. Australia is aiming for 1:1 but has begun by offering schools grants for one computer per two students (www.digitaleducationrevolution.gov.au). In contrast to 1:1 computing, tens of thousands of schools in many nations have invested in classroom sets of computers, generally with wireless networking capability, which are either shared by many classrooms or assigned to only one. Although students in those cases are not provided with a personal laptop, some personalization can be provided if students' documents are stored on a server and are thus available from any machine. A few school systems have adopted "thin client" solutions, meaning that the machines students use are cheap and easy to maintain, whereas the major computer power and the software are provided by a small number of computers or servers. The republic of Macedonia (formerly part of Yugoslavia), for example, uses inexpensive computer terminals linked to regular PCs, at a seven-to-one ratio, for its 360,000 students (*4*).

What these varied approaches have in common is putting powerful, networked computer capability into the hands of more students on a routine basis. And as interest has grown in laptop programs, especially since 2001, schools have also adopted related digital tools and services, including online courses, interactive electronic whiteboards, handheld devices (sometimes called clickers) that beam students' answers to a receiver and a display, graphing calculators, and "probes" for collecting science laboratory data in digital form (*5*).

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Table 1. The estimated 5-year total cost of ownership (TCO) for a smart classroom in an urban secondary school in a developing nation, based on using ultra-low-cost computers and the Linux operating system. [Adapted from (*31*)]

Cost item	5-year TCO	% of TCO
Initial costs per classroom		
Hardware	$11,397	17.5%
Retrofitting, networks, cabling, and deployment	$1,779	2.7%
Total initial costs	$13,176	20.2%
Recurrent costs		
Training	$16,000	24.5%
Internet	$2,100	3.2%
Service and support	$20,801	31.9%
Electricity and consumables	$636	1.0%
Total recurrent costs	$39,537	60.6%
Hidden costs		
Replacement computers, repurchase, and deployment	$10,043	15.4%
Other	$2,533	3.9%
Total hidden costs	$12,576	19.3%
Total 5-year TCO, 32 seats	$65,290	100.0%
TCO per seat	$2,040	

Evidence of Effectiveness

To measure the extent to which a laptop or other technology program is effective, one must know the goals against which success is measured as well as the outcomes. One would also like to have information about the nature and quality of the program design and about details of implementation so that reasons why programs do or do not work can be better understood (*6*). Gathering and analyzing all of those data is expensive and a challenge.

A widely reported outcome in both the developed and the developing world is that programs providing computers to schools increase the technology skills of teachers and students (*7*, *8*). Sometimes, as in the case of the World Links program supported by the World Bank in 26 developing countries, this is an explicit program goal (*8*).

Research and evaluation studies also report that laptop programs increase students' engagement with academic work, which is an important finding given the large dropout rates in many secondary schools (*7*, *9*). Participants are often enthusiastic about laptop programs, including teachers, students, parents, and administrators (*10*, *11*). As a result, many programs have been supported for years.

Not surprisingly, research also shows that at school students use laptops frequently to search for information of various kinds. Students report that they benefit from Internet search tools and digital resources that allow them to access information more quickly and efficiently (*12*).

There is strong evidence—but usually drawn from studies besides those focused on laptop programs—that a variety of specific educational applications of computers are effective. For example, using a word processor has been shown to help students learn to write (*13*); certain drill-and-practice applications assist students in learning facts and skills (*14*); some science laboratory simulations can be more effective learning tools than actual laboratory equipment (*15*). (Other articles in this issue supply additional information about particular computer applications.)

In some cases, there is evidence that laptop programs are important contributors to students' academic achievement. A public charter high school in Colorado that serves many students from low-income families provides an example (*16*). Physics classes there make use of an interactive electronic textbook stored on students' laptops, computer-based physics simulations developed by a Nobel Prize winner, probes for collecting laboratory data, and other digital tools. In 2007–2008, 30% of the seniors at the school took an Advanced Placement physics test, compared to about 3% nationally, yet students at the school scored at or slightly above the national average on the test, making the yield of capable physics students exceptionally high. The school does not claim that laptops alone cause this outcome—the teachers are excellent and many other factors play a role, including the digital resources used to teach physics—but data show the laptops are heavily used for academic work, and the administrators, teachers, and students believe that the 1:1 laptops contribute to the school's success. Animated physics simulations are part of the electronic textbook, so students interact and experiment with this textbook, not just read it. Teachers routinely make use of computer software called ExamView that provides instant feedback about how students have responded to assessment questions, and teachers may then assign students to groups on the basis of that information. Several times each year the teachers study assessment data, gathered using ExamView, to find out how well students are performing on education standards. The school's alignment of educational goals, instructional materials, student assignments, teacher practices, and assessment techniques illustrates that computers will be most effective when used as part of a thoughtfully coordinated, systemic approach.

A review of 30 studies of 1:1 programs found few with rigorous designs, but the studies measuring learning outcomes showed consistent, positive effects on students' writing skills (*7*). However, studies finding evidence of other academic achievement gains in laptop programs involving large numbers of schools, particularly studies using quantitative methods, are scarce in wealthy countries (*7*) and rarer in developing countries. In what is probably the first study of its kind, the Canadian government recently funded an evaluation of 1:1 pilot programs in Argentina, Costa Rica, Uruguay, and Columbia (www.idrc.ca/en/ev-129437-201_104122-1-IDRC_ADM_INFO.html). A study underway in Texas is unusual because it is a 4-year longitudinal study, costs millions of dollars, and includes not only more than 20 experimental schools that use laptops but also a matched comparison group of schools that do not (*12*). After 3 years, the researchers found positive impacts of laptops on technology use and proficiency, increased interest among teachers in student-centered instruction, reduced student disciplinary actions, and greater teacher collaboration. However, there was generally no significant impact on students' test scores in reading and writing and only a weak impact in mathematics.

Policy research from many countries finds that a key difficulty is that instruction often focuses mostly on basic skills and memorizing facts and less on complex ideas or teaching students to be flexible thinkers (*17–20*). Some policy-makers hoped that the introduction of computers would lead directly to better instruction. However, the Texas study found that the availability of computer technology by itself had little or no impact on the intellectual challenge of teachers' lessons, concluding that across classrooms lessons generally failed to intellectually challenge students.

It is clear is that simply providing computers to schools is not enough to increase student achievement or change the nature of instruction. At a minimum, learning goals, curricula, teaching strategies, and assessments must change as well. Also, computers are often underutilized (*21–23*). Leaders must provide teachers and administrators with a clear vision of how computers are to be used; appropriate digital resources must be made available; effective, ongoing professional development needs to be provided to teachers; technical support must be available for computers, networks, printers, software, and other components; local leaders, including school principals and teacher leaders, need to be trained and supported; and so on. For example, one crossnational study found that teachers' competence in using technology, as well as the amount of their training in uses of technology for instruction, was associated with greater use of technology for instruction (*24*).

Costs/Affordability

Despite these challenges, interest in laptop programs is likely to continue growing, in part because a new generation of low-cost laptops has been developed, including the OLPC XO machine, the Intel Classmate, the Asus Eee PC, and others. Someday there may be a $100 laptop, although no one has yet achieved such a low price. The cost of installing wireless computer networks also declined greatly in the past decade.

Regardless of the price of technology, the investments in creating effective laptop programs are large. The Australian government has recently committed Au$1.2 billion for its school technology program. In the U.S., one national program alone, the E-Rate program, has spent about US$20 billion since 1998 to help connect nearly all schools to the Internet (*5*).

Yet the cost of laptop programs consists of much more than the price of buying computers and connecting them to networks. Schools should consider the total cost of ownership (TCO), including training of teachers and administrators, technical support, software, replacement costs of aging equipment, and other items. In the United States, the direct and indirect costs of 1:1 programs per client computer are over $1000 annually (www.classroomtco.org/gartner_intro.html). Even in the developing world, where labor costs are lower, one recent estimate of the annual per-seat cost of a 1:1 classroom is more than $400 (*25*). Table 1 shows that the hardware itself composes only about one-third of the total in a developing nation, whereas training, service, and support account for more than half.

But it is a mistake to compare TCO to a baseline of zero. Almost no policy-makers suggest that all computers and Internet connections be removed from schools or that teachers need not be trained to make use of the resources available on the World Wide Web. Indeed, desktop computers have become far more prevalent in schools in many nations during the past decade (*26*). Thus, alternatives to laptop programs cost substantial money, too. Policy-makers also expect that laptop programs will reduce certain costs, such as those for textbooks and assessments (*27*).

The Future of Laptop Programs

Computers are different than other technologies used in schools because they are all-purpose machines. They can be used as a library, a way to model invisible phenomena, a communication device, a link to other tools (such as telescopes or online databases), a device students use to create knowledge artifacts in many media, and so forth. Computers' flexibility makes them uniquely powerful educational tools but also means that quality educational interventions or treatments cannot be realized simply by providing more computers.

Policy-makers and the public need to be clear about the educational and social goals for laptop programs (which will vary according to local needs and aims) and assure that the necessary elements are in place to reach those goals. Political leaders' beliefs that computer-based learning tools are powerful are well founded, as is shown by research as well as by the everyday experience of using the Internet. However, if the goal of laptop programs is to change educational goals; to improve patterns of teaching, learning, and assessment; and to help transform schools into more effective institutions; more needs to be done than acquire laptops and a corresponding technical infrastructure. Curricula need to be revised, better assessments developed, teachers must learn new approaches, and schools have to support teachers as they learn to teach in new ways. As one study of more than two dozen countries' use of information and communication technology recommended, "policies that adopt a balanced, holistic approach catering for [the multiple changes needed] will be more successful than policies focusing on one or two strategic areas" (*24*).

Poorer nations face particularly challenging choices because large-scale technology installations are expensive, and their school systems are simultaneously trying to extend current education systems to reach large numbers of unschooled children (*28*) and trying to radically transform schooling. Policy-makers in some developing nations, such as India and parts of Latin America, believe that although computers and the Internet are important for schools, instead of funding 1:1 programs their best strategy for incorporating technology is to proceed at a slower pace, pilot testing different approaches in order to identify which programs effectively meet their needs (*29*). Computers are an increasingly important educational tool, but only as part of carefully designed policies affecting many aspects of education (*30*). A laptop program that does not seriously address the need for education reform is not an appropriate option for any school or nation.

References and Notes

1. B. Johnstone, *Never Mind the Laptops: Kids, Computers, and the Transformation of Learning* (iUniverse, Incorporated, New York, 2003).
2. M. F. Astiz, A. W. Wiseman, D. P. Baker, *Comp. Educ. Rev.* **46**, 66 (2002).
3. F. Reimers, in *Perspectivas Sobre la Reforma Educativa*, J. C. Navarro *et al.*, Eds. (Inter-American Development Bank, Washington, DC, 2000).
4. NComputing Incorporated, *Republic of Macedonia First Nation to Provide a Computer for Every Student (Case Study, Education)* (NComputing, Redwood City, CA, 2008).
5. A. A. Zucker, *Transforming Schools with Technology: How Smart Use of Digital Tools Helps Achieve Six Key Education Goals* (Harvard Education Press, Cambridge, MA, 2008).
6. A. A. Zucker, *J. Educ. Comput. Res.* **30**, 371 (2004).
7. W. R. Penuel, *J. Res. Technol. Educ.* **38**, 329 (2006).
8. R. Kozma *et al.*, *Int. J. Educ. Dev.* **24**, 361 (2004).
9. Comenius Center, *Informe Final—Enlaces Portátil: Abriendo Camino para un País Digital* (Centro para el desarrollo de innovaciones en educación, Universidad de Santiago, Santiago, Chile, 2008).
10. D. Davis *et al.*, *Henrico County Public Schools iBook Survey Report* (Development Associates, Incorporated, Arlington, VA, 2005).
11. D. L. Silvernail, D. M. M. Lane, *The Impact of Maine's One-to-One Laptop Program on Middle School Teachers and Students: Phase One Summary Evidence* (Maine Education Policy Research Institute, Gorham, ME, 2004).
12. K. Shapley *et al.*, *Evaluation of the Texas Technology Immersion Pilot: Outcomes for the Third Year (2006-07)* (Texas Center for Educational Research, Austin, TX, 2007).
13. A. Goldberg, M. Russell, A. Cook, *J. Technol. Learn. Assess.* **2**, article no. 1 (2003).
14. J. A. Kulik, *Effects of Using Instructional Technology in Elementary and Secondary Schools: What Controlled Evaluation Studies Say* (SRI International, Arlington, VA, 2003).
15. N. D. Finkelstein *et al.*, *Phys. Rev. Spec. Top.* **1**, 1 (2005).
16. A. A. Zucker, S. T. Hug, *J. Sci. Educ. Technol.* **17**, 586 (2008).
17. R. C. Pianta *et al.*, *Science* **315**, 1795 (2007).
18. PROBE team, *Public Report on Basic Education in India* (Oxford Univ. Press, New Delhi, 1999).
19. United Nations Development Program, *Arab Human Development Report: Building a Knowledge Society* (United Nations, New York, 2004).
20. G. Ferrer, G. Valverde, J. M. Esquivel Alfaro, *Aspectos del Curriculum Intencional en América Latina: Revisión de Tendencias Contemporáneas en Curriculum, Indicadores de Logros, Estándares y Otros Instrumentos* [PREAL (Partnership for Educational Revitalization in the Americas), Washington, DC, 2002].
21. L. Cuban, H. Kirkpatrick, C. Peck, *Am. Educ. Res. J.* **38**, 813 (2001).
22. M. Durando *et al.*, *eMature Schools in Europe* (European Schoolnet, Brussels, 2007).
23. *Harnessing Technology Review 2007: Progress and Impact of Technology in Education* (British Educational Communications and Technology Agency, Coventry, UK, 2007), p. 80.
24. N. Law, W. J. Pelgrum, T. Plomp, Eds., *Pedagogy and ICT Use in Schools Around the World: Findings from the IEA SITES 2006 Study* (Springer and Comparative Education Research Centre, University of Hong Kong, Hong Kong, 2008).
25. Vital Wave Consulting, *Affordable Computing for Schools in Developing Countries: A Total Cost of Ownership (TCO) Model for Education Officials* (Vital Wave Consulting, Palo Alto, CA, 2008).
26. Programme for International Assessment, *Are Students Ready for a Technology-Rich World? What PISA Studies Tell Us* [Organization for Economic Cooperation and Development, Paris, 2005].
27. A. A. Zucker, R. Mcghee, *A Study of One-to-One Computer Use in Mathematics and Science Instruction at the Secondary Level in Henrico County Public Schools* (SRI International, Menlo Park, CA, 2005).
28. EFA Global Monitoring Report Team, *Education for All by 2015: Will We Make It?* (United Nations Educational, Scientific, and Cultural Organization, Paris, 2008).
29. H. Azinian, *Un Mapa del Debate Sobre la Iniciativa Un Computador por Niño en América Latina y el Caribe* (International Development Research Centre, Montevideo, Uruguay, 2007).
30. P. Hepp *et al.*, *Technology in Schools: Education, ICT and the Knowledge Society* (World Bank, Washington, DC, 2004).
31. Vital Wave Consulting, *Affordable Computing for Schools in Developing Countries: A Total Cost of Ownership (TCO) Model for Education Officials* (Vital Wave Consulting, Palo Alto, CA, 2008), p. 14.

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REVIEW

Online Education Today

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Online education is established, growing, and here to stay. It is creating new opportunities for students and also for faculty, regulators of education, and the educational institutions themselves. Much of what is being learned by the practitioners will flow into the large numbers of blended courses that will be developed and delivered on most campuses. Some of what is being learned will certainly improve pedagogical approaches and possibly affect other important problems, such as the lengthening time to completion of a degree. Online education is already providing better access to education for many, and many more will benefit from this increased access in the coming years.

In a 1995 *Science* article, Eli Noam of Columbia University opined that the Internet would pave a difficult road ahead for traditional academic institutions; he wrote, "as one connects in new ways [the Internet], one also disconnects the old ways" (*1*). Thirteen years after Noam's article and 15 or so years after Internet usage began its rapid acceleration, online learning has become an important element in education, although it is not evenly distributed across institutions.

The term "online learning," however, obscures vast differences in methods supported by this educational approach. We limit this discussion to online education in traditional, regionally accredited, degree-granting institutions. Within this discussion, we include "blended courses," that is, those that feature some online elements but less face-to-face time than encountered in an equivalent traditional course. We do not discuss online education in the rapidly developing kindergarten through grade 12 environment, online corporate training, or the free educational resources (complete courses in many cases) being made available online by some universities, such as the Massachusetts Institute of Technology (MIT), Yale, Stanford, and a few others (*2*). These are widely accessed throughout the world but do not provide credit as courses or as partial fulfillment toward degree completion. These efforts can thus be thought of as use of the Internet to disseminate, free of charge, valuable, high-quality information, but not credentials,

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