# Developing Accessible Cyberinfrastructure-Enabled Knowledge Communities in the National Disability Community: Theory, Practice, and Policy

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Since publication of the Atkins Commission report in 2003, the national scientific community has placed significant emphasis on developing cyberinfrastructure-enabled knowledge communities, which are designed to facilitate enhanced efficiency and collaboration in geographically distributed networks of researchers. This article suggests that the new cyberinfrastructure movement may not fully benefit those participants with disabilities, unless closer attention is paid to legal mandates and universal design principles. Many technology-enhanced learning communities provide geographically distributed collaboration opportunities that expand the inclusion of diverse peoples and help close the digital divide. However, to date, most collaboratory efforts have not emphasized the need for access among people with disabilities nor meeting minimum standards for technological accessibility. To address these concerns, this article reports on two pilot collaboratory studies that explore the role advanced information, communication, and collaboration technologies play in enhancing geographically distributed collaboration among specific research and applied networks within the national disability community. Universal design principles inform the design of the collaboratory and its use and our efforts to ensure access for all. Data for this article come from Web-based surveys, interviews, observations, computer logs, and detailed, mixed-methods accessibility testing. Emerging results suggest that with deliberate and systematic efforts, cyberinfrastructure can be more accessible and generate benefits among persons with disabilities. The authors provide lessons learned and recommendations for future research, policy, law, and practice.

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Many technology-enhanced learning communities provide geographically distributed collaboration opportunities that expand the inclusion of diverse peoples and close the digital divide. The phrase *digital divide* generally refers to the gap between those with access to digital technology, which can serve as a gateway to membership in the information society and greater participation in employment and democratic processes (Strover, 2003, p. 275). Since the publication of the Atkins Commission report in 2003 (Atkins et al., 2003), the national scientific community has placed significant emphasis on developing cyberinfrastructure-enabled knowledge communities designed to facilitate enhanced efficiency and collaboration in geographically distributed networks of researchers. However, to date, most collaboratory efforts have not emphasized the need for full access to the collaboratory infrastructure by people with disabilities nor meeting minimum standards for technological accessibility. Burghstahler (2002) explained that persons with disabilities can, and in a majority of situations do, face a second level of digital divide by being unable to use commonly existing technological tools even if they have access to them.

Although there is tremendous potential for collaboratories and the new cyberinfrastructure movement to transform science with cutting-edge

research opportunities and to provide a model for other forms of geographically distributed collaboration, it may not benefit those participants with disabilities unless closer attention is paid to U.S. legal mandates and to universal design principles. Universal design (UD) refers to the creation of products and environments, as well as practices, programs, and services, that are accessible to and usable by all persons, including individuals with disabilities, without adaptation or specialized design (Center for Universal Design, 2006; Myhill et al., 2007). Universally designed technologies provide for input and interaction in multiple alternative and equally effective ways. In 2004, Congress codified this conception of UD into federal law by passing the Assistive Technology Act, although they did not specifically mandate its use in public or private research (29 U.S.C.A. § 3002[19], 2005).

Furthermore, a primary purpose of the Americans With Disabilities Act of 1990 (ADA) is to remove barriers to the full integration and equal opportunity of people with disabilities in all aspects of U.S. society (Blanck, Hill, Siegel, & Waterstone, 2004). Barriers take many forms and impede not merely physical access (e.g., a hotel room or public restroom) but also access to meaningful communication (e.g., telephone, television, e-mail, or lecture), participation (e.g., in a classroom, boardroom, or parent-teacher or community association meetings), and benefit of programs and services (e.g., enrolling for social security benefits, health care coverage, or college courses; 42 U.S.C. § 12101).

Despite progress, a divide remains. One explanation is the lack of UD principles used by designers and manufacturers of electronic and information technology (Blanck, Hill, Siegel, Waterstone, & Myhill, 2006; National Council on Disability, 2004). The philosophy of UD is distinct from current practices of adaptable and accessible design, and it is important for designers, developers, and content providers to understand the tenets of each. As Myhill and colleagues (2007, p. 12) explained,

> Technologies that are adapted to meet the needs of specific populations, or even individuals, are less desirable than other designs because they can be expensive, time-consuming, and idiosyncratic. Technologies designed to be accessible provide content that can be accessed using assistive technologies, such as screen readers, and are more generally available to a wide audience. However, universally designed technologies are designed to be always accessible and can be used universally without the use of assistive technologies.

To address these concerns, this article reports on two pilot collaboratory studies that explore the role advanced information, communication, and collaboration technologies may play in enhancing geographically distributed collaboration among specific research and applied networks within the national disability community. UD principles and our efforts to ensure access for all inform the design of the pilot collaboratories and their use. In addition, the accessibility of the technologies included for users of assistive technology devices is strongly considered and evaluated.

The first section presents the background to collaboratories and cyberinfrastructure and explores the role cyberinfrastructure could play in closing the digital divide by enhancing diverse geographically distributed participation, regardless of level of education, socioeconomic status, and bandwidth. We explore the implications of legal mandates on the further development and expansion of cyberinfrastructure-enabled knowledge communities. The second section describes two related studies conducted by the Burton Blatt Institute: Centers of Innovation on Disability (BBI) and the Collaboratory on Technology Enhanced Learning Communities (Cotelco) to explore the degree to which a pilot collaboratory may be built that uses UD principles and meets or exceeds federal accessibility standards. We explain the study design, and data collection, which includes Web-based surveys, interviews, observations, computer logs, and detailed, mixed-methods accessibility testing. In the third section, we present emerging findings from the pilot studies, which suggest that cyberinfrastructure may be made more accessible, generate benefits among persons with disabilities, and provide lessons learned for policy and practice. Finally, in the last section, we provide recommendations for the research, law, and science going forward.

## CYBERINFRASTRUCTURE AND OPPORTUNITIES FOR CLOSING THE DIGITAL DIVIDE

### Background to Collaboratories and Cyberinfrastructure

In 1993, the U.S. National Research Council published a landmark report titled *National Collaboratories,* which articulated a vision of how information and communication technologies could be brought to bear on the challenges of facilitating scientific collaboration among geographically distributed scientists (National Research Council, 1993). The report built on earlier work by William

Wulf and others from a workshop in 1989 sponsored by the National Science Foundation (NSF) and identified the increasing demands for scientists to collaborate with colleagues located in research laboratories all over the world. Wulf (1989, p. 7) called a collaboratory a "center without walls," and he urged the nation's researchers to use modern information and communication technologies for closely coupled distributed collaboration.

Early examples of fields taking advantage of collaboratories include the space physics community (Olson et al., 1998), oceanographers, and molecular biology (National Research Council, 1993). Each of these scientific communities immediately benefits, in various ways, from its researchers being better networked with other researchers (Finholt, 2002a, 2002b). An NSF-funded project at the University of Michigan, called the Science of Collaboratories, studied these collaboratories (www.scienceofcollaboratories.org) and identified common elements to predict success and failure of these initiatives. An important observation was that those collaboratories that paid significant attention to the social dimensions—not just the technological—had a higher likelihood of success.

Although the collaboratory movement started at the NSF, other federal agencies picked up the baton, and the National Institutes of Health, National Aeronautics and Space Administration, and others recognized the need for increased collaboration among their scientists as well (Finholt, 2001, 2002a, 2002b). However, in many ways, the collaboratory movement took on the patina of elitism. It was seen that only high-profile scientists could access and participate in collaboratories (Cogburn, 2003, 2005). This characterization is the opposite of what many of the early collaboratory developers had hoped would emerge through the "distributed intelligence" capabilities of a collaboratory (Finholt, 2002b, p. 75). They believed the increased use of information and communication technologies could allow for greater interaction between scientists at nonelite institutions with scientists at elite institutions (Finholt, 2002b).

## Broadening the Reach of Collaboratories to Close the Digital Divide

In 2003, Dan Atkins was asked by the NSF to chair a Blue Ribbon panel to examine the status of collaboratories and to explore ways to broaden the concept to include social and behavioral scientists and beyond. This panel created a new term, *cyberinfrastructure,* to express the desire that collabor-

atory infrastructure become more widespread and make a greater impact on science, technology, and national competitiveness by involving larger and more dispersed communities in geographically distributed collaboration (Atkins, 2006).

Although the *Atkins Commission Report,* as the document has become known, broadens the conception of collaboratories to encompass larger and more diverse groups of scientists, others, such as our work in Cotelco, have pushed the boundaries of this concept further. Within Cotelco, we have evolved the collaboratory concept to include larger groups of geographically distributed social actors, in at least three ways: (a) learning environments, such as our Global Graduate Seminar on Globalization and the Information Society (taught in real-time between three universities in South Africa and three in the United States; Cogburn & Levinson, 2003; Cogburn, Levinson, Atkins, & Weilbut, 2001); (b) policy environments and transnational nongovernmental organizations, such as our collaboratory for the Task Force on the World Summit on the Information Society organized by the World Federation of United Nations Associations; and (c) distributed groups of social and behavioral scientists. These projects used collaboratory approaches to enhance the participation of diverse social actors in activities important to them, such as global policy processes or educational and scientific activities.

Although these previous projects have advanced our understanding of how to enhance access to geographically distributed collaborations for persons from developing countries and from nongovernmental and community-based organizations, one critical area has been overlooked, not just in these projects but also in the broader collaboratory and cyberinfrastructure movement: enhancing access for people with differing levels of physical, sensory, and intellectual abilities. This aspect of the digital divide is one that receives far less attention than the dominant understanding of the concept, which focuses on access to telecommunications, the Internet, and the World Wide Web (see, e.g., National Telecommunications and Information Agency, 1999).

## Legal Mandates for Accessible Technology

The rise of the disability civil rights movement, bolstered by passage of federal and state antidiscrimination laws, coincided with technological advances that have enhanced the inclusion and equal participation of people with disabilities (Klein et al., 2003). Although not contemplated by those

who envisioned and drafted the ADA in the late 1980s, the accessibility of the Internet is implicated significantly by ADA Title III requirements for the services of public accommodations (e.g., department stores, cinemas, restaurants, private colleges) and the Title II requirements for state and local government bodies, including public colleges. Federal agencies, federal contractors, and technology purchased for their use are subject to Section 508 of the Rehabilitation Act of 1973 (Myhill et al., 2007). The Hearing Aid Compatibility Act of 1988 (HAC Act) requires telephone hearing aid compatibility with telecommunication devices (47 C.F.R. Part 68).

Although the U.S. Circuit Courts of Appeals are divided on the extent to which public accommodations offering their goods and services via the Internet are subject to the ADA, as the matter continues to be litigated, the majority view suggests that these businesses cannot exclude people with disabilities from their Web services, if the Web has a nexus with a business that has a permanent physical location (Blanck et al., 2004; Sliwa, 2006). Similarly, in 2004, the Attorney General's Office of the State of New York arrived at two Assurance of Discontinuance agreements with Ramada Franchise Systems and Priceline.com to correct the alleged inaccessibility of their online services, such as making hotel reservations for consumers with visual impairments (Attorney General of the State of New York Internet Bureau, 2004a, 2004b). Retailers in the United Kingdom face similar mandates and challenges (McCue, 2006).

Project Civic Access, a program of the U.S. Department of Justice, promotes voluntary review of ADA compliance of the programs and services offered by cities, counties, towns, and villages (U.S. Department of Justice, 2006a). For instance, the Davies County Library system (Kentucky) agreed, in part, to (a) establish and implement a Web site accessibility policy, (b) ensure that all Web site content is accessible, and (c) regularly "(at least annually) enlist people with disabilities to test its pages for ease of use" (U.S. Department of Justice, 2006b). Presently, BBI in collaboration with the DBTAC: Southeast ADA Center (Southeast DBTAC) is investigating whether Title II entities are carrying out their obligations under Project Civic Access.

ADA Title IV charges the Federal Communications Commission (FCC) with ensuring the accessibility and availability of telecommunications such as through telephone and video relay services for people with vision and hearing impairments (47 U.S.C. § 225). Access to telecommunications is being revisited since the hurricanes that struck the Gulf Coast in August 2006 left tens of thousands of people with disabilities without adequate means to receive emergency information and call for assistance (Heppner, 2006; National Council on Disability, 2006). Providers of emergency information who intend to protect life, health, and property, such as may be threatened by tornadoes, hurricanes, tidal waves, earthquakes, widespread fires, toxic gas discharge, and civil disorder, must ensure the accessibility of broadcasts that interrupt regular programming (47 C.F.R. § 79.2).

Mandatory minimum requirements for telecommunication providers entail "us[ing] a system for incoming emergency calls that, at a minimum, automatically and immediately transfers the caller to an appropriate Public Safety Answering Point." Moreover, communications assistants (CAs), formally known as TDD (i.e., telecommunications device for the deaf) operators, who are employed by telephone relay services providers, are required to "be sufficiently trained to effectively meet the specialized communications needs of individuals with hearing and speech disabilities" (47 C.F.R. § 64.604(a)(1)(iv)). CAs must be "able to interpret effectively, accurately, and impartially, both receptively and expressively, using any necessary specialized vocabulary" (47 C.F.R. § 64.604(a)(1)(iv)). FCC rules enforcing the HCA Act require phones to (a) produce a magnetic field of sufficient strength and quality to permit coupling with hearing aids that contain telecoils and (b) provide an adequate range of volume (47 C.F.R. §§ 68.316–.317)). However, at present, Internet-based voice-over-Internet protocol does not fall under FCC regulation (FCC, 2006).

Section 508 of the Rehabilitation Act as amended in 1998 requires federal government agencies to purchase and use accessible electronic and information technology for the benefit of federal staff and consumers with disabilities that is comparable to the access and use by people without disabilities (36 C.F.R. § 1194.1). As a major purchaser of technology, software and hardware manufacturers have seen the financial benefit of redesigning or updating their products and marketing them specifically to federal agencies (Klein et al., 2003). In line with these positive developments, the Section 508 Standards for Electronic and Information Technology provide direction to these manufacturers as well as to Web site designers and other users of technology (Klein et al., 2003). A variety of alternative guidelines are widely available, some with notable market sector, national, or international reception (Klein et al., 2003; Myhill et al.,

2007; University of Minnesota, 2005). Significant among these are the Web Accessibility Initiative guidelines promulgated by the W3C World Wide Web Consortium (see http://www.w3.org/) and regarded internationally as the premier standard (W3C, 2006).

Because they are most implicated by these guidelines, the communication technologies of primary focus to this study are software applications, operating systems, Web-based information and applications, and telecommunications, video, and multimedia products under the 508 Standards (36 C.F.R §§ 1194.21–24). For instance, the Elluminate Live application (i.e., the real-time, virtual interface collaborative application used in this study) may require "caption decoder circuitry which appropriately receives, decodes, and displays closed captions from broadcast, cable, videotape, and DVD signals" (36 C.F.R § 1194.24(a)), "a standard non-acoustic connection point for TTYs," and "[m]icrophones . . . capable of being turned on and off to allow the user to intermix speech with TTY use" (36 C.F.R § 1194.23(a)).

Computers and assistive technology play a central role in the lives of many people with disabilities, especially since the passage of the ADA (Myhill et al., 2007). Voice-recognition software aids people with limited use of their hands and arms (fine and gross motor skills, respectively) to interface with a computer without the use of a keyboard or mouse (Samant, Myhill, & Blanck, 2006). Extra wide or dual monitors permit those requiring large print to increase the size of text, graphics, and computer applications while maintaining the full application in view (Ross, 2006; Thompson, 2005). The Assistive Technology Act of 1998 was passed with the objective of using state and national initiatives to increase the availability of funding for assistive technology programs (National Assistive Technology Technical Assistance Partnership, 1999). All 50 states receive federal funding to run assistive technology programs that offer a range of services such as assistive technology device demonstrations, loans, assistive technology exchange and reutilization services, and training and technical assistance at dedicated sites (National Assistive Technology Technical Assistance Partnership, 1999; Sobie, 2003).

Despite the promise of remote access and collaboration from multiple locations, people with disabilities face disadvantages in possessing the tools required to connect to these geographically distributed collaborations, at work and home. One-third of full-time employees with disabilities, compared with one half of those without disabilities, use computers on the job (Schur & Kruse, 2002). People with disabilities altogether continue to (a) live in households with computers at significantly lower rates (39.7%) than people without disabilities (63.6%), (b) live in households with Internet access at significantly lower rates (33.0%) than people without disabilities (59.1%), and (c) use the Internet at home at significantly lower rates (26.4%) than people without disabilities (54.4%; Dobransky & Hargittai, 2006).

UD principles presently assist engineers using computer-aided design of medical technology (Nighswonger, 2001). UD principles are evolving into government, industry, building, product, environmental design, curriculum, and educational standards (Armstrong, 2005; Beecher & Paquet, 2005; Bowe, 2000; Casper & Leuchovius, 2005; CEN/CENELEC, 2002; Marsden, Meehan, & Calkins, 2001). Around the globe, businesses and corporations (e.g., Fuji, Toyota, Panasonic) are applying UD principles for their good economic sense "of paying attention to the needs of . . . user groups" (Marcus, 2003; Saito, 2006). Although UD principles are being applied to practices, programs, and services in education, employment, and the consumer marketplace, their limited use in the design and creation of information and communication technology services and products remains a challenging barrier to eliminating the digital divide faced by persons with disabilities (Blanck et al., 2006; National Council on Disability, 2004).

## DESIGNING, DEVELOPING, AND USING ACCESSIBLE COLLABORATORIES

### Research Questions

In 2006, Cotelco and BBI began the process of envisioning and designing two new pilot collaboratories to address the unique needs of scholars, researchers, advocates, and people with disabilities partnering in cutting-edge disability research, policy development, outreach, and dissemination. These collaboratories take lessons learned from the scientific collaboratories and provide a virtual community with real-time communication capabilities and dynamic project-specific Web portals permitting, in part, extensive digital libraries and asynchronous information sharing.

We asked two primary research questions: (a) To what degree can accessible pilot cyberinfrastructure be implemented within the national disability community? and (b) How is the cyberinfrastructure practically used? When investigating the use of cyberinfrastructure, we looked essentially at two different aspects of usage: (a) setting up and

designing the content management system and collaboratory for optimal accessibility and effectiveness and (b) how participants and collaborators used its content and features. Both of these pilot collaboratories share a common simultaneous mixed-methods research design with several other Cotelco collaboratory projects, allowing for in-depth case studies but also, in the larger project, for extensive cross-case analysis.

**Participants in the Study/Case Study Sites**

In choosing the participants and sites for the study, we wanted to identify geographically distributed networks within the national disability community, both researchers and practitioners, that we assumed would benefit from increased opportunities for collaboration. As such, we were able to draw a purposeful sample for the study by identifying two networks of disability experts collaborating with the BBI on two distinct projects. The first site is organized around a geographically distributed network of policy experts working in the Southeast DBTAC, and the second is organized around a geographically distributed network of social and behavioral science researchers collaborating on a multi-institutional research project.

*The First Case: Southeast DBTAC Pilot Collaboratory*

The first pilot collaboratory was focused on supporting the Southeast DBTAC and its geographically distributed regional affiliates covering eight states.[1] The Southeast DBTAC is 1 of 10 regional centers across the United States funded by the National Institute for Disability and Rehabilitation Research (NIDRR) "to provide information, training, and technical assistance to employers, people with disabilities, and other entities with responsibilities under the ADA" (ADA & IT Technical Assistance Centers, 2006).

*The Second Case: Employer Demand Collaboratory*

The second pilot collaboratory is focused on supporting the geographically distributed 27-member research team on the 5-year Demand-Side Employment Placement Models project funded by the NIDRR. These researchers collaborate on nine large-scale studies from their respective locations

at six partnering universities[2] and the headquarters of a national small business lending agency. Together, the projects will develop, identify, and evaluate employment demand-side models and translate findings into practical tools for businesses in different market sectors to improve employment outcomes for people with disabilities (Burton Blatt Institute: Centers of Innovation on Disability, 2006). As described above, these two pilot collaboratories are part of a larger study conducted by Cotelco to make cross-case comparisons and contrasts between various pilot collaboratory approaches. Design, implementation, and testing of these collaboratories will enable us to learn more about the barriers to the social and economic independence of people with disabilities and enable all relevant stakeholders to enhance their capacity for and accessibility to distance learning. In the next section, we describe the common research design developed for both of these pilot collaboratories.

**Method**

The design for these two studies takes a dominant qualitative approach, with a less dominant quantitative component. Creswell (2002) refers to this as a QUAL+quant design, meaning the study is primarily qualitative in nature, which allows us to write thick description analyses of each case, with quantitative elements to assist with comparisons and limited generalizability. The two populations were purposively chosen based on their characteristics. For example, the Southeast DBTAC is a heterogeneous network of disability advocates from independent living centers; vocational rehabilitation programs and service agencies; local, state, and federal agencies; telecommunications relay services; and higher education, among others. In choosing to build and study a pilot collaboratory with this group, we aimed to explore collaboratory approaches in a disability policy community geographically distributed across eight southeastern states.

The Employer Demand project was selected because it contains a relatively large number of geographically distributed social science, legal, and behavioral science researchers on multiple university campuses working together on interrelated research projects. The Employer Demand Collaboratory is closer to the traditional scientific under-

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[1] These are Georgia, Florida, North Carolina, South Carolina, Tennessee, Kentucky, Mississippi, and Alabama.

[2] These are Syracuse University, the University of Iowa, West Virginia University, the University of Illinois at Urbana-Champaign, Rutgers University, and the University of California at San Francisco.

standing of a collaboratory, whereas the Southeast DBTAC collaboratory sought to understand the potential of collaboratory approaches to be extended to larger communities and to help bridge the digital divide.

## Baseline Data Collection

After choosing the participants for the two case studies, we began to collect baseline data on the selected populations. We used three techniques to collect baseline data: (a) interviews with the key project leaders, (b) secondary data collection of key documents and Web sites, and (c) a Web-based survey of all collaboratory participants. The interviews were central to understanding the background to each of the networks and the goals and structure of the project. We also used these interviews to help identify the various tasks and roles that would be ongoing within the two projects.

The survey contains 39 questions, primarily closed-ended, and a few open-ended questions (see the Appendix for sample survey questions). More important, the survey also collects network data (i.e., collaboratory user data) on existing communication and collaboration patterns within the two networks (Wasserman & Faust, 1994). Other items on the survey measure demographic variables as well as trust, experience with information and communications technologies, and measures of social capital (i.e., interpersonal connections and goodwill generated through social networks; Adler & Kwon, 2002; Portes, 1998). This combined qualitative and quantitative data collection allows us to learn a great deal about the collaboratory participants and provides a baseline from which we will measure any changes over time on key variables.

## Rapid Prototype Design and Development

Following the baseline data collection, we began to assemble the basic elements of the prototype collaboratory infrastructure, based on the NSF-funded Science of Collaboratories (SOC) project (see www.scienceofcollaboratories.org). The SOC project identified three elements seen as common within most of the geographically distributed collaborations they studied: (a) people-to-people, (b) people-to-resources, and (c) people-to-facilities. Each collaboratory element should be supported by specific sociotechnical infrastructure. Following Finholt (2002b, p. 340), we recognize that "scientists are principally interested in conducting science, not in becoming computer scientists." Therefore, various components of the collaboratory need

**TABLE 1. Universal design principles**

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| Equitable use | Does not disadvantage or stigmatize any group of users |
| Flexibility in use | Accommodates a wide range of individual preferences and abilities |
| Simple, intuitive use | Easy to understand, regardless of experience, knowledge, language skills, or current concentration level |
| Perceptible information | Communicates necessary information effectively regardless of ambient conditions or sensory abilities |
| Tolerance for error | Minimizes hazards and the adverse consequences of accidental or unintended actions |
| Low physical effort | Efficiently and comfortably used with a minimum of fatigue |
| Size and space for approach and use | Appropriate size and space for approach, reach, manipulation, and use, regardless of body size, posture, or mobility |

to be accessible via the Web, require minimal system configuration, be cross-platform and low-bandwidth intensive, and, where possible, not require the installation of new software applications.

However, given our goal of exploring the degree to which cyberinfrastructure may be made more accessible to people with various kinds of abilities, we went a step further and designed the prototype collaboratory infrastructure for our two projects in light of UD principles. Table 1 presents the seven core UD principles (Center for Universal Design, 2006).

UD principles play an important role in our research methods and are consistent with the paradigm that disability is a social construct relative to the built environment, rather than inherent in the person (Blanck, Adya, Myhill, Samant, & Chen, 2007). UD principles were joined by principles drawn from the literature on computer-supported cooperative work, computer-supported collaborative learning, and management literature on virtual teams to design and assemble the prototype cyberinfrastructure for the projects.

The technologies used in project collaboratories are not limited to specific software or hardware. After all, a collaboratory is a laboratory without walls, and the technologies selected are the researchers' preferred means of enabling the geographically distributed project team members to effectively communicate, share, and have equal access to important and relevant information and collaborate. That said, several technologies notably are used: the Internet, Web browsers, and screen readers to access and interface with the In-

ternet; a content management system; e-mail; and a Web conferencing application that integrates voice- and video-over-Internet protocol (IP) with instant messaging (IM), application sharing, an interactive whiteboard, and digital recording. Web conferencing represents a collection of information and communication tools that enable multiple users to interact and collaborate in synchronous, real-time meetings using high-speed broadband networks. By and large, the technologies noted above are software applications. Each of these technologies has its own inherent properties with varying levels of accessibility and will be described below in relation to their role in the collaboratory.

## Implementing the Prototype Collaboratory

As we moved into this phase of the project, the research team expanded and began to meet weekly. The expanded team consisted of the authors, doctoral and graduate students in information science and technology, information management, telecommunications and network management, rehabilitation counseling, special education, and BBI-affiliated researchers with backgrounds in law, instructional design, and engineering. The team, themselves operating as a collaboratory, used Web conferencing to hold weekly meetings with three purposes: (a) design the project and later the pilot collaboratory infrastructure; (b) review the week's progress toward building the pilot collaboratories for the two project groups, including problem solving and goal setting; and (c) apply the collaboratory technologies in these weekly meetings as a means of communicating and evaluating the utility and flexibility of the technology.

Between these weekly meetings, researchers engaged in three tasks with the collaboratory technologies. One team assessed the accessibility of the Elluminate application. A second team built the project Web portals. A third team assessed the accessibility of the emerging Web portals and provided feedback to the research team for weekly discussion. In turn, weekly meetings would recommend courses of action for the portal designers to correct identified inaccessibility and improve usability.

*People-to-people.* To facilitate the people-to-people collaboration, we developed a Listserv for the networks, using Listserv software. Listservs and mailing lists are in practice one of the most basic asynchronous tools to support geographically distributed collaboration (Handel & Herbsleb, 2002). They allow both the project coordinators and the network participants to be able to communicate frequently with each other. In addition, we introduced presence awareness packages (i.e., AOL and Yahoo IM) into the project team, with plans to gradually roll them out to the rest of the networks. IM generally conveys text input in real-time between two or more people using computers connected through the Internet. These presence awareness systems and group chat applications allow for rapid person-to-person synchronous interactions and facilitate scheduling and informal social interactions necessary for the growth of identity and trust within the distributed networks (Handel & Herbsleb, 2002).

*People-to-resources.* Geographically distributed collaborations, like their co-located counterparts, require access to shared documents, data sets, articles, and other meeting artifacts. To facilitate this aspect of the cyberinfrastructure, we designed and developed a unique portal for each project (see http://seadata.cotelco.net and http://bbi-empdemand.syr.edu). The Web portals are based on a class of software application called a content management system (CMS). A CMS is a software application "for organizing and facilitating collaborative creation of documents and other content . . . [and] is sometimes a web application used for managing websites and web content. . . ." (Wikipedia, 2006). There are two main types of CMSs, open source and commercial, each with inherent strengths and weaknesses having implications for accessibility. In our projects, we designed the portals using an open source CMS called DotNetNuke (see http://www.dotnetnuke.com). Cotelco has used the DotNetNuke application framework to design CMS portals for a variety of projects concerned with ensuring successful geographically distributed participation, regardless of such factors as socioeconomic status, education, and bandwidth. Observing Cotelco's success in this respect, we selected the DotNetNuke application to better understand how it might facilitate greater and easier participation for persons with disabilities.

*People-to-facilities.* Finally, to create an environment for teams and networks within the project to meet regularly, regardless of where they are located physically; to share PowerPoint slides, Web sites, and data; and to use voice- and video-over IP, we integrated Web conferencing into the prototype cyberinfrastructure. Specifically, we integrated our Web conferencing server, built on technology licensed from Elluminate *Live!* (a private Canadian firm), into the portal for each pilot collaboratory. Elluminate *Live!* is a real-time, virtual interface that brings geographically distributed individ-

uals together for interactive live meetings, teaching, or presentations using, for instance, multimedia, application sharing, whiteboards, and small-group discussion (Elluminate, 2006b). Elluminate was chosen because of its cross-platform functionality, its compliance with Section 508 of the Rehabilitation Act, and its conformance with W3C's Web Accessibility Initiative (WAI) guidelines as well as its commitment to promote accessibility for persons with disabilities (Cogburn & Kurup, 2006; Elluminate, 2006a).

*Evaluating the Accessibility of the Web Portals*

Common issues with CMS accessibility include whether (a) navigation is possible without a mouse, (b) content is accessible by a screen reader, and (c) source code can be edited to overcome barriers (National Center on Disability & Access to Education, 2006). CMS Matrix (n.d.) provides comprehensive user comparisons of more than 130 factors for more than 650 different CMSs. One interoperability factor compares whether CMSs meet the WAI standards, however, in only very simplistic terms: "yes" indicates compliant, "limited" indicates compliance, or "no" indicates not compliant.

Web portal accessibility was evaluated using the following tools, mainly designed to aid manual testing of Web sites: (a) the Accessibility Toolbar developed by the Accessible Information Solutions team of Vision Australia (2006) using the Internet Explorer browser,[3] (b) the User mode in the Opera Browser, and (3) the Mozilla/Firefox browser Accessibility Extension developed by the Illinois Center for Instructional Technology Accessibility (2005) at the University of Illinois at Urbana-Champaign.[4] Manual tests included tabbed browsing,[5] turning off images, turning off styling elements, color contrast, and text size manipulation. In addition, the Web portals were tested using the widely used JAWS screen reader by Freedom Scientific (see http://www.freedomscientific.com/fs_products/software_jaws.asp).

The researchers evaluated the Web portal in a novel manner, by applying the principles of universal design to the user's experience in light of Section 508 standards. Evaluating the accessibility of the Web portals was informed by the first six principles of UD, which apply as follows:

1. Does the portal accommodate a wide range of individual preferences and abilities?
2. Is it easy to understand, regardless of experience, knowledge, language skills, or current concentration level?
3. Does it communicate necessary information effectively regardless of ambient conditions or sensory abilities?
4. Does it minimize the adverse consequences of accidental or unintended actions?
5. Can the tool be efficiently and comfortably used with a minimum of fatigue?
6. Does the portal disadvantage or stigmatize (perhaps draw stigmatizing attention to) any group of users?

Five researchers, knowledgeable of the 508 standards, manipulated the Web portal with the tools noted above and took anecdotal notes of their experiences informed by applying the UD principles. The researchers then compared their findings, as summarized in the Preliminary Results/Findings section below.

*Evaluating the Accessibility of the Elluminate Application*

Elluminate touts its *Live!* application as "leaving no user behind." This includes features that support the mandates of the ADA as well as Section 508 compliance. For instance, Elluminate's self-identified accessibility features include, in part, (a) multiple streams of closed captioning, (b) short-cut key menu and dialog activation, (c) scalability of visual content, (d) auditory notifications, and (5) a Java Accessibility Bridge for screen readers (Elluminate, 2006a). The project team used the weekly Web conferences as opportunities to observe, practice with, and challenge the application's accessibility features, applying UD principles and knowledge of 508, when discussing Elluminate's strengths and shortcomings. Each weekly meeting was electronically archived to provide an anecdotal record of these discussions, which are summarized in the next section.

**PRELIMINARY RESULTS/FINDINGS**

As discussed, two primary research questions were asked in this study: (a) To what degree can accessible pilot cyberinfrastructure be implemented within the national disability community? and

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[3] Includes commonly used tools such as The Wave and Cynthia Says.

[4] Manual testing was extended to other common Web browsers, such as Netscape Navigator, SeaMonkey, Flock, and Lynx using the Lynx Viewer (see http://www.delorie.com/web/lynxview.html).

[5] Tabbed browsing, that is, tabbing through the Web page, is a method of visually tracking the path of a screen reader, which helps to identify inaccessible graphics, drop-down menus, and tables, among others (Klein et al., 2003).

(b) How is this cyberinfrastructure practically used? This section presents results of our study, using both of these questions to guide the presentation of the findings. The communication technologies of primary focus to this article are those most implicated by accessibility guidelines, namely, software applications, Web-based information and applications, and telecommunications, video, and multimedia products. This is because persons with vision, hearing, fine motor, or cognitive impairments and learning or attention difficulties experience the greatest barriers to effective communication when technologies demand multisensory interaction (e.g., unimpaired hearing, vision, attention, and fine motor skills) or permit limited forms of input/interaction (e.g., speech without closed captioning or mouse without keyboard access; Klein et al., 2003). In contrast, applying UD principles to the ways in which we use technology and the technologies we choose to use provides for input and interaction in multiple alternative and equally effective ways (e.g., keyboard, mouse, or voice input; visual graphic or text output; Myhill et al., 2007).

**Developing Accessible Pilot Collaboratories**

To answer the first research question, we applied UD principles to an evaluation of each major technology used in the pilot collaboratory infrastructure developed for the geographically distributed communities under examination. Because both communities are using the same CMS for their Web portals and the same Web conferencing application for their meetings, we do not distinguish the findings with respect to these tools. We reference Section 508 accessibility standards when providing specific examples of accessibility and inaccessibility.

*Accessibility of the Web Portals*

*Accommodates a wide range of individual preferences/abilities.* Persons with significant visual impairments or blindness have some of the greatest challenges when accessing the Web, a highly visual experience. Individuals with reading or cognitive impairments may be similarly disadvantaged. Screen reader applications provide an interface with the Web by reading aloud the text of the Web page primarily in the order in which the content appears in the code. Web page creation applications, however, typically are aimed to create the visual representation without a deeper understanding of the complete functioning of HTML structural elements for screen reader navigation

or a natural order of presenting information (Klein et al., 2003).

HTML tables used for the sole purpose of appearance (e.g., content layout and visual presentation), and not for the strict purposes of presenting tabulated data, can pose severe difficulties for users relying on the ordering in code for navigation (Klein et al., 2003). It may be assumed that a sighted user would, just by virtue of the formatting, scroll to the main text without being forced to go through nonessential content (e.g., logos, search boxes). However, a device such as a screen reader scans text in the order in which it appears in the actual code. Using a table for the visual representation of the page does a disservice to people using such assistive technology, especially if the order in which content is inserted in different table cells makes sense only in its visual representation in a browser and does not flow logically as linear text within the code. Trying to accommodate this concern while setting up the CMS affects either the number of template panes the user can implement or the location of essential content.

Cascading style sheets (CSSs) are an excellent tool to assign positioning and visual quality information to textual data, thus determining how it is viewed by a browser irrespective of its hierarchical place in the code (Klein et al., 2003; W3C, 2000). This facilitates logical ordering of information in the actual code while maintaining the desired visual effect on the Web page. In part, the CMS limited the Web portal designer's flexibility to efficiently implement designer-defined CSSs for greater accessibility. Moreover, while permitting lay users to add and structure content, the CMS did so at the expense of greater manual coding flexibility. For instance, the CMS provides the user with a selection of design templates that are precoded and not available for user manipulation. These templates, essentially created for the benefit of nontechnical users, allow the addition of content in different areas of the Web page (e.g., navigation pane, main body) without worrying about its layout or underlying markup. Unfortunately, the template code uses built-in tables for layout and design without allowing the user to change this basic format. These tables also have a predetermined order in the coding template, which the screen reader will follow.

In addition, the CMS included JavaScript, which permits Web pages to have dynamic content such as pop-up menus and rollovers. Some screen readers, such as JAWS, have special modes to read JavaScript but do not perfectly interpret all such features. Other screen readers cannot interpret

JavaScript at all. When JavaScript cannot be interpreted, essential content conveyed by the Script will be skipped over as nonexistent. The CMS supported Web links and graphic images built using text or alternative text and were readable by the screen reader. The portals also supported tabbed browsing, color contrast adjustment, and access keys to jump to the site map (Alt+S) and main content (Alt+C), for instance. The text size was found to be as adjustable as the browser would permit (e.g., significant range in Mozilla/Firefox and Opera, limited range in Internet Explorer).

*Easy to understand.* The Web portals provide content that is visually organized well, meaningful link tabs (e.g., Discussions, Events, Projects), and graphics with self-explanatory alternative text tags. After logging in to the portal as a registered user, many more panes and text hyperlinks become available in the CMS to provide a user with opportunities to edit, rearrange, and add to the portal's content. For the user with a disability, the additional content, if not coded while keeping accessibility issues such as screen reader navigation in mind, will pose additional barriers to successful navigation of core content and will cause possible frustration when making edits.

*Effectively communicates necessary information.* Most Web pages have main headings followed by subheadings and subtopics. HTML coding facilitates the use of header elements, which mark up the hierarchical ranking of content headings. Header elements further facilitate people using senses other than sight to navigate a Web site by distinguishing the comparative level of headers. The Web portals initially contained minimal usage of header elements. A sighted user can make out the difference between the heading levels through formatting features (e.g., all caps, italics, bold, underlined, font size). Someone relying solely on a screen reader, however, will be unable to identify the heading structure on the page on the basis of visual formatting.

Sophisticated screen readers such as JAWS interpret most HTML coding elements, such as headers, thereby increasing navigation efficiency by allowing users to understand not just the text but also its purpose on the Web page. By using appropriate commands, a screen reader user can navigate directly to the different heading levels (e.g., pressing the H key will take the cursor to header level 1, commonly the main page title). Many accessibility toolbars also provide a header navigation feature. Hence, like a clear title that orients the reader to essential content, header elements orient the user to pick and choose what he or she

wants to read. However, the CMS does not provide the user with complete flexibility to incorporate a top-down heading structure by using HTML markup to designate any desired block of text as a heading. It offers building blocks to create the main title of the page or site and a subheading but limited user control beyond that.

Essential information consistently was presented in text (or clear alternative text) for graphics. In addition, content appeared in high contrast to its background: (a) Employer Demand (i.e., dark blue or black text on a solid white background, white or red text on a solid black background) and (b) Southeast DBTAC (i.e., dark blue or red text on a solid white background, white on a solid blue background).

*Minimizes adverse consequences of accidental actions.* Browsers commonly minimize the adverse consequences of accidentally activating a link by providing a Back button. This is especially beneficial for someone with fine motor impairments that cause mouse guidance to be inaccurate. The similar function of Sticky Keys (a Microsoft operating system feature), which permits the user to adjust the amount or length of pressure necessary to activate a button or key, assists people with varying fine motor difficulties. Both of these functions were compatible with the CMS.

*Efficiently and comfortably usable with minimum fatigue.* Voice recognition inputs and screen reader outputs, for instance, as assistive technologies, attempt to supplement the existing interface for people with disabilities. This is in contrast to the purpose of applying UD principles when designing the interface for effective use by all people without the need for an assistive technology. As a supplementary tool, assistive technology devices frequently add an element of work for the user with a disability that a user without a disability does not require. By virtue of this extra effort, efficiency can be diminished or fatigue hastened. CMSs are not yet designed with UD principles as a foundation.

*Avoids posing disadvantages or creating stigma for users.* Distinguishable from Web pages with multiple moving or flashing graphics, lengthy text, or excessive numbers of hyperlinks, the CMS permitted the project team the flexibility to meaningfully limit and select content for the portals. Not merely for persons using a screen reader or tabbed browsing, avoiding excess motion and content is beneficial to persons with attention deficit disorder and learning disabilities, who easily may become distracted or confused by these factors (Ellison, 2002; Learning Disabilities Association of

Minnesota, 2007). Flashing graphics similarly pose the concern of stimulating seizure in a user with a photosensitive seizure disorder (Epilepsy Action, 2007). However, as frequently noted, persons with significant visual impairments are most likely to be disadvantaged by Web portal content, arrangement, presentation, or reliance that requires average visual acuity.

The inability of a person with a disability to meaningfully participate in activities with persons who do not have disabilities historically and presently causes unnecessary stigmatization. When a technology is designed for the user without a disability, it assumes the fault is in the user with an impairment. UD embraces the concept that when a technology is designed for equivalent use by all people, regardless of disability, fault resides not in the user but in the technologies designed only for users without disabilities in mind.

### Accessibility of the Web Conference Meetings

*Accommodates a wide range of individual preferences/abilities.* The Web conference meetings are dynamic interactive experiences with simultaneous multiple inputs and outputs from geographically distributed virtual attendees. The Web conference tool supports multiple forms of input and output (e.g., instant group chat, voice- and video-over IP, interactive application sharing and whiteboard) and manually inputs transcription for real-time closed captioning. The tool also has a digital recording capacity that the researchers used to record the Web conference meetings for archive and later review.

For a person with a significant hearing impairment, all interactions are accessible except the voice-over IP. Real-time closed captioning, such as by simultaneous and highly accurate voice recognition, is becoming available where the software has been trained to recognize the specific voice. Presently, this is beyond the capacity of the Web conference tool. Alternately, we found that a skilled transcriptionist could input accurate transcription that the tool makes available through its closed captioning option with minor delay, much less than awaiting response to a group chat question. However, if the closed captioning is not created simultaneously during the meeting (and thus not recorded), when a person with a significant hearing impairment reviews the archived digital record, captioning of the voice-over IP communication will be absent and cannot be added after the fact.

Greater challenges arose for persons with sig-

nificant visual impairments who use screen readers to access the content of windows-based applications and Web browsers. The screen reader does not alert the user to group chat messages appearing and is not able to access information attendees display on the whiteboard because the whiteboard is a graphical rather than textual interface. Although text-based, shared applications generally are accessible to a screen reader, it is unclear how efficient this process would be as an attendee is talking through points (e.g., data) in the application. Simultaneous voice output from both voice-over IP and the screen reader produces interference. Similarly for the user of voice recognition software, competing voices preclude effective participation. Together, these challenges for the screen reader may mitigate its use, thus limiting the user with significant visual impairments to voice-over IP and no other outputs.

*Easy to understand.* Web conferences are dynamic interactive experiences, with multiple attendees potentially providing simultaneous inputs. For persons with attention deficit disorder or learning disabilities susceptible to overstimulation, this may interfere with comprehension and effective interaction. For instance, one user may benefit from the ability to hear the current speaker, who is pointing to and discussing information on the whiteboard and simultaneously enter a group chat question for the speaker to address. Another user may be trying to follow the speaker's discussion while being distracted and confused by the frequent scrolling of a group chat conversation taking place among various attendees. In addition, becoming successful and proficient with the Web conference tool takes time and practice. Although basic tools (e.g., group chat, raising a virtual hand, virtual applause, conducting an audio check, and using voice-over IP) generally can be learned with 10 to 15 minutes of practice, this may not be the case for a person with an intellectual impairment. More advanced tools may take significantly greater time, assistance, and practice.

*Effectively communicates necessary information.* The necessary information in a Web conference is the same input and output of group chatting, closed captioning, voice- and video-over IP, and the interactive whiteboard and application sharing, discussed above. For persons with significant hearing or vision impairments, effective communication may be barred in one or more of these media.

*Minimizes adverse consequences of accidental actions.* Users of screen readers and voice-recognition software may experience greater accidental

actions than other users. Screen readers may not provide a reliable way to back up when the user incorrectly selects a hyperlink or toolbar option. A voice recognition program can be only as accurate as the vocabulary and pronunciation it has learned from the user. New vocabulary or deviations in pronunciation that arise in the context of a Web conference pose challenges. However, these are limitations inherent in the screen readers and voice recognition programs rather than in the Web conference tool.

*Efficiently and comfortably usable with minimum fatigue.* Screen reader use in the Web conference, producing a second voice overlapping that of the current speaker, is highly susceptible to creating user discomfort and fatigue. In contrast, if a transcriptionist is entering real-time closed captions, the attendee with a significant hearing impairment will not likely experience any greater fatigue than if watching a captioned television news report or movie. The user of voice recognition software as their primary source of textual input may experience difficulty following the present speaker's discussion if simultaneously preparing a group chat message. Users with varying attention, learning, or cognitive impairments may experience discomfort or fatigue keeping up with multiple simultaneous inputs/outputs.

*Avoids posing disadvantages or creating stigma for users.* As discussed above, the inability of a person with a disability to meaningfully and effectively participate in activities with persons who do not have disabilities creates unnecessary stigmatization.

**Using Collaboratory Infrastructure**

To answer the second research question (How is the cyberinfrastructure practically used?), we used a mixed-methods analysis (i.e., interviews, observations, content analysis) to describe how the participants in the collaboratory actually used the infrastructure developed for the projects. The results of that evaluation are presented below.

*People-to-People*

The technologies to support the people-to-people aspect of the collaboratory are primarily Listservs and IM applications. A Listserv for the Employer Demand project was established that included the e-mail addresses for all of the participating researchers. To date, a limited number of messages have been sent out to the list ($N = 20$), mostly to announce meeting dates and to provide project updates; only one Listserv has been established. Ide-

ally, a number of separate Listservs would be established for various networks and subnetworks within the projects. To date, we have not yet established a Listserv for the Southeast DBTAC project, which, although it had an earlier start, has not progressed as rapidly as the Employer Demand project.[6]

As Handel and Herbsleb (2002) showed, presence awareness systems and particularly group chat applications can provide a tremendous boost to geographically distributed collaborators. From our baseline data collection, we know that 23 participants have used IM. However, in our case, we have thus far implemented IM only within the project management team. This implementation has been very successful, with the project director for both networks (first author) and the collaboratory coordinator for both networks (second author) communicating nearly every week on IM. We standardized our IM client as AOL IM (a free IM client, available for download at http://www.aim.com/) simply for compatibility and disseminated this throughout the project leadership team.

*People-to-Resources*

As we describe above, a CMS is the primary collaboratory infrastructure used to enhance the people-to-resources element of our collaboratory. Despite some of the accessibility challenges identified in the previous section, the project portals have been one of the more successful elements of the pilot collaboratory development. Both project portals have been designed to be as accessible as possible under current conditions and have served as a major organizing point both for public information about the projects and for the various project teams.

For each network and subnetwork in the projects, we have created separate roles within the CMS, so that we can assign relevant rights (e.g., read, write access) using high levels of granularity. This means, for example, that when a member of a specific project in the Employer Demand Collaboratory logs into the portal, she or he is able to see not only what a member of the public can see but also information (i.e., folders, documents, discussions) unique to their team (i.e., not visible to collaboratory participants who are not members of her or his team). Both portals have grown in size and evolved their own unique structure to reflect the corresponding structure of the project.

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[6] Possibly because of clearer project goals on the Employer Demand project.

*People-to-Facilities*

Finally, the technology used to support the people-to-facilities element of the collaboratories is Web conferencing. Our Web conferencing server, built on technology licensed from Elluminate, is one of the most cross-platform Web conference tools on the market (Cogburn & Kurup, 2006). We have integrated access to the Cotelco Web conferencing server into each of the project portals. Also, we began each collaboratory with a presentation from the second author on the collaboratory concept and organized a series of hands-on training sessions for the collaboratory leadership team and participants.

To date, the Web conferencing has been most effective within the Employer Demand collaboratory. In the Southeast DBTAC collaboratory, we were able to use Web conferencing to hold project-planning meetings with the director but have not held Web conferences with the participants. In contrast, we have held a series of meetings with various segments of the Employer Demand project, including (a) the leadership team, (b) the entire network of geographically distributed participants, and (c) each of the project teams. Preparation for these meetings included substantial remote interaction by members of the Cotelco team to prepare computers and troubleshoot potential problems, but no face-to-face visits were needed by any technology support staff. Overall, these findings are encouraging and lead us to think about the implications of these two pilot studies.

**Discussion**

The purpose of these two pilot studies is to study the degree to which collaboratory infrastructure may be of benefit to the national disability community. As discussed, two primary research questions were asked: (a) To what degree can accessible cyberinfrastructure be developed within this community? and (b) How is the cyberinfrastructure practically used? Although the pilot studies are less than 2 years into their 5-year grant periods, the preliminary findings present a clear indication of the short- and long-term potential of cyberinfrastructure for the national disability community.

In our first pilot study, the Southeast DBTAC collaboratory aimed to illustrate the potential of a geographically distributed management structure and the increased potential for integrating resources and information from a range of community and policy-making practitioners. As a geographically distributed research network, the Employer Demand collaboratory is much closer to the

original conception of a collaboratory. Perhaps this similarity explains the more rapid progress in this pilot collaboratory than in the Southeast DBTAC.

As anticipated by the authors, the communication technologies involved in the pilot collaboratories most implicated by accessibility concerns were software applications, Web-based information and applications, and telecommunications, video, and multimedia products. Largely, this proved correct. The current versions of the CMS and Web conferencing tool used presented various barriers to effective communications while offering potential solutions to some barriers. Persons with significant visual impairments likely are most affected by incomplete or limited access to the essential content of the Web portals and Web conferences.

Individuals with fine motor or hearing impairments experience fewer instances of incomplete access, although it is likely that they encounter barriers to one or more types of essential content (e.g., inability to fully use voice recognition programs because of interference with other speakers, digitally recorded content that is not closed captioned). Importantly, these barriers are associated with the Web conferences and not with the Web portals.

People with cognitive impairments may encounter barriers to more advanced features of both Web conference meetings and the Web portal (e.g., moderating and application sharing, editing Web portal content). Individuals with attention deficit disorder (with and without hyperactivity) and learning disabilities likely experience greater difficulty, discomfort, or fatigue with simultaneous multiple inputs/outputs of the Web conference tool than with the Web portal.

Based on the extraordinary potential for a cyberinfrastructure to enhance the ability for geographically distributed networks to collaborate more efficiently, we predict that the collaboratory organization form will become more widespread in science, industry, and policy making. If that is the case, it is imperative that UD principles are included in their design, development, and implementation. Although doing so additionally may require up-front effort for those new to UD principles, these pilot studies have shown that it is possible to address these principles meaningfully in the design and implementation of collaboratories. Furthermore, if open-source application frameworks are used to develop these products, it would be wise to use the opportunities they present to modify code and build customized modules on UD principles.

Existing technology does not appear to allow the creation of a universally designed Web portal, for

instance, whereby a person with a visual impairment could shed their reliance on screen readers or magnifiers. The present study, however, demonstrates that applying UD principles to our understanding of the technologies and their uses for cyberinfrastructure-enabled knowledge communities is an important framework for improving 21st-century access to information for people with varying disabilities. In the future, the application of UD principles to cyberinfrastructure technology design may obviate expensive and complex assistive technology.

## RECOMMENDATIONS FOR COLLABORATORY DEVELOPMENT, LAW, AND PUBLIC POLICY

We offer several recommendations for interdisciplinary teams designing collaboratories and for law and public policy. First, hundreds of CMSs are available, many at no cost to the Web developer. Careful consideration of these systems' compatibility with Section 508 or WAI Web accessibility standards and assistive technologies and the flexibility to permit manipulating the code for greater accessibility are vital when selecting a CMS, if their collaborative benefits are to be realized by people with disabilities. The same holds true for Web conference tools. Emerging real-time closed captioning using the latest voice recognition technology offers a great possibility for collaboratories composed of a relatively finite membership and could ensure that all Web conferences are archived with captioning. Applying UD principles across disciplines in higher education and program and product design may preclude reliance on expensive assistive technologies and raise public awareness of UD benefits for all.

Second, in terms of future research and collaboratory development, we encourage other researchers to follow our lead by including UD principles in their empirical studies. This area of research would benefit from more carefully controlled laboratory experiments, including analyses of the usability of these applications by people with varying physical, sensory, and cognitive abilities, and across browsers and operating systems. Also, more field studies of the type described here would help us better understand the impact of these approaches on the national disability community.

Finally, in terms of law and public policy, W3C currently serves on the Telecommunications and Electronic and Information Technology Advisory Committee among several dozen industry, disability, standard-setting, and government organiza-

tions and bodies, for the purpose of reviewing the 508 standards and recommending improvements (71 Federal Register 38,324, 2006). The W3C, a strong advocate for accessibility, has the opportunity to encourage applying the UD principles as a baseline for 508 standard design. Federal technology standards, where federal funds are involved, could come to mandate a new higher standard of equality and inclusiveness for people with disabilities. As science and many forms of commerce and employment move increasingly to take advantage of these developments, patient and principled attention must be paid to ensure cyberinfrastructure is fully accessible.

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## APPENDIX

### Sample Questions From the Collaboratory Member Survey

Note: Contact the second author, Dr. Derrick Cogburn, for a complete copy of the survey codebook.

Closed question      Open-ended question

4. What is your highest level of education completed? **C**
6. What is your primary field of training? **O**
7. Which category would best reflect your current family income? **C**
11. Which of the following statements best reflects the style of leadership that you most prefer? **C**
12. What type of organization do you primarily work within? **C**
16. What is your primary role/function within the organization? **C**
17. In an average month, how frequently, if at all, do you interact *face-to-face* with the following members of the Employer Demand Project? **C**
18. In an average month, how frequently, if at all, do you interact *virtually* (e.g., using instant messaging, Web conferencing, e-mail lists, blogging, application sharing, document repositories, etc.) with the following members of the [ ] collaboratory? **C**

22. On the following scale, how confident do you feel in your ability to work effectively with your [ ] team members without being located in the same building? C
25. From the following list, which item gives you the greatest sense of community, or feeling of belonging? C
26. Now, I want to ask you some questions about how you view other people. Generally speaking, would you say that most people can be trusted or that you can't be too careful in dealing with people? C
29. The members of the [ ] collaboratory. . . .
    a. approach their jobs with professionalism and dedication.
    b. are competent in the preparation for their job
    c. are reliable and will not make my job more difficult by careless work.
    d. are trusted and respected by most people.
    e. are considered to be trustworthy.
    f. do not require me to monitor their performance.
30–32. For each of the following (basic, intermediate, advanced) information and communication technologies, please rate your personal experience. C
34. On a scale of 1–5 (1 being lowest), how often do you use any of the following assistive technologies when working with personal computers and/or the Internet? C
35. What operating system do you use most frequently? C
36. Where do you usually access the Internet/World Wide Web when doing your research work? C
37. At what speed do you usually access the Internet/World Wide Web from this location? C