

The Future of the Internet in Science

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Abstract:

How are scientists going to make use of the Internet several years from now? This is a case study of a leading-edge experiment in building a 'virtual institute'-- using electronic communication tools to foster collaboration among geographically dispersed scientists. Our experience suggests:

- Scientists will want to use web-based document management systems.
- There will be a demand for Internet-enabled meeting support tools.
- While Internet videoconferencing will have limited value for scientists, webcams will be in great demand as a tool for transmitting pictures of objects and settings, rather than "talking heads."
- A significant share of scientists who do fieldwork will embrace mobile voice, data and video communication tools.

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Introduction:

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- A large share of scientists who do fieldwork will embrace mobile voice, data and video communication tools.

The setting for these findings is a research consortium called the NASA Astrobiology Institute. From its founding in 1998, the Institute was conceived as an experiment in using Internet and other communication tools to stimulate new

ways of working among scientists who are geographically dispersed. It is comprised of a core of about four hundred researchers, in a wide range of disciplines, from one international and eleven U.S. research institutions.

There are a growing number of products and services supporting distributed group work. They not only include "groupware", but more significantly e-commerce, workflow tools, and web-based collaborative product management services. Typically, however, such efforts are focused on business users, rather than scientists.

Currently, distributed group work tools tailored for scientists are mostly restricted in scale and scope. Often under the banner of "collaborative laboratories" (or "collaboratories"), some efforts have sought simply to provide scientists with access to general Internet communication tools, such as videoconferencing and knowledge databases.[1] Other efforts have focused on small numbers of laboratories, and highly specialized, discipline-specific applications.

Probably the most important exceptions are the development efforts of scientific e-commerce companies. Like many other e-business ventures, they are starting to think about providing additional value to their customers by providing them with tools for collaboration. None of these efforts, however, have resulted in publicly fielded applications.

Given this lack of technologies, the strategy we have chosen for developing long-distance collaboration in the Institute is to contribute to the development of interdisciplinary 'generic' applications for scientific collaboration. We integrate, evaluate and learn from existing applications and from near-commercial research prototypes.

We conduct informal user studies, mainly through meetings among the Institute staff on day-to-day difficulties in technology selection, integration, development and communicating with users. We have invested little in training, opting instead to provide simple tutorials at large meetings, distribute instructional sheets and e-mails, and provide individualized help by telephone.

Technically, our approach is to move the Institute members along a spectrum of communication practices and tools. (See Figure 1.) The spectrum begins with the most common collaboration practices used by researchers in the Institute, including face-to-face meetings, telephone conversations and e-mail. Our observation is that collaborations will continue to be initiated using these means, and this is the place to start to build a community among researchers, and.

Figure 1: Institute Collaboration Practices and Technologies

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The next step introduces document management systems, which allow for more efficient distribution of information to large numbers of people.

The third step introduces tools to help meetings be more productive, especially when taking place among people in different locations. Thus far, we are using applications developed for general business use.

In the final step, we expect to introduce a range of tools which are more advanced technically and are focused specifically on the needs of interdisciplinary groups of scientists working at a distance. Key examples are mobile Internet applications for diverse groups of researchers doing fieldwork.

Overall, it has been hard work. Studies of adoption of groupware show that it is almost always difficult to get a community to use new communication technologies—even when they already work together as a community. In the case of the Institute, we are struggling to foster a new community at the same time that we are introducing technologies that are new to many scientists.

In addition to such organizational and cultural barriers, we face other, recurring problems common in the world of groupware:

- Lack of functional integration with tools already in use
- Problems of "critical mass", in analogy to Metcalfe's Law: The more people use a network, the more useful it becomes.
- Design flaws which result in usability problems.

Even with these difficulties, however, we've found that there are a few applications that show promise. We believe these technologies—namely, web-based document management systems, Internet-enabled meeting support tools, video of work objects and mobile communications for fieldwork—have the potential to be adopted among scientists for general, interdisciplinary purposes in the next four to six years.

The Archival Web: Web-Based Document Management Systems

First thing Thursday morning, Joe is called on to put together a presentation on his team's project for an unexpected visitor. He has the source material for the portion of the project he supervises, but the work of a number of his collaborators at universities in different states need to be included in his presentation. Fortunately, the project team has a group of file folders on the web where they have been posting and sharing their joint work, and Joe is able to quickly locate the text and images he needs to assemble his presentation.

For most people today, the web is a one-way, 'read-only' medium. However, it will soon be possible to combine the web's ease of use with new ways to upload,

download and revise information¹. In the Institute, we currently use a prototype system for sharing and managing documents among researchers on the web².

In this context a "document" is any computer file—from text to video. "Document sharing" often means that two or more groups of people in different locations view the same document at the same time. "Document management" generally refers to library-like repositories, particularly of official reports in hierarchical or regulated organizations.

Many companies are using web-based document management systems to allow large groups of people to share relatively static documents, on an ad hoc basis, with people who can't be identified in advance, over an extended period of time. The documents are often being generated by a large group of people who are not explicitly known in advance.

To the extent that web pages are used to publish information within organizations and to the wider world, web-based document management systems can reduce the workload of webmasters by allowing individual users to simply upload or download a file directly to a location on the web. Web-based document systems can also play both "sharing" and "management" roles. In addition to serving as a repository, for example, our prototype system has been used effectively in teleconferences, for people in different places to see and revise a document at the same time.

There are companies that offer document management tools free on the web to general users, such as eGroups™ and others that charge for the service. There are companies that use the web for intranet-like corporate document repositories, such as Infodata Systems. There are also companies such as UPS and Pitney Bowes which have begun to promote web-based document sharing as an alternative to overnight delivery services and e-mail attachments.

Proponents have argued that these web-based document systems will reduce the need for, or even replace, many features of today's offices, such as paper document repositories and e-mail attachments, and that webmasters will no longer have to spend time simply posting documents for others.

Actual work practice at the Astrobiology Institute validates some of these predictions, but not all. Our experience, though mixed, suggests that web-based document management systems will be readily adopted by scientists, particularly for the kind of repository use described above. One of the most compelling reasons for this is that these systems streamline the process of creating records of meeting presentations. Rather than requiring administrative initiative, as is the case with paper repositories, online repositories are more dynamically and efficiently stocked during the normal course of meetings and presentations.

¹ Among other developments, a new standard for the web, called WebDAV, may make this possible.

² This system is called Postdoc, developed by the Computational Sciences Division at NASA Ames Research Center. See <http://ace.arc.nasa.gov/>.

There is no longer a need for the administrative work of collecting and posting presentation materials following a meeting. There is also less need for meeting attendees to take detailed notes during a presentation, since they can access and work directly with the actual presentation materials during and after the meeting.

Indeed, our prototype system in the Institute has been put to use mainly by the central administrative office, as a repository for presentations and reports. Presentations are uploaded for use in scheduled meetings, including an educational seminar series, and then occasionally looked at later for other purposes. Reports of various kinds and lengths are uploaded, stored and organized in the system, thereby reducing administrative overhead.

Web document systems will not make a significant reduction in the amount of e-mailed enclosures in the near future, at least among scientists. Although scientists often send attachments to each other—often to more than one person, and often large files—the only replacement for attachments we have seen so far is in the uploading of reports. Even in that case, the report is often sent as an e-mail attachment for good measure.

Web document systems will also not replace webmasters in the near future. Although there is clearly a need to be able to publish information to web without having to go through a webmaster, the technology has not matured to the point that ordinary users will make some documents, or parts of documents, accessible to the general public on the web.

In addition to the organizational and cultural barriers mentioned in the introduction, we recognize a key reason that scientists will be less quick to adopt document systems for more dynamic information sharing and project management: relative task independence. As compared to engineers, for example, the progress of individual researchers on a daily, weekly, or monthly basis is not directly contingent upon progress of their peers.

In summary, we expect web-based document sharing to be rapidly adopted by the scientific community for archival and long-term knowledge retention, as well as for real-time support for documents shared in meetings. However we do not expect web-based document systems to fully replace e-mailed documents any time soon.

The Interpersonal Web: Making Meetings More Productive

"Okay, it doesn't look like Maria is going to make the meeting. Let's get started. The first item on the agenda, as you can see..." The head of the Institute calls to order eleven Principal Investigators in their monthly meeting. Each is located at a different university or research organization. They converse over a high-quality audio-video system, and view and revise documents using electronic

whiteboards. As the meeting progresses, notes and revisions to the agenda and other documents are automatically saved, as a history of the meeting.

Meeting support tools are electronic aids for people who need to talk with each other to get work done. Thanks to the Internet, such tools can be used from different locations. A key technology is the electronic whiteboard, on which agendas, presentations and other documents can be displayed and revised. Using a whiteboard, for example, it is easier for everyone to be on the same page, figuratively and literally, and for note-taking and agreement on the notes to take place on the fly.

Meetings using well-designed electronic tools can be highly effective. In fact, some studies show that teleconferences or videoconferences that use electronic meeting support tools are typically just as effective as face-to-face meetings using similar tools, and more effective than face-to-face meetings without similar support.

Although their uptake among users has been slower than sometimes predicted, meeting support tools are widely recognized as having the potential for introducing significant efficiencies and improving the quality of many work products. This is partly due to the multimedia features of meeting support tools: one can not only hear but also see the progress of the meeting through an agenda, for instance. These tools also reduce the need for additional meeting time to handle administrative matters. For example, presentation, note-taking and distribution of materials can all happen simultaneously as the meeting transpires.

In the NASA Astrobiology Institute, we have several reasons to believe that scientists will be receptive to such innovative technologies in the near future. First, meetings are crucial to the performance of scientific work. A large portion of scientists' everyday work involves project management, program management, and other types of administrative tasks and technical discussions. Second, the highly specialized literary practices involved in scientific work require tools that aid in the manipulation of images and inscriptions. Third, most scientists we've talked with concur with these observations.

We have also observed that the needs of scientists for meeting support tools are not much different from those of the business community. This increases the probability that meeting support tools will find general acceptance among the scientific community, because mainstream technologies developed for business use will be readily available for purchase and use by scientists.

One meeting support tool with which we are particularly familiar is our web-based document sharing system, which has very successfully supported Institute videoconferences. Astrobiologists have found it easier to use than the current common practice of using NetMeeting® to share slide presentations. The hardware we have chosen for presenting the applications—huge touch-screen whiteboards—are popular and relatively trouble-free. They offer a familiar user interface that emulates a computer screen, with similar ways of clicking and writing on its surface. These whiteboards are able to display and annotate documents and images stored in our web-based document sharing system.

Researchers have almost immediately recognized the value of the whiteboards, and have rapidly learned to use them. Moreover, our observation of meetings confirms what many studies have shown: that objects such as the whiteboards can become important points of focus, and can aid in orienting all of the participants to the same information.

We take the reaction to the whiteboards as an indication of the present value of meeting support tools; we expect their value to increase as the number and quality of available meeting support software applications increases. Today touch-screen whiteboards are expensive for scientists, but as prices come down, we expect that many research organizations will want to purchase them, particularly as their associated applications become more standardized, reliable and usable.

The Visual Web: Using Video for Science

“What’s this thing over here?” Susan is a paleogeologist in California. Her partner on this project is a biologist several hundred miles away in Oregon. They are looking at simultaneous live images from an electron microscope. As they talk, they both control the physical movement of the microscope, exploring different regions of the sample. They also make marks and annotations on the images, which they save for a record of their discussion.

When most people think of video for collaboration they think of videoconferencing, videophones, and desktop video—so-called 'talking heads'. People have long predicted that this type of video would be the next revolution in communications. These predictions have been largely based on the intuition that because ordinarily we see people in face-to-face conversation, audio-only communications (such as the telephone) can be improved with a visual channel.

A large body of research has shown, however, that the added benefits of video for such conversations are either nonexistent or minor, particularly in work situations. One of the main reasons is that video communications are highly sensitive to quality: bad video is disturbing to watch, and long audio lags derail conversation. In other words, video can actually make speakers feel more distant from each other.

When quality is not a problem, videoconferencing typically benefits social and emotional aspects of conversation, aspects that are non-task-oriented and noncognitive, such as greetings, negotiations, and intercultural communication, but videoconferencing is not particularly helpful for exchanging information, especially in technical settings.

Another common prediction about videoconferencing systems is that they will reduce or even eliminate the need for business travel. In reality, studies find that

videoconferencing does not reduce travel at all, but does increase interaction between business trips by filling in between the face-to-face meetings. Also, videoconferences are found to be particularly useful in certain niches (e.g. distance learning), but not for all types of meetings.

The fact that videoconferencing may not be useful in ways that it was expected to be does not mean that the technology is without value. If a videoconferencing system is top-notch, it may add humanizing touches to what would otherwise be a high-quality audio conference. Such touches include a visual point of focus, a face to go with a voice, and a visual channel for awareness of the presence and participation of individuals in the meeting.

In any case, one of the most robust research findings is that video is most useful in conjunction with a suite of meeting support tools. This is consistent with the general finding, in studies of meeting support, that "the more, the better", when it comes to multimedia, and other effective tools for aiding conversations. In particular, high quality document presentation has been noted as a requirement for successful videoconferences.

Our experiences have reinforced these research findings on the usefulness of video communication. Within the Institute, videoconferences are used for live seminars, administrative meetings, and meetings to discuss new potential research themes which cross-cut existing research groups. In discussions about potential new research themes, video appears to be a catalyst for the brainstorming phase, and it then becomes less useful when a group settles in to develop ideas. At that point, e-mail becomes the primary medium of communication.

These seminars and meetings are well attended, and the scientists enjoy the video channel. But of course, reliability and ease of use are still major stumbling blocks. As our participating scientists put it ironically, "Video's great—when it works."

Our overall assessment is that scientists will not be early adopters of videoconferencing technology. If, as some observers have predicted, there is a coming wave of business users that will adopt videoconferencing³, our experience suggests that scientists will not be among the first to participate in such a development.

In part this is because there is no critical problem in scientific work solved by videoconferencing. Video is nice to have in meetings but not necessary. With a speakerphone and a whiteboard or other tools to see and revise text and pictures, groups can get work done efficiently and effectively.

We do envision a future, possibly a few years from now, in which low-quality video has become so cheap and ubiquitous that scientists will make some use of it. Desktop webcams using Internet Protocol are already proliferating. Such devices might be used to check if a person is present, for instance, and for

³ See e.g., PriceWaterhouseCoopers Technology Forecast: 1999

greetings. After that, the video frame would be ignored or even turned off, in order to focus more on the text and pictures that are at the core of technical discussions. High-quality Internet video will only be available to scientists in limited settings, such as the Astrobiology Institute, and can be used for the videoconferencing uses we have described, among others.

After a large number of scientists have access to webcams, we foresee their use shifting from videoconferencing to their use for viewing objects and settings of interest in joint work. The simplest and probably earliest examples of this would include panning around a lab to show equipment under discussion or pointing a camera at a landscape for a discussion of geology. Eventually, however, we also expect more specific applications to become more popular.

One example of this is "remote microscopy," or the sharing of a microscope between two or more people at a distance. There are many scientists for whom images from microscopes are the central, everyday concern of their team. Remote microscopy allows people to navigate within and make marks on images, and thus is a specialized form of meeting support. Considering the efficiencies of meeting support tools for even co-located conversants, remote microscopy arrangements may become preferred to sitting cheek-by-jowl and having fewer facilities for annotation.

The Mobile Web: Where No One Has Gone Before

Several colleagues are on a field trip in a remote part of Australia. The common mishap of forgetting a document is a thing of the past now that all of the maps and papers are stored on portable computers and accessible via satellite and other wireless networks. Roving over the land in vehicles and on foot, they stop in various places. They have a web camera running so researchers who were unable to travel can see and hear proceedings at the sites. This includes an ongoing conversation with a researcher at UCLA, who gives her comments and advice, based on data and images beamed to her office computer.

Broadband Internet mobile communications have not yet arrived, but will soon. By 2005, industry analysts expect at least several companies to offer broadband mobile Internet services via satellite, with a host of wholesalers and retailers selling the services. By 2010, it is expected that access prices will have dropped below five cents per minute.

In anticipation of such services, the Astrobiology Institute has begun a series of demonstration projects to test the validity of our view that such services will be a boon to scientists doing fieldwork. We believe such services will be immediately valuable in supporting the use of video as data. This phrase is used to describe

the use of live video, not to focus on the heads of people talking, but to document the places they are working and the things they are working with, and to share that visual information with others.

In the Institute, there are various activities that people call "field trips," ranging from astronomers traveling to observatories, to scientists undertaking dangerous treks in remote parts of the Arctic. For the sake of this analysis, we do not consider a trip to an observatory as field work, because the information technology needs of such an activity are essentially the same as working in the observatory. By this definition, about half of the United States scientific labor force is part of a discipline which does field work. This includes biologists, earth scientists and environmental scientists. (See Figure 2.)

Figure 2: Field Disciplines as a Share of U.S. Natural Scientists.1

From our perspective, fieldwork involves collecting data and samples outdoors using mobile objects such as maps and notebooks, typically in groups, and often in remote locations. Data collection, or generating information, is distinct from physical sample collection, although most fieldwork involves sample collection, and samples must be accompanied by at least some descriptive information, such as labels. The use of mobile objects includes activities like taking notes and annotating a map. The fact that fieldwork takes place outdoors (in a non-built environment) has implications for its practice and for the support that can be offered by information technology.

General-use technology for fieldwork has largely been developed for specialized applications, and there has been little research on the topic. We decided to begin to address this gap with studies of our own. We learned from a broad sampling of researchers who do fieldwork—including accompanying them on some trips.

We found that mobile communications will be a boon to a significant subset of researchers who work in the field. Initial applications will simply transport to the field narrowband Internet services of the types currently used in the office: voice, e-mail, and accessing the web for things such as scientific papers, contact information, and weather reports.

Among broadband applications, we believe that video has the potential to be widely used among these scientists—but not for talking heads! Rather, we expect to see the uptake of "video as data": live images of landscapes and objects.⁴ Alongside voice, and data streams from specialized instruments, video as data could lay the foundation for productive consultations with colleagues who are not able to be present in the field. Even the poor quality of webcam video available today, for example, can give a distant researcher a sense of the terrain, the

⁴ Video as data articles.

location of measurement devices and the activities and composition of the group in the field.

We also believe that field researchers will be able to make better use of mobile communications if their physical interfaces allow hands-free operation, particularly on difficult terrain. Examples of such interfaces would include wearable computing devices, voice-to-text annotation and pen-based computers.

We believe in these expectations in spite of an attitude one frequently encounters when talking to scientists about better communications between their field sites and their labs. Many scientists will extol the virtues of being isolated: "I like being away from the phone. No one bothers me." These individuals may not be among the first to embrace mobile communications.

We suspect, however, that if only some members make use of mobile technology solutions, the overall efficiency of the group will increase. It is therefore not necessary that every scientist adopt each new tool for the group to derive the benefits of mobile computing and communications, as long as someone carries the phone and other devices.

Conclusion

The NASA Astrobiology Institute is one of the world's largest experiments in geographically dispersed, interdisciplinary scientific collaboration via the Internet. But what makes the experiment distinctive is its focus on generic scientific applications.

Our experience suggests that scientists will adopt document-management tools and meeting support tools sooner than many other types of products. We expect scientists to use webcams and other forms of live video communication to communicate about objects and places, but we do not expect videoconferencing in and of itself to have a major impact on the conduct of scientific work.

The most clear-cut technology need we identified was for field scientists to have access to Internet communications. Mobile Internet technology is advancing rapidly, and is expected to become a major industry within the next few years. Estimates for the market in mobile Internet access suggest that there will be hundreds of millions of users worldwide by 2004. This new proliferation of platforms, including telephones, handheld devices and laptops, will be embraced by field scientists as soon as these technologies become mainstream.

We have considerable confidence in these expectations because they are derived from multiple sources of information, including a close acquaintance with the practicalities of scientists' work, before and after introduction of the introduction of new technologies.

Our experience does not, however, provide reliable guidance as to how rapidly or widespread these applications will become. In part, this is because the adoption

rate of these innovations will be shaped by forces other than scientists' practical needs and opportunities.

Our guess, for instance, would be that web-based document management tools might be taken up in the next year by at least 10% of working scientists in the US and Europe—if such a service were to be marketed to scientists. This estimate depends on, among other things, the widespread recognition of science as an important market for collaboration tools.

Since scientists' needs in meetings are broadly similar to that of the business community, we expect that scientists will follow trends among business users. Large business will be the first to make the investment, followed by small businesses and research organizations.

In our experience with the NASA Astrobiology Institute we are seeing how Internet technologies and related applications are enabling collaborative work among geographically dispersed teams of scientists. As is often the case, actual practice is turning out to be different than expert predictions might have expected. Perhaps this is because these visions were more expressions of marketing hopes or simply a reflection of the possibilities inherent in new technologies. Nonetheless, we see real value for certain Internet technologies in the performance of scientific work, and we have described the areas where we feel these technologies will have their most immediate impact.

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¹ Source: National Science Foundation(1995).