

# Collaboratories to Support Distributed Science: The Example of International HIV/AIDS Research

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The use of collaborative technologies to support geographically distributed scientific research (or collaboratories) is gaining wide acceptance in many parts of the developed world. Such collaboratories hold great promise for international cooperation in critical areas of scientific research, such as HIV/AIDS. We have extensive experience with the design, development, deployment and evaluation of such collaboratories in a number of areas of science and engineering. We have identified a number of critical success factors, and discuss three in particular: collaboration readiness, collaboration infrastructure readiness, and collaboration technology readiness. We have recently begun the baseline assessment of two collaboratory opportunities for international HIV/AIDS collaboration, one in Botswana and one in Durban, South Africa. We present our preliminary assessment of the prospects and challenges for developing these collaboratories.

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## 1. INTRODUCTION

Since science has always been a form of what we now call ‘distributed knowledge work,’ scientists were among the first to recognize the potential of emerging information and communication technologies for enhancing and extending their work. For instance, electronic mail first became widespread within scientific communities. As additional networked tools became available, a more coherent vision emerged of how technology-mediated science could be conducted. By the late 1980s the concept of a collaboratory was being discussed in the United States at places like the National Science Foundation and the National Research Council. Collaboratories were defined as a ‘...center without walls,’ in which the nation’s researchers can perform their research without regard to geographical location’ (Wulf, 1989). The vision was that scientists who are geographically dispersed could work together using appropriate technology to access each other, remote tools, databases, and instruments (National Research Council, 1993; Kouzes, Myers & Wulf, 1996; Finholt & Olson, 1997).

Major research centers and laboratories all over the world provide environments that have accelerated the pace of scientific advances. As the frontiers of knowledge are pushed back the problems get more and more difficult, often requiring large, complex teams – frequently multidisciplinary – to make progress. Exotic and expensive equipment or facilities can only be justified if they are designed and deployed collaboratively, maximizing their impact on a science community.

The collaboratory is emerging as a new option for the organization of scientific activity (Finholt & Olson, 1997). The great contrast, of course, is that the key mediating principle of the laboratory is collocation, namely, having all of the human and material resources required for scientific research at a particular place. The collaboratory changes this, by using communication and computing technology to relax the constraints of distance and time, creating an instance of a virtual organization (Davidow & Malone, 1992; O’Hara-Devereaux & Johansen, 1994). Like all emerging virtual organizations, the collaboratory is both an opportunity with some very useful properties but also a challenge to human organizational practices.

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The emergence of global challenges to science, such as the HIV/AIDS epidemic, have made all the more urgent the refining and dissemination of collaboratory technology to facilitate effective multinational scientific collaborations. In this paper we will review our experience base with collaboratories in a number of fields, highlighting a number of factors that are critical to the success of new collaboratories. Then we will focus on the opportunities for collaboratories for HIV/AIDS research in southern Africa.

## 2. OUR EXPERIENCE BASE

Our research group at the University of Michigan has been involved in collaboratory projects for more than a decade. Table 1 lists our major projects. We include both science collaboratories in several fields, as well as several engineering collaboratories created for partners in industry. More information about these projects, as well as an extensive listing of collaboratory projects carried out by other institutions, is available at [www.scienceofcollaboratories.org](http://www.scienceofcollaboratories.org).

Project Name	Start Date	Sponsor	Domain	Partner(s)
UARC, SPARC	1992	NSF	Upper atmospheric physics research and education	SRI, JPL, MIT, Danish Meteorological Institute, U. Maryland, Rice, Southwest Research Institute, Cornell U.
	1995	Ford	Global automotive product design	Ford, Steelcase
Medical Collaboratory	1995	NSF	Clinical radiology	UM Medical Center, MCARE
	1995	IBM	Global financial reporting	IBM
Great Lakes Regional CFAR	1998	NIH	HIV/AIDS research	Northwestern, Wisconsin, Minnesota
Nancy Pritzker Depression Research Network	1998	Pritzker Fdn	Brain research	Stanford, Cornell
Product Development Collaboratory	1998	Lucent	Global telecom software design	Lucent
Manufacturing Collaboratory	1999	NIST	Design Engineering	Auto parts manufacturer
NEESgrid	2000	NSF	Earthquake engineering research	NCSA, ANL, Mid-America Earthquake Center, USC
Waterford Project	2000	Evans Fdn	HIV/AIDS research	UCSF, Harvard, Maryland, Internet2
Africa Collaboratories	2001		HIV/AIDS research	Harvard

Table 1. *Collaboratory Projects at the University of Michigan*

## 3. LESSONS LEARNED

Our broad experience with attempts at collaboratory projects has revealed that not all communities are ready for collaboratory technologies (see further details in Olson & Olson, 2000; Olson, Finholt & Teasley, 2000). There are three dimensions to this finding: collaboration readiness, collaboration infrastructure readiness, and collaboration technology readiness.

### 3.1 Collaboration readiness.

Readiness to collaborate or experience with collaboration is clearly the most basic prerequisite for an effective collaboratory. In UARC, our space physics collaboratory, we began the project with a community that had considerable experience with collaboration and major incentives to do so. The field had pre-specified “rules of the road” for how data would be shared, and an infrastructure for creating data repositories. Coordinated Data Analysis Workshops (CDAWs) were operated by the National Space Science Data Center at Goddard Space Flight Center so that science teams met to further investigate their data and coordinate the analysis and interpretation/understanding with other teams. This community was “collaboration ready”.

In contrast, in some of the biomedical areas we have studied such collaboration readiness was not present at the outset. Much biomedical research is highly competitive, with both individuals and co-located laboratories working hard

to be the first to achieve some breakthrough. Often the critical component to collaboration readiness was a real need that required working together in order to achieve a science goal. For instance, the need to enroll patients into clinical trials more quickly in order to make more rapid progress on the evaluation of treatment options was a major incentive in the Great Lakes Regional CFAR. Collaboration readiness has several broad components: motivation to collaborate, shared principles of collaboration, and experience with the specific elements of collaboration.

### 3.2 Collaboration infrastructure readiness.

Modern collaboration tools require adequate infrastructure to operate properly. Clearly such bandwidth intensive tools as digital video and high quality audio require adequate networking. Many off-the-shelf applications will run effectively only on state-of-the-art workstations with up-to-date operating systems and network environments. So an adequate technical infrastructure can be critical to success, although as we will point out below, a number of very useful collaboration tools operate today over infrastructure available in the developing world.

Another important piece of infrastructure is technical support. All collaborative technologies are deployed on a technology base that must be properly maintained and supported. Running effective networked infrastructure requires a non-trivial investment. These support issues increase as the technology becomes more sophisticated. Even with contemporary off-the-shelf tools there are still many issues that require good local technical support to ensure that everything operates smoothly. There can be daunting set-up processes to get client software to all sites, to ensure version consistency across all sites, to get participants registered, and to recover from interruptions in service.

### 3.3 Collaboration technology readiness.

Collaboration technologies have been available as research prototypes for almost two decades, but it is only in the mid-90s that a wide range of such technologies has begun to appear in products. For instance, e-mail was first used by researchers in the 1960s, but it has not become commonplace until the 1990s. More advanced collaborative technologies such as e-mail attachments, discussion databases, application sharing, and desktop video are still emerging in many communities.

Our experience with both science and industrial laboratories is that there is a normal progression for the adoption of collaborative technologies, shown in Figure 2. Users unfamiliar with a 'simpler' technology find it hard to grasp or adopt a more advanced one. Attempts to leapfrog this progression can often result in frustration or failure. For instance, in our experience the more advanced collaborative technologies in Figure 2 require a considerable investment in training. Thus, early in a collaborative project it is essential to assess the state of technology readiness in the community in order to ensure success. Again, several of our failed attempts to launch collaborative projects were because the level of technology readiness in the relevant community was too primitive. The specific organizations neither had the experience or the base of technical support to advance very far in the progression of technologies shown in Figure 2.

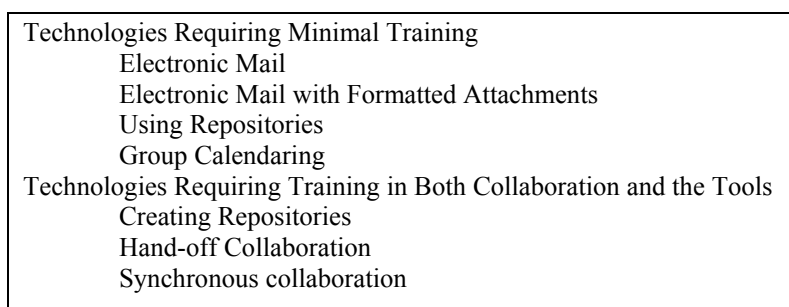


Figure 2. *Hierarchy of Collaborative Technologies*

## 4. RISK MITIGATION

There are design and evaluation strategies that can reduce the risk of failure in laboratories.

### 4.1 User-Centered Design.

Many system developers agree that it is important to design information technology with users in mind. However, in actual practice, most technologies are designed with only the designers themselves consulted as potential users. Even when users are consulted, their needs and requirements are assessed superficially. One of the difficulties is that asking users what they need is a very poor way to design good software. Users are not particularly articulate about their work practices, in part because these practices are often embedded in individual and organizational routines that are tacit and difficult to see. The result is technology that fails to meet the real needs of users, is very difficult to use, or has no long-term impact on indicators that are socially valued.

Many methods have been proposed to facilitate the development of effective and usable software (e.g., Nielsen, 1993; Shneiderman, 1997; Olson & Moran, 1996), and the evidence is encouraging that the use of such methods leads to better quality software. One method that has repeatedly yielded good results is iterative design with fairly tight cycles of design-development-deployment-evaluation (Landauer, 1995).

We have used this strategy in our own collaboratory projects. A number of practical problems arise in carrying out such a strategy. Where does one start? How does one gather data for purposes of feedback? How does redesign proceed? What are the step sizes for successive generations of the software?

Our experience with the Upper Atmospheric Research Collaboratory (UARC) is instructive here. The goal of the UARC project was to enable Internet-based real-time data acquisition experiments in upper atmospheric physics. Early in the project we devoted much attention to the issue of how to extract user needs and how to refine the emerging system prototypes that were being deployed to real users (McDaniel, Olson & Olson, 1994). We drew on concepts from human-computer interaction (e.g., Olson & Olson, 1997), object-oriented analysis and design (e.g., Jacobson, Christerson, Jonsson & Overgaard, 1992), and business process reengineering (e.g., Hammer & Champy, 1993) to derive specific, concrete methods for moving from in-depth interactions with users to running code. The two biggest obstacles to user acceptance of software are the speed and reliability of the software itself. As systems become more complex or rely on emerging technologies for their implementation it becomes increasingly difficult to achieve levels of performance that are acceptable to users.

Another approach to providing collaboration software is to use off-the-shelf applications, as we did with the collaboratory for the Great Lakes Regional Center for AIDS Research (GLR CFAR). Based on interviews with scientists and their research staffs, we identified two activities important for supporting existing collaborations and getting new collaborations started. First, the scientists expressed a need for a way to run distributed lab meetings that would allow conversation over shared data, including, for example, images from a specialized microscope located at only one of the sites. The expectation for this activity was that it be fully interactive so that participants, from few to many, could interact with each other in real time. Second, the scientists wanted a way to broadcast seminars to share information from experts inside and outside the center. Here the expectation was to be able to broadcast to as many members as possible. Microsoft NetMeeting was selected for real-time document, image and equipment sharing. Cross-platform issues involved in using NetMeeting were resolved by having the Macintosh users use Timbuktu Conference, and later, Virtual PC. PlaceWare Auditorium, a web-based presentation tool, was selected for virtual presentations. Telephones were used in addition to groupware tools in the absence of any good Internet-based solution for multipoint audio.

## 4.2 Longitudinal Evaluation

The impact of UARC on the practice of space physics was assessed longitudinally via active measures, such as regular administration of questionnaires about communication and collaboration, and unobtrusive measures, such as content analysis of chat, action and network logs (e.g., McDaniel, Olson & McGee, 1996). The effect of the GLR CFAR collaboratory on AIDS research has been tracked longitudinally through similar measures (Yerkie et al, 2002). Several broad insights have emerged. There have been effects on: training and education, elaboration and maintenance of social networks, and emergence of new organizational forms.

### 2.4.1 *Effects on training and education.*

UARC offered a tantalizing view of how collaboratory use might change the course of graduate training in space physics. For example, use of UARC allowed students early participation as active members of research teams -- in contrast to the traditional organization of space physics, where only the most senior students joined in data collection and analysis efforts. Specifically, UARC afforded a kind of engagement with learning that has been described as "legitimate peripheral participation" (Lave & Wenger, 1991) or learning in a "community of learners" (Rogoff, 1994). Evidence of success may have important implications both for enticing more students to pursue science-related careers and in focusing practicing scientists on the importance of outreach activities for sustaining public interest in science.

Registered members of the GLR CFAR use collaboratory technology to participate in virtual seminars and virtual lab meetings. Attendees of these meetings have reported that they have provided a means to get access to information that they would not have received otherwise. Senior scientists have also broadened the access to their own scientific practice to the more junior members of their research teams by bringing in members of their lab groups to these virtual lab group meetings. In addition, several of the junior members of the GLR CFAR have used the virtual seminar series to present pilot data and receive feedback for submitting competitive grant applications. A high rate of funding by the junior members of the GLR CFAR demonstrates the value of this mechanism for training and professional development.

### 2.4.2 *Elaboration and maintenance of social networks.*

Recent work in the sociology of science (e.g., Walsh and Bayema, 1996) points to the significance of the Internet as a mechanism in science for making and maintaining collegial ties. Yet, theorists have observed that the nature of these electronic ties differ from conventional ties (Wellman et al., 1996). Collaboratories represent virtual meeting places

with great potential for generating serendipitous encounters that may escalate into substantial scientific collaborations. In the UARC experience, most collaborations pre-dated the creation of the collaboratory. However, there were instances of interactions around data collection campaigns that suggested the potential for collaboratories as vehicles for bringing together scientist with complementary interests.

In the GLR CFAR, the collaboratory was used by scientists for collaborations that pre-dated the grant, but almost half of the collaborations were with new colleagues. Most of these new collaborations were with junior and mid-career scientists who became involved with the collaboratory during the first year. The most striking feature of the collaborations was the representation of cross-disciplinary work, such as collaboration between microbiologists, immunologists and biostatisticians. In fact, most of these collaborations represented the breaking of disciplinary boundaries to produce research that is designed to have an impact on both bench and bedside (Teasley & Wolinsky, 2001). The director of the project characterized this as a change from 'little science to big science.'

#### 2.4.3 *Emergence of new organizational forms.*

Science is a collaborative enterprise, and the traditional environment for scientific collaboration is the laboratory. Laboratories facilitate collaboration in two ways. First, as physical settings, laboratories provide scientists access to each other and to rare or expensive instruments (Allen, 1977; Hagstrom, 1965; Kraut, Egido, & Galegher, 1990; Pelz & Andrews, 1966). Second, as social organizations, laboratories certify and disseminate knowledge, train future generations of scientists, and produce agreement about scientific beliefs and practices (Knorr-Cetina, 1981; Latour, 1987; Latour & Woolgar, 1979; Lynch, 1985; Traweek, 1988). Recent developments in the evolution of information technology suggest that laboratories as physical settings may be less essential for scientific collaboration than were formerly the case, and that the collaboratory may be emerging as a new organizational form for science (Finholt & Olson, 1997).

## 5. COLLABORATORY OPPORTUNITIES FOR HIV/AIDS RESEARCH IN SOUTHERN AFRICA

The Human Immunodeficiency Virus and the Acquired Immune Deficiency Syndrome (HIV/AIDS) continues to infect and destroy large portions of Africa's population, particularly in southern Africa. According to a recent status report on the worldwide HIV/AIDS epidemic released by UNAIDS, the HIV infection rates in South Africa (19.9%) and Botswana (38.5%) are among the highest in the world. Current efforts to combat HIV/AIDS are focused on three areas: (1) anti-retroviral drug trials; (2) vaccine trials; (3) and awareness and education efforts.

Given the daunting nature of this epidemic, a number of multinational collaborations are underway in southern Africa to directly work on the epidemic and to further develop local human resources for the work. Recently, we have formed partnerships with two such projects at Harvard University that are seeking inroads in this epidemic. Both projects are working closely with local officials and investigators. These projects are:

- The Botswana Harvard Partnership (BHP; see further details at [www.bhp.org.bw](http://www.bhp.org.bw)) between the Harvard AIDS Institute (Dr. Max Essex, principal) and the Ministry of Health in Botswana was launched in 1996. The partnership conducts research on mother-to-child transmission of HIV, drug resistance testing of the HIV-1C virus before and during treatment, and vaccine development. The partnership is also working with researchers in Botswana to identify the strengths and weaknesses of the medical infrastructure in Botswana and to increase access to counseling and testing. The Partnership opened the first HIV reference laboratory and training center in Botswana, and is the first in the world built specifically to investigate an HIV subtype known as 1C, the type now responsible for more than half the world's AIDS-virus infections. The Botswana-Harvard Partnership has a staff approaching 80 on site in Botswana.
- Researchers from the Partners AIDS Research Center at the Harvard Medical School (Dr. Bruce Walker, principal), the Nuffield Department of Medicine at the University of Oxford (Dr. Philip Goulder), and the Nelson R. Mandela School of Medicine at the University of Natal (Dr. Hoosen Coovadia, principal), have been carrying out a cooperative research on HIV/AIDS for several years. They are seeking to expand the scope of their work, and to establish a center of excellence in Durban that will provide a magnet for talented African researchers, keeping key elements of the work in proximity to a region critically affected by the epidemic. Their plans include a state-of-the-art research program in clinical translational HIV pathogenesis, a comprehensive training program focused on HIV for doctoral and post-doctoral students as well as technical staff and nurses, and associated infrastructure to facilitate the multinational collaboration at the heart of these programs.

We have conducted an initial round of assessments of the needs and technical feasibility for Internet-based support for the long distance collaborations involved in these two projects. These are active, vibrant collaborations, whose work could be materially advanced with improved infrastructure. Our initial investigations suggest interesting challenges for a collaboratory that spans the developed and developing worlds.

### 5.1 Collaboration readiness.

Our initial observations suggest that these projects have a high degree of collaboration readiness. These are already-established, ongoing collaborations, in which many of the ‘rules of the road’ have already been developed. There are established collaboration procedures, explicit understandings about who is allowed access to unpublished data, and a continuing need to access the expertise and resources across sites. However, implementation of new collaboration technologies may require some reinterpretation of their established ways of working together. Collaboration technology potentially allows more project members to directly participate in collaborations with other research sites. While many of the participating scientists have trained together or in similar institutions, there are a number of project members who are relatively unfamiliar with the culture and norms at the other project sites.

Successful interactions between collaborators require a certain amount of ‘common ground.’ Participants who have more in common with each other will have an easier time communicating (Clark, 1996). This can become even more important when the interactions require a high degree of trust or negotiation, or directly involve areas where there may be high levels of cultural difference. For example, these collaborations involve ethical oversight committees from both the United States and Africa that must meet to discuss the ethical regulations imposed on the research. Ethical norms tend to be culturally specific, and negotiations about ethical issues require high levels of trust. Research in our lab suggests that trust development may be hampered in computer-mediated communication, but paying explicit attention to building common ground before using the technology can counteract these effects (Rocco, 1998; Zheng, et al., 2002).

### 5.2 Collaboration infrastructure readiness.

An obvious challenge in these projects is working with the current collaboration infrastructure in Africa. Even when the necessary bandwidth is available, communication networks tend to be unreliable and subject to overloading at peak times of day. Network failures can cause a great deal of frustration when the ability to reach collaborators is necessary for the normal progress of work. Collaboration tools that are designed to work at low bandwidth have made new kinds of computer-mediated communication possible for African scientists. For example, bandwidth-preserving technologies like pre-caching content, distributed server architectures, and highly compressed audio and video codecs are now available in several commercial products. However, users will be unlikely to fully adopt the technology if they can not count on the network being available.

Other infrastructure differences between the United States and Africa can also cause problems. Even when the networks are working perfectly, social, organizational, or political factors may influence the adoption of various technologies. Pricing structures for network connectivity tend to be quite different in the United States and Africa. In the United States, end users tend to pay low or no per-minute fees. On the other hand, it is quite common for users in Africa to have per-minute connection charges for both voice and data communications. This can affect the choices that participants make about what media to use or how to use it. In the United States, for example, Instant Messaging is being adopted both as a short messaging platform and to provide awareness information about colleagues (e.g., as a way to see who is on line). In part because of the cost of a persistent Internet connection, IM is not as widely used in Africa. Similarly, cell-phone based SMS is extremely popular in Africa for sending short messages, but it has not been widely adopted in the United States.

### 5.3 Collaboration technology readiness.

In these international collaborations, we see very different levels of collaboration technology readiness between sites. Many of the participants in the United States are proficient with e-mail attachments, using remote databases, synchronous collaboration and other more advanced collaboration tools. On the other hand, many of the African participants in the collaborations have not experienced these technologies. It is important to not only provide technologies that meet the current level of collaboration technology readiness, but also to work to build a adequate level of readiness across the collaboration sites. Collaboration technologies require that the participants share a common understanding and facility with technologies before they can be successfully used to support distributed work. We must provide appropriate training and guidance so that all collaborators are able to comfortably use the collaboration technology.

### 5.4 Opportunities from collaboration.

The potential benefit of international, technologically mediated scientific collaborations goes beyond the immediate impact on the scientific investigation. Some of our earlier work suggests that scientists may be able to work faster and more efficiently with the help of communication and information technologies. Additionally, there are possibilities for interesting secondary effects. Scientists involved in the collaboration may be able to make new and useful connections to other scientists, expanding and enriching their professional networks. With most HIV/AIDS research originating in the United States and Europe, scientists in Africa are at a disadvantage for keeping up with the progress in their field. The ability to participate in a seminar or lecture being given in another country can help bring African researchers more directly into the scientific mainstream. Similarly, students who participate in the collaborations may gain a new source of mentorship, or access to expertise that otherwise might not have been available.

## 6. SPECIFIC ACTIVITIES

In order to address these concerns and capitalize on these opportunities, we plan to proceed with three interrelated activities:

### 6.1 Collaboration infrastructure development and technology deployment.

We will create infrastructure, both technical and human, to support these long distance collaborations. The projects currently rely very heavily on travel, and such simple distance tools as e-mail and expensive telephony. We have an extensive experience base with supporting such projects in other parts of the world, and have made preliminary assessments of the prospects for such infrastructure at the sites covered by the two Harvard projects. While the networking and telecommunications situations in Botswana and South Africa are still undergoing development, we already know that there are new useful tools we can provide for these collaborations. We already have experience with conducting a long distance graduate seminar between American and South African universities, using available off-the-shelf technology (Cogburn, 2002). Further, there are promising developments on the horizon as advanced networking makes its way toward southern Africa.

Unfortunately, many African institutions lack the human and institutional resources to build these capacities alone. Partnering with US academic institutions may help, but these arrangements are sometimes costly and unsustainable. Further, many academics and scientists in developing countries feel isolated, and insufficiently involved in global research communities. A collaboratory has the potential to help bridge this gap and provide a distributed space for collaboration between faculty, staff, and students in both developed and developing countries around the world.

### 6.2 Longitudinal evaluation of impact.

We want to know whether the creation of collaboratory infrastructure makes any difference on the science- process and pace. We have the concepts, methods, and skills to answer this question, through a longitudinal study of the deployment and use of the infrastructure. We have already worked with HIV/AIDS researchers in the US. We have seen that appropriate collaborative tools and practices can accelerate the planning of clinical trials (Teasley & Wolinsky, 2001). We are already in the process of collecting baseline data about current practices across the US and African sites, but now need to ensure on ongoing evaluation effort over several years.

### 6.3 Human capacity development.

We seek to engage colleagues in both Botswana and South Africa who will become proficient in the deployment, maintenance, and assessment of collaboration tools. This is essential if these capabilities are to spread effectively beyond these initial two projects. We will use (1) distributed graduate seminars; (2) training and continuing education; and (3) distributed seminars to build and enhance a community of practice within the region.

## 7. BEYOND THESE INITIAL PROJECTS

The successful deployment of collaboratory technology for these two projects can provide a stimulus for the dissemination of these capabilities throughout the region. For example, the new laboratory in Botswana is already being used by HIV/AIDS researchers from neighboring countries. Collaboratory tools can enhance these regional interactions both by reducing the need to travel between sites and by offering a means of maintaining engagement with cross-site collaborators after meeting face-to-face. And, of course collaboratory technology can be used for in other areas than HIV/AIDS, such as education, government, and economic development.

## 8. CONCLUSION

The collaboratory presents a new model for organizing distributed scientific work, but the challenges of doing science between the United States and Africa are yet to be fully realized. The concept of 'readiness' provides a useful way to think about how to develop and implement technologies to connect researchers across diverse contexts. Through longitudinal evaluation, we will examine the impact of collaboratory use for the participants and the science they produce. This project promises to give us a deeper understanding of the issues and opportunities of technologically-mediated, international collaboration.

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