

## 2. Background:

### How We Got Here and Why Now

We reflect briefly on the current state of information technologies for learning and the many strands of prior research that have created the conditions for the major new waves of innovation possible today. A strategic cyberlearning focus by NSF will build upon this history.

#### 2.1 Technology and Educational Environments of 21st Century Learners

Why is this such a propitious time for a cyberlearning initiative? How can we build productively on what has been learned before? A cluster of interacting factors have contributed to the flowering of this new opportunity and challenge:

- **A new participatory Web culture.** New Web functionalities during the past several years have made participatory media culture a reality, contributing to the personal, professional, and educational lives of learners (Jenkins, 2006; Jenkins, Clinton, Purushotma et al., 2006). In less than 3 years, the public video upload site YouTube has become the third most trafficked Web site in the world, with 2.9 billion video streams viewed in February 2008 (*Who's Watching What Video Online and Where: Results from Nielsen Online*, 2008). Increasingly, such capabilities are being used for education as well as informal learning. Hundreds of millions of people, and large proportions of the U.S. population, from middle school to adults, publish blogs, photos, videos, book reviews, social profiles, useful bookmark lists, and other content online for others to use and learn from. (See the many Pew Internet and American Life Project reports.) An important characteristic of such rapid adoption of these platforms is continuous beta releases that improve constantly from user feedback.

- **The ease of deploying software at Web scale.** The emergence of the Web over the 1990s brought with it an astonishing capability: virtually anyone could publish data on a global scale. This was a radical change from the pre-Web era, and

our social institutions are still digesting the consequences. This ability is rooted in basic principles of Web architecture (Jacobs & Walsh, 2004): all information resources are linked together with the same linking mechanism (interoperability), and publishers do not need permission to create links (openness). Shortly after the turn of the century, information technologists began to demonstrate that the same principles permitting data access at Web scale can also apply to programs. With Web service architectures, developers can deploy software components and services that are accessible from any Web browser. There are now several popular Web application development platforms—both proprietary, such as Microsoft's .NET, and open source, such as the Linux/Apache/MySQL/Perl (LAMP) suite. With these platforms, just as anyone can publish content at Web scale, anyone can create software programs and make them immediately accessible to a global audience. Very recently, initiatives like Amazon's Web Services and Google's App Server have begun making scalable Web hosting infrastructures openly available to all Web developers. As a result, the development gap between small-scale testing of Web programs and massive-scale deployment is vanishing. It is no longer necessary to make large financial investments to have a huge impact in deploying software on the Web.

- **Open educational resources.** "Open educational resources" (OER) was first adopted as a term at UNESCO's 2002 Forum on the Impact of Open Courseware for Higher Education in Developing Countries, funded by the William and Flora Hewlett Foundation (Atkins et al., 2007). OER are educational materials and resources offered without cost for anyone to use anytime and under a license to remix, improve, and redistribute. It includes learning content at different levels of granularity for students and teachers at all levels of learning, including videos, books, lesson plans, games, simulations, and full courses and open-access content; open-source software tools that support the creation, delivery, use, and improvement of open learning content, including searching and organization of content;

content and learning management systems (e.g., Moodle, Sakai); online learning communities; and intellectual property licenses (e.g., Creative Commons) to promote open materials publishing, design principles, and content localization. Open-source course management systems are being deployed widely in universities, and to some extent in K–12.<sup>5</sup> OpenCourseWare (OCW), initiated in 2002 by Massachusetts Institute of Technology (MIT), publishes free, extensive materials about 1,800 courses, including syllabi, lecture notes and often complete lectures, assessments, readings, and so on. Since 2002, more than 100 other universities from all over the world have published their own materials and formed the OCW Consortium. Hundreds of open full courses—including lecture courses from Yale, Berkeley, and MIT; suites of multimedia courses, and cognitive tutor courses from Carnegie Mellon—populate the Web and serve secondary schools as well as universities. In the developing world, the OER movement has been immensely well received as these countries work to broaden their access to education and, simultaneously, improve its quality.

• **From mass markets to millions of niches.** The “Long Tail” marketplace phenomenon, as popularized by *Wired* magazine editor Chris Anderson (2006), refers to the new business models made possible by distributed access to consumers and products. Web-based companies such as Amazon, Netflix, and Apple iTunes have realized new kinds of profits by selling small volumes of hard-to-find items to a large number of buyers. Anderson characterizes the need of brick-and-mortar businesses, which are constrained by shelf space, to sell large volumes of a small number of popular items, as the “hits” business model. The Long Tail refers to the populace under the distribution curve who purchase harder-to-find items, and the reachable market size, it is argued, has grown in some cases by a factor of two or three compared with physical retailing locations because of the new long tail dynamics of Web purchasing. A key

technological capability that makes the Long Tail model work is the success of data-driven “recommendation engine” software (Resnick & Varian, 1997), which uses the aggregated purchasing and browsing patterns of users to guide those who follow them to find items that they may like. Many Amazon book purchases come via this route, and more than 60 percent of Netflix video rentals come from such recommendations, which drive demand down the long tail.<sup>6</sup> The relevance of Long Tail phenomena to education and cyberlearning is evident: learning trajectories, whether for STEM or other content, no longer need be constrained to the “hits” now represented by published textbooks and traditional pedagogical channels. As the costs of online publishing go down, the quality of learning object metadata improves, and search engines make it easier to find learning niche content, a different ecosystem of learning materials will evolve. Libraries already are finding vast new audiences for the old and obscure material now being digitized, and are distinguishing themselves in the marketplace of ideas by expanding access to their special collections.

• **Ubiquitous computing, mobiles, and broadband networking.** More and more frequently, learners have access to one or more of their own computers for learning, more commonly at home but also at school. The Pew Internet and American Life Project currently estimates that 75 percent of adults and 90 percent of teenagers in the United States go online, and 80 percent of adults have a cell phone. There are more than 1 billion computer users in the world, with predictions of 2 billion users by 2015,<sup>7</sup> and 3.5 billion mobile phone subscribers,<sup>8</sup> with emerging mobile phone technologies already sharing many of the functionalities with laptop computing. A recent Pew Internet and American Life Project report (Horrigan, 2008a) states that 62 percent of all Americans now participate as part of a wireless, mobile population in digital activities away from home or work, with youth particularly

5 For examples of K–12 implementation case studies, see <http://www.k12opentech.org/implementation-study-3-moodle>.

6 Netflix ships almost 2 million DVDs per day to its 8 million customers, and has more than 2 billion movie ratings contributed by its members about more than 9,000 full-length movies and television episodes.

7 See <http://tinyurl.com/yvbw32>.

8 See <http://tinyurl.com/3xgsk6> and <http://tinyurl.com/3cmmfr>.

attuned to new access. African Americans and English-speaking Latinos are more likely than white Americans to use nonvoice data applications on their cells. Furthermore, another Pew report concludes, “With the Federal Communications Commission auctioning spectrum well-suited for high-speed wireless applications, and with some companies beginning to open up handheld devices to application developers, more innovations in wireless access are on the horizon. In particular, ‘cloud computing’ will emerge in the coming years—moving applications and data storage away from the desktop or laptop to remote servers managed by high-speed networks. Computing applications and users’ data archives will increasingly be accessible by different devices anytime, anywhere over fast and widely available wireless and wired networks. It is hard to overstate the importance of online access becoming decoupled from desktop computing” (Horrigan, 2008b). With such networked devices as computers and mobile phones come the benefits of Metcalfe’s Law (Gilder, 1993)—the value of a communications network grows exponentially with growth in the number of users (e.g., the Internet, the Web, social networking).

• **New collaborative modes, media richness, and virtual worlds.** Today distributed teams in research laboratories, businesses, and education can collaboratively conduct their activities using Internet telephony, videoconferencing, and screen sharing and be “together” in immersive graphic worlds. Scientific work further incorporates shared data repositories, software data-analytic workbenches, and remote instrumentation in collaboratories (Bos, Zimmerman, Olson et al., 2007). The increasing prevalence of broadband networking access (half of American adults now have broadband access at home) has also made possible distributed high-resolution multimedia learning, gaming environments, and participatory media culture contributions. Finally, advances in computer graphics, interactive visualizations, and immersive technologies now provide verisimilitude to the physical world, a window on unseen processes, and support for hypothetical explorations.

## 2.2 A Cyberlearning Infrastructure Based on Knowledge About Learning

How can the potential of cyberlearning be realized? NSF has funded pioneering research and development in learning and teaching technologies for most of its existence. And of course its contributions to the development of the Internet, to Web browsers, to high-performance computing and communications, and to other core enabling technologies of the present global cyberinfrastructure have helped pave the way for these cyberlearning opportunities (The Internet’s Coming of Age, 2001; *A Brief History of NSF and the Internet*, 2003). New technologies follow complex trajectories often supported or thwarted by other technologies, infrastructural issues, competing standards, social systems, political decisions, and customer demands. Vacuum tubes and transistors are good examples: vacuum tubes were initially developed for radios but spurred the development of televisions and mainframe computers. Transistors transformed all these applications and led to completely new opportunities, including portable computing devices. The history of these innovations is littered with failures, dead ends, abandoned standards, and phenomenally creative inventions.

Learning technologies build on these innovations and also need to interface with complex social systems, including families, schools, and political decisionmakers. From early efforts to create electronic books to current efforts to design online courses, initial attempts to use new technologies require extensive trials and refinement before they succeed. Often early designs fail because they do not realize the full potential of the technology, as is typical of early technologies. Often innovations that succeed in one learning context need customization to work in another. In education, we are only now benefiting from advances in scientific understanding of how people learn (Sawyer, 2006), of what constitutes good teaching, and of which tests and indicators validly assess impact or predict future success. Cyberlearning has

tremendous potential right now because we have effective new technologies, increased understanding of learning and instruction, and widespread demand for solutions to educational problems.

A series of NSF and other federally funded contributions specific to learning and education have laid the groundwork for effective research in the area of cyberlearning (Being Fluent with Educational Technology, 1999; Ainsworth et al., 2005; Bransford, Brown & Cocking, 2000; Feurzig, 2006; Pea et al., 2003; Roberts, 1988; Roschelle, Pea, Hoadley et al., 2001; Zia, 2005). Numerous interdisciplinary, multidirectorate NSF programs in the past decade or so have contributed to the opportunity space for new cyberlearning activities. These include the following programs: Collaborative Research on Learning Technologies (CRLT) (Guzdial & Weingarten, 1996; Sabelli & Pea, 2004); Learning and Intelligent Systems (LIS) (Gentner, Linn, Narendra et al., 1995); Knowledge and Distributed Intelligence (KDI); Information Technology Research (ITR) (Cummings & Kiesler, 2007; Sabelli & DiGiano, 2003); the Interagency Educational Research Initiative (IERI), jointly with the U.S. Department of Education and National Institute of Child Health and Human Development, spawned by the President's Council of Advisors on Science and Technology 1997 report; Human and Social Dynamics (HSD); Sciences of Learning Centers (SLC); and the recent Advanced Learning Technologies (ALT) program.

These programs have developed the following successful products:

- Visual programming languages designed for children (DiSessa, 2000; Repenning, 2000; Smith, Cypher & Tesler, 2000)
- Microworlds for learning computational thinking in science, technology, engineering, and mathematics (DiSessa, 2000; Resnick, 1994; White, 1993)
- Intelligent tutoring systems in algebra, geometry, and programming (Koedinger & Corbett, 2006)

- Microcomputer-based laboratories and handheld computing versions of probeware and sensors for capturing and graphing data during scientific inquiry (Linn & Hsi, 2000; Mokros & Tinker, 1987; Resnick, Berg & Eisenberg, 2000; Rogers, Price, Fitzpatrick et al., 2004; Roschelle et al., 2001; Thornton & Sokoloff, 1990; Tinker & Krajcik, 2001)
- Online learning communities for teachers and learners in many subject domains (Barab, Schatz & Scheckler, 2004; Hiltz & Goldman, 2005; Palloff & Pratt, 2005; Pea, Gomez, Edelson et al., 1997; Polman, 2000; Schlager & Fusco, 2003; Shrader, Fishman, Barab et al., 2002; Steinkuehler, Derry, Woods et al., 2002)
- Data visualization environments for examining and understanding complexity in the STEM disciplines (Edelson et al., 1999; Linn et al., 2006; Pallant & Tinker, 2004)
- Scientific inquiry support environments in biology, chemistry, and physics (Blumenfeld, Fishman, Krajcik et al., 2000; Linn, Davis & Bell, 2004; Quintana, Reiser, Davis et al., 2004; Reiser, Tabak, Sandoval et al., 2001; Sandoval & Reiser, 2003)
- Educational robotics (Resnick, Martin, Sargent et al., 1996; Rusk, Resnick, Berg et al., 2007)
- STEM learning games and virtual worlds (Barab, Hay, Barnett et al., 2001; Barab, Thomas, Dodge et al., 2005; Dede, Salzman, Loftin et al., 2000; Nelson, Ketelhut, Clarke et al., 2005).

The previous works exemplify the potential of transformative technologies available from the 1970s to the beginning of the 21st century. These projects provided pioneering contributions in an era of stand-alone and early networked educational microcomputing in classrooms and introduced scientific inquiry incorporating real-time sensor data capture. A new generation of projects has brought to teaching and learning examples of the resounding power of the Internet and Web technologies, educational collaboratories, and interactive scientific visualizations to aid learners in understanding complex topics; online learning communities;

Web-based video learning for teacher professional development; and other advances that have leveraged network infrastructure capabilities. *A new generation of cyberlearning contributions promises greater pervasiveness and mobility, scale, cumulativity, and effectiveness in supporting the learning enterprise from K to gray.*

During the past decade, the sciences of how people learn and the design of technologies for supporting learning, teaching, and education have begun to productively coevolve. The interdisciplinary emphases of many of the aforementioned programs have helped spawn the kinds of productive collaborations that have brought learning scientists together with computer scientists, engineers, interaction designers, subject matter experts, social scientists with varied expertise, designers of assessments, and educators. The National Research Council's influential volumes on *How People Learn* (Bransford et al., 2000) and *Knowing What Students Know* (Pellegrino, Chudowsky & Glaser, 2001) have contributed to a research and partnership environment that is increasingly applying principles of learning and assessment in new learning and teaching technology designs.

The debate over scientific research in education and the U.S. Department of Education's focus in its Institute for Educational Sciences on randomized clinical trials as the gold standard for science have had significant influence. Recently, however, there is also a broad realization that rapidly changing technological environments and new workforce demands (*Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, 2007) call for new metrics and methodologies. The measures of student progress need to align with the skills required in school, the workforce, and life. The methodologies of design experiments and rapid prototyping play important roles in developing transformative advances for STEM learning and teaching, which iteratively adapt new tools to the needs of learning and teaching in the disciplines (Cobb, DiSessa, Lehrer et al., 2003; Design-Based Research Collective, 2003).

Educational research and practice now recognize how much the nature of learning and teaching is shaped by the properties of the systems and contexts in which such activities take place (Bransford et al., 2000; Shonkoff & Phillips, 1998). Researchers have studied teacher preparation, teacher learning, teaching standards, and teacher implementations of innovative curricula (Borko, 2004; Davis, Petish & Smithey, 2006). Investigators have begun to examine the nature of assessments (Heubert & Hauser, 1999); school leadership (Gerard, Bowyer & Linn, in press); and broader relationships between school, home, and community (Duschl, Schweingruber & Shouse, 2007).

As a result of these advances, it is time to strengthen the research programs supporting cyberlearning. These advances signal a new era for the role of technology in education. Whereas prior research has shown benefits for a few classrooms, a single school, or a single topic, we are now poised to conduct investigations in much more complex contexts. It is now possible to draw on more powerful technologies to design curriculum, support teachers, and monitor progress. These factors underscore the importance of funding research on cyberlearning to transform education. Many groups, including the National Mathematics Advisory Panel (*Foundations for success: Report of the National Mathematics Advisory Panel*, 2008) and the Committee on Prospering in the Global Economy of the 21st Century (*Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, 2007) have called for more large-scale, sustained, and systematic research on these opportunities to solve pressing educational problems.



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