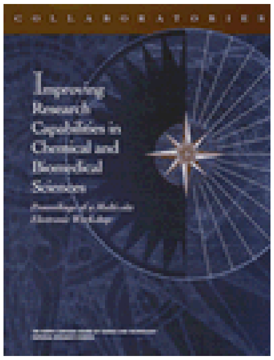

Collaboratories: Improving Research Capabilities in Chemical and Biomedical Sciences: Proceedings of a Multi-site Electronic Workshop

North Carolina Board of Science and Technology and National Research Council

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C O L L A B O R A T O R I E S

Improving Research Capabilities in Chemical and Biomedical Sciences

Proceedings of a Multi-site Electronic Workshop

North Carolina
Board of Science and Technology

and

National Research Council

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Much appreciation is extended to the facilitators and local organizers at each of the sites: Marye Anne Fox and Charles G. Moreland from North Carolina State University, Charles E. Putman and Norman L. Christensen from Duke University, William H. Glaze from the University of North Carolina at Chapel Hill, Johannes M. Boehme from Wake Forest University, and John C. Toole of the University of Illinois at Urbana-Champaign from the CDC site in Washington, D.C. They were instrumental in identifying the appropriate participants and stimulating the discussions. The University of North Carolina at Chapel Hill served as the host site for the workshop, and its staff provided much support.

Although there are many individuals to thank for bringing about this workshop, a special note of appreciation goes to Tamae Maeda Wong of the National Research Council and Cary Nourie of the North Carolina Board of Science and Technology, who first explored the idea of a multisite electronic workshop. From the State of North Carolina, the assistance of Margie Boccieri enabled us to coordinate the local organizers at multiple sites. Other staff members who should be fully recognized for their hard work in arranging the meeting and preparing the workshop proceedings are Claire Twigg of Georgetown University; Trudy Guffey of the North Carolina Board of Science and Technology; Sandra Hackman, editorial consultant; and Mark Keenan of the National Research Council. We also thank the following individuals for their participation in the review of these proceedings: Melvyn Ciment, William E. Gordon, Judith C. Hempel, James W. Poirot, and Ernest J. Wilson, III.

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Jane Smith Patterson
Senior Advisor to the Governor
for Science and Technology,
State of North Carolina

William A. Wulf
President,
National Academy of Engineering

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SUMMARY

The United States is today the undisputed world leader in science and technology. Yet the ability of the nation to remain at the forefront scientifically, and thereby benefit in economic growth, national security, environmental quality, health, education, and other areas, requires that we place increased emphasis on pursuing science and technology in an international context. To capitalize on discoveries made elsewhere and facilities located elsewhere, we must have world-class researchers who maintain constant communication and work frequently in collaboration with the best scientists around the world.

Bruce Alberts
President
National Academy of Sciences
March 25, 1998
Testimony before the
U.S. House of Representatives

The importance of international cooperation in science and technology is increasingly receiving attention as states such as North Carolina actively engage their scientific communities to improve their overall R&D capabilities and promote economic growth. Supporting research collaborations that utilize advanced computer and network technologies is one means by which to leverage scarce funds and promote scientific development. Collaboratories provide an excellent mechanism for harnessing these technologies to advance scientific frontiers.

Collaboratory—a term coined by Dr. William A. Wulf, now president of the National Academy of Engineering—combines the words "collaboration" and "laboratory." In a white paper exploring the idea almost a decade ago, Dr. Wulf defined a collaboratory as "a center without walls, in which users can perform their research without regard to geographical location—interacting with colleagues, accessing instrumentation, sharing data and computational resources, and accessing information in digital libraries." This vision is today becoming reality but faces challenges—both in creating the needed technologies and in convincing the scientific community to take full advantage of the tremendous opportunities they offer.

In 1993, the National Research Council (NRC) published a far-reaching report on the possibilities for harnessing sophisticated communication technologies to enhance scientific collaboration. This report[1] specifically examined the potential of collaboratories for sparking cutting-edge work in oceanography, space physics, and molecular biology. As the NRC report noted, researchers were then starting to use advanced computer-based tools for research, and the development of such tools was advancing steadily.

Yet the nation needed to make a conceptual leap to adopt a new paradigm for conducting science that enabled researchers in any field to easily access people, data, instruments, and results. The challenge in gaining acceptance for such networked inquiry was twofold: encouraging researchers in discrete fields, each with its own culture, to develop an interdisciplinary mind-set and work habit; and integrating the technologies needed to make high-end collaboration possible. The NRC report recommended establishing pilot projects to foster progress toward these ends.

In the six ensuing years, several pioneering collaboratories have begun to yield valuable experience and results. These efforts are being driven by two complementary trends: the growing complexity of research required to address the scientific, technological, and medical needs of the next century, and the expansion of scientific competence throughout the world. However, most of the research community has yet to learn about and fully use sophisticated networking technologies such as collaboratories that can allow researchers to ask new questions and approach research in entirely new ways.

To bridge this gap, on August 12, 1998, the National Research Council, joined by the State of North Carolina, convened a multisite electronic workshop to explore progress in and barriers to making collaboratories a central feature of research in chemical and biomedical sciences. The workshop brought together the "builders" of the communication technologies and potential "users" in the chemical and biomedical research communities. Participants included academic researchers in physical and biological sciences, university administrators, technologists, and state and federal policymakers. To demonstrate the potential of electronic technologies, this event was conducted as a "virtual workshop," relying on real-time video to allow "attendees" in several locations to participate. The North Carolina Board of Science and Technology, led by Ms. Jane Smith Patterson, Senior Advisor to the Governor for Science and Technology, pioneered many advanced technology programs in support of research such as the state information highway, and served as a co-organizer and sponsor. Thus, the workshop linked participants from four

[1]National Research Council. 1993. *National Collaboratories: Applying Information Technology for Scientific Research*, National Academy Press, Washington, D.C.

North Carolina locations: North Carolina State University, Wake Forest University, Duke University, and the University of North Carolina at Chapel Hill, as well as the Centers for Disease Control and Prevention (CDC) in Washington, D.C.

Workshop speakers were asked to provide an overview defining the benefits of collaboratories and inform the general participants on the status of pilot programs and applications. They were also asked to articulate issues that arise when research and educational activities are conducted using collaboratories. The role of the facilitators at each site was to stimulate discussions and explore questions on the potential impact of collaboratories in basic research fields. Jane Smith Patterson and William Wulf served as moderators, participating from the main site of the workshop, the University of North Carolina at Chapel Hill.

As workshop speakers pointed out, until recently collaborative research has required face-to-face contact, and the process of sharing results and responding to new discoveries has required extended amounts of time. But more bandwidth and higher computing speeds now enable researchers based in many different locations to share vast amounts of complex data and sophisticated models and to jointly analyze results. Audio and video conferencing, shared computer displays, online notebooks to which multiple researchers contribute, and remotely controlled laboratory instruments are only a few of the tools being developed to serve these needs. Dr. Wulf, in his presentation, articulated his original vision for collaboratories and conveyed excitement for a system that will revolutionize the scientific process.

The U.S. Department of Energy (DOE) has been a primary funder of these technologies, as well as pilot projects, through its DOE 2000 initiative, and the workshop included several representatives from these efforts. Dr. James D. Myers of the Pacific Northwest National Laboratory explained the various kinds of interdisciplinary collaborations and biochemical research tools that his institution is spearheading under the DOE program. Dr. Mary Anne Scott of DOE detailed several interdisciplinary projects and advanced collaboratory technologies being funded by her agency. And Dr. Ralph L. Scott described a collaboratory effort by DOE to make a myriad of information available online in multiple formats—in effect, a new kind of online library—to both researchers and the public.

To emphasize their international potential, Dr. S. Yona Ettinger of the U.S.-Israel Binational Science Foundation described international collaboratories devoted to chemical research. He also highlighted collaboratories' potential for training medical professionals in remote areas and enabling small countries to participate in state-of-the-art research. Dr. John W. Jost of the International Union of Pure and Applied Chemistry, which sets standards for chemical research worldwide, discussed the need for compatibility even among mundane communication tools to make the standard-setting process more effective. Ms. Patterson spoke to North Carolina's potential for furthering the collaboratory concept and promoting academic research and industrial development.

During the event, attendees from various locations engaged in discussions facilitated by Dr. Marye Anne Fox from North Carolina State University, Dr. Charles

E. Putman and Dr. Norman L. Christensen from Duke University, Dr. William H. Glaze from the University of North Carolina at Chapel Hill, Dr. Johannes M. Boehme from Wake Forest University, and Dr. John C. Toole of the University of Illinois at Urbana-Champaign from the CDC site in Washington, D.C. A primary concern that emerged from these exchanges was the need to support collaboratory technologies, as well as interdisciplinary research, where benefits are the greatest. Dr. Wulf cited the Space Physics and Aeronomy Research Collaboratory[2] as an example of combining data and knowledge from different groups to yield much greater results than if the data were analyzed separately. Dr. Christensen, Dean of the Nicholas School of the Environment at Duke University also pointed out that collaboratories are vehicles for bridging differences among the disciplines and that doing so "is incredibly important if we are to focus on compelling, large-scale problems." He saw a "particularly important set of opportunities" for electronically mediated research collaborations on North Carolina's coastal environment because "universities, shoreline research institutions, and offshore vessels must keep in close contact." Collaboratories allow a "delicate balance" to exist that acknowledges the differences among disciplines while working toward a common research goal.

To date, the use of interactive technology has varied greatly from discipline to discipline and across fields and institutions. Dr. Myers pointed out that the norms for sharing data, as well as for publication and peer review, varied significantly. In an article by Wulf et al.,[3] sociological issues that enable collaboratories in various fields were discussed. "Collaborative technologies will have to provide the autonomy, trust, sense of place, and attention to ritual that foster creativity among participants." The payoff is achieving research capabilities that greatly exceed those available in any single laboratory.

Researchers in several disciplines expressed interest in exploring how their research field can utilize collaboratories. Discussions of the key issues necessary to enable collaboratories focused on institutional infrastructure and funding support. Participants noted that the collaboratory concept focuses on spanning disciplines whereas most science funding is awarded through individual disciplines. Common infrastructure and collaboratory tool development that could enhance all fields require funding support from various sources. Ms. Patterson cited North Carolina's experience in building backbone technology for the statewide information highway and encouraged others to factor in technology costs as an essential aid for teaching and research. She suggested that faculty members insist on access to sophisticated communications technology as a condition of work, much as industries require such infrastructure before locating in a given region. Dr. Robert

[2]Formerly known as the Upper Atmospheric Research Collaboratory.

[3]*Collaboratories: Doing Science On The Internet*, Richard T. Kouzes, James D. Myers, William A. Wulf, *IEEE Computer*, Volume 29, Number 8, August 1996.

Annechiarico, Director of Research Computing in the Department of Public Health Science at Wake Forest University, underscored the need to put the collaboratory concept high on the agenda of funding agencies. Only when the principal investigators demand it will universities and agencies be able to provide the necessary tools and funds.

Although advances in electronic communication were considered important, concern for the "up-front" costs, particularly for smaller and remote sites, was raised. The technology costs could pose a barrier to smaller institutions—yet these are the very institutions that could most benefit from electronically mediated research. Dr. Melvin Johnson, Associate Vice Chancellor for Academic Affairs at North Carolina A&T State University inquired about minimum system requirements for participation and was informed that currently it can be a simple Internet connection through a modem, as long as video is not required. Dr. Alan Blatecky of MCNC emphasized the value of next-generation tools to provide better high-speed connections for all institutions regardless of size, thus "leveling the playing field." Further discussion of international participation with developing countries also raised similar concerns.

To allow seamless interfaces among people, scientific instruments, computer tools, and networks, Dr. Boehme at Wake Forest University stressed the importance of technology standards for interactive tools. Dr. Myers cited the Department of Energy's efforts as well as those of private industry in working with scientists, software developers, and instrumentation companies to establish protocols for the communications interface. He also noted that the Collaborative Electronic Notebook System Association involving chemical and pharmaceutical companies is exploring the issue of standards while also addressing electronic issues such as document authenticity. On this topic, agencies such as the Patent Office and the Food and Drug Administration are working to determine how electronic notebooks can substitute for paper notebooks in submissions to regulatory agencies.

Participants proved highly interested in using collaboratories to enhance education and promote graduate and undergraduate research. Dr. Marye Anne Fox, Chancellor at North Carolina State University, initiated discussions on the impact of collaboratories on graduate training in interdisciplinary research. Noting the example of the Space Physics and Aeronomy Research Collaboratory, Dr. Myers pointed out that graduate students from several disciplines now interact in this cutting-edge collaboratory, which involves remote accessing of radiotelescopes in Greenland and sharing information and analysis from various sites around the world. Thus, students are given opportunities that have traditionally been reserved for principal investigators. Dr. Glaze also pointed out that collaboratories will play a significant role in undergraduate education, serving as "virtual study abroad." Such study will prove "not quite the same as being there but nevertheless give students flexibility to try new things."

Participants also expressed keen interest in using collaboratories to facilitate joint research with scientists and engineers globally. Dr. Bettie Sue Masters, a biochemist from the University of Texas Health Science Center at San Antonio and Chair of the U.S. National Committee for the International Union of Biochemistry and Molecular Biology, iterated the value of technology links for international cooperation, citing the new opportunities for interaction through, for example, Internet symposia and online journals. Dr. Brian Hoffman of Northwestern University pointed out that international collaboration in biophysics and biochemistry is already widespread, where the best researchers working on a particular protein will interact from different laboratories in different countries. As research collaborations become increasingly dependent on advanced technologies, concern was raised for the scientists in developing countries that lack the basic infrastructure. Dr. Irving Lerch, Director of International Affairs for the American Physical Society, acknowledged that electronically enhanced physics collaborations in Asia, Europe, and the United States have proved productive, but that tapping into the intellectual resources of Africa and Latin America has been challenging because of the limited telecommunication networks. High-tech tools thus threaten to leave research in less developed regions "in the dust." Debating potential solutions to this problem, participants agreed that a partnership between the commercial sector and the government is required to provide the needed communication infrastructure. Dr. Wulf further added that satellite communications, over land-based systems, are likely to change the issues dramatically in a fairly short period of time. Ms. Patterson agreed, saying that although researchers and institutions will inevitably have to pay to use the telecommunications network, sophisticated infrastructure, including wireless, is already being deployed around the world, including Africa. The primary issue that remains is therefore the cost of connectivity and adequate bandwidth.

Different forms of collaboratories now support various research areas. Yet information on these collaboratories and the underlying technology tools enabling research collaborations are not widely disseminated. Dr. Wulf stressed a need "to just publicize these activities . . . as a first step." Dr. Greg Forest of the University of North Carolina at Chapel Hill and Dr. Alan Blatecky of MCNC noted the value of a clearinghouse to serve as a repository for shareware and to evaluate technologies for establishing standards. Dr. Marye Anne Fox of North Carolina State University saw a role for institutions such as the National Academies to lead such efforts involving the scientific community at large. Too often today, attendees noted, existing collaboratories and their results go unnoticed by the larger scientific community and the public.

Finally, participants acknowledged the potential twofold payoff of collaboratories: they both enhance the productivity of research and stimulate economic development. In North Carolina, the driving force for developing a statewide technology infrastructure was to support research and facilitate technology transfer. Dr. Psalmonds commented that increased productivity from collaboratories offers an exciting opportunity for stimulating economic development through university-industry partnerships. By encouraging the flow of promising research from the public to the private sector, collaboratories can help incubate commercially useful techniques. Dr. John Simon of Duke University commented that by "interlacing researchers, collaboratories can produce more bang for the buck."

Overall, the enthusiastic participation of site leaders and attendees yielded thoughtful ideas on near-term needs, long-term goals, and concrete steps for fulfilling the enormous potential of collaboratories. Dr. Glaze summed up the general tenor of the meeting by identifying two immediate needs for making collaboratories a central model for scientific research: "pushing the envelope" of the technology that makes collaboratories possible and further exploring the sociological aspects of education and interdisciplinary research collaborations. Dr. Wulf agreed that it is "impossible to predict precisely" how collaboratories can best be employed and that prototypes involving real users are critical first steps in exploring their potential. Conferees encouraged institutions and researchers worldwide to pursue the exciting opportunities offered by electronically mediated collaboration in opening new doors to scientific discovery.

IMPROVING RESEARCH CAPABILITIES THROUGH COLLABORATORIES

WILLIAM A. WULF
NATIONAL ACADEMY OF ENGINEERING

When I was asked to become Assistant Director of the National Science Foundation (NSF) in 1988, I had a few months before I began my new job in which to ponder what I could do that would really make a difference. It soon became perfectly clear that I could leverage the productivity of engineers and scientists, encourage interdisciplinary work, and expand the pool of researchers with information technology. The concept became known as "collaboratory"—a contraction of the words "collaboration" and "laboratory"—and consists of a computing environment that supports research among scientists and engineers that are not collocated.

For example, we talk a lot about interdisciplinary research, but the probability that the right people to attack a particular problem will be physically collocated is actually low. This is especially true in smaller institutions. Moreover, a large number of bright young Ph.D.s go to teach at four-year colleges and find a shortage of colleagues to work with either in their area or in related ones. Exacerbating this problem is the fact that instrumentation is becoming more and more crucial to research but also getting more and more expensive; we can't replicate it everywhere. There is a huge talent pool we are not tapping into because many young researchers do not have access to the best equipment.

It seemed to me that a seamless interface between a computational environment and a physical experimental environment, and possibly even a theoretical one, would help address these problems and also advance science. It also seemed obvious that we could accomplish this with the technology then available. In 1988 the Internet was reasonably fast, and we had T-1 lines[1] across the country. We had what we thought were powerful workstations as well as supercomputer centers. More and more instruments were collecting data in digital form. Work on visualization had become quite advanced, and virtual reality was demonstrable. So a physical environment existed for creating collaboratories. Moreover, a community composed primarily of psychologists was beginning to study the sociology entailed in computer-supported cooperative science and engineering research. But

[1]T-1 line: 1.544 megabytes per second.

I had no concept of how hard it would be to move from my first insights to where we are today.

There are at least three reasons why electronically based collaboration hasn't advanced faster and further. One concerns funding. The federal bureaucracy doesn't help much in this kind of cutting-edge situation. While at NSF, I had to carve money out of my budget that was supposed to be spent on computer science—a heretical move—to support collaborative work with physicists and chemists. Moreover, information on the sociology of cooperation, although becoming available, was still sparse. I realized that the community studying that sociology had some distance to go when I found that the papers for their conference were produced on typewriters.

But the predominant reason for the slow pace in moving toward collaboratories was the relatively low demand from the research community: practicing scientists did not fully understand or appreciate the potential. And since the benefits were not obvious, they were not willing to allocate scarce research dollars for developing the needed but not well-defined tools. In an environment where everyone believes that science and engineering research is underfunded, the notion of giving up dollars that could be used to produce useful results doesn't make much sense to the bench scientist or engineer.

I have therefore spent a significant part of my time over the intervening 10 years trying to convince people of the technology's potential. Most everyone understands Moore's Law, which postulates that the density of computer chips doubles about every 18 months. But the impact of Moore's Law—and thus the potential for changing science—is sometimes hard to appreciate. One example, perhaps, can bring home this potential.

Two and one half years ago, the ENIAC, arguably the first electronic digital computer in the United States, celebrated its fiftieth anniversary. The ENIAC was built at the University of Pennsylvania, primarily to calculate ballistics tables. It weighed 30 tons, had 18,000 vacuum tubes, and filled a space roughly the size of a squash court. Today I carry a computer in my briefcase that is a hundred times faster. When I tell people that, they think I mean my laptop, but I'm referring to a Valentine's Day card that plays a tune when I open it. The computer in that card is a hundred times faster than the ENIAC. It is not a hundred times more powerful—that's a little different. But the point is that the card cost $3 and that it represents a use of technology that would have been absolutely inconceivable to anyone who built the ENIAC. Even if we had known Moore's Law, we would not have guessed this particular outcome.

Most everyone knows about IBM's marketing study that predicted a market for only half a dozen computing machines. The company was thinking in terms of computing ballistics tables. Ken Olsen, past president of Digital Equipment Corporation and probably the fastest-rising star in the 1970s, said at an annual meeting in 1978 that he could see no reason why anyone would want a computer in their home. This was two years before the introduction of the personal computer. Bill Gates wondered why anyone would want more than 640 kilobytes of memory. I carry 32 megabytes now, and I wish it were 64. In each case, people made assumptions about what the technology could be used for. Bench scientists have the same problem—one we somehow have to surmount.

I must admit that I, too, made a lot of assumptions in 1988 when I began talking about collaboratories. For example, I didn't think about technology's implications for communications: 1988 was five years before the advent of the World Wide Web. I thought of electronic documents as e-mail or text files for word processing, not as hyperlinked documents with motion and sound.

I have now come to believe that the paper document is dead; we are just not aware of it yet. A user is much more likely to follow a hyperlink than to look up a reference; the effort involved is just incommensurate. Hyperlinks will change the way we write. And a few years from now we will not be able to put a research report on paper even if we want to, partly because it will contain motion and sound. We have learned about the importance of visualization and animation to the understanding of physical phenomena. That possibility is cut off when we put something on paper. Why do we hinder the communication of the understanding we ourselves gained from our animated visualizations when we try to convey that understanding to others? It doesn't make sense, and the technology that prohibits that communication—paper—is doomed as a result.

But the possibilities go much further. One of the principles of the scientific method is that scientists should be able to reproduce an experiment. In practice that doesn't happen as often as it should because the effort involved is so large. If computers further automate laboratory equipment, we may be able to embed in a research article the program that controlled the experiment. In a very real sense the article would include the experiment. I would then be able to click on a graph and not simply see the data but also feed them into my model—and feed my data into the other researcher's model. Such abilities will enable participants to reproduce and build on experiments much more easily. All of these developments will change the sociology of research. We are talking not simply about using a technology but about changing the types of questions we can ask and improving research capabilities. That is the goal.

One of my favorite prototypes for illustrating how collaboratories can change the nature and quality of science is the Space Physics and Aeronomy Research Collaboratory.[2] This facility is a multidisciplinary research collaboration that allows scientists from globally dispersed sites to participate in team science and education projects. In 1993 we prepared a report entitled *National Collaboratories: Applying Information Technology for Scientific Research*. One of the scientists from that activity was a solar physicist, and it was from his experience and the National

[2]Formerly known as the Upper Atmospheric Research Collaboratory based at the University of Michigan.

Research Council report that the Space Physics and Aeronomy Research Collaboratory facility was built.

What are the next steps down this road? Cooperative research projects that rely on electronic tools, whether called collaboratories or not, will occur as the natural evolution of today's research. The only question is whether we will build collaboratories more or less quickly, whether we will build them to interoperate, and whether we will develop standards that help leverage the results. This report, and the electronic town meeting on which it is based, were designed to help ensure that such leveraging would occur.

TOOLS FOR COLLABORATION

JAMES D. MYERS
PACIFIC NORTHWEST NATIONAL LABORATORY

At Pacific Northwest National Laboratory we have created a collaboratory at the Environmental Molecular Sciences Laboratory (EMSL), a facility that opened its doors in 1997. EMSL encompasses about 200 researchers, some 70 laboratories, and one of the world's fastest supercomputers, all basically doing molecular-level research to enhance our understanding of environmental issues. The EMSL is a U.S. Department of Energy (DOE) user facility. About half of the time on EMSL instruments is available to outside users. EMSL is located in the middle of a desert in eastern Washington and is fairly difficult to reach. Given this challenge, providing an electronic means for outside users to do research there, and for onsite researchers to collaborate with outside scientists, is a priority. For these reasons and to support EMSL's interdisciplinary approach, we have wholeheartedly adopted the concept of electronic collaborative research.

Much of the research that EMSL does that is related to collaboratories is done in partnership with many national laboratories, universities, and companies, as a participant in DOE's DOE 2000 Project. EMSL is also collaborating with the National Center for Supercomputing Applications at the University of Illinois, Urbana-Champaign to develop real-time electronic tools for collaborative research and the Collaborative Electronic Notebook Systems Association, a consortium of chemical and pharmaceutical companies to promote electronic notebooks.

One direction for the development of collaborative tools is to support real-time interactions. Such tools include video conferencing, shared browsers, whiteboards, chat boxes, and shared applications. These technologies enable participants to discuss data, draw sketches directly on a whiteboard that others can view, call up data in their visualization applications and rotate and zoom-in on images, and easily guide each other across the Web. Remote camera controllers allow users to pan, tilt, and zoom the camera around a room, focusing on a lecturer or members of an audience if desired. In the laboratory it can focus on equipment or view experimental procedures.

Another new technology is an electronic notebook, the equivalent of a bound paper laboratory notebook that enables scientists to use the Web to post text, images, data files, and graphs for colleagues. Anyone with a modern computer, a good Internet connection, and an inexpensive camera and echo canceller can collaborate using these tools. We may one day collaborate in three-dimensional immersive environments wearing stereo goggles, but no such fancy equipment is needed to collaborate remotely today. As scientists use Internet collaboration tools more frequently, they will become integral to the overall research environment.

Before deciding which tools to use in their work, researchers first need to consider what occurs when they do science and how collaboration can help. Setting up a collaboratory is not simply a matter of running a remote experiment. Remote control software may let participants perform the experiment, but they will also need access to the sample preparation procedures, instrument settings, and other information usually recorded in a local paper notebook today. Before the experiment can be considered, potential participants must discover the remote resource, understand its capabilities, contact the local researchers, develop trust, and perhaps receive training on a remote instrument. Even if the researchers decide to visit the EMSL to conduct the actual experiment, they can meet people, understand procedures, and learn about the instrument before they arrive. Remote researchers must also find effective techniques for analyzing the data and consulting with coresearchers in writing up publications. Because scientific data are often complex and multidimensional, researchers will need to be able to confer with local researchers familiar with analysis of data from EMSL instruments.

Taking all such tasks into consideration allows one to identify the suite of tools that can best help facilitate the collaboration. Because every scientist does unique work and experiments are by definition at the cutting edge, scientific collaborations do not lend themselves to a cut-and-dried business or assembly-line approach. No one can say, "I want the latest quarterly numbers so I can run them through the same spreadsheet I ran them through last week" and work only by mailing data files around. Instead, researchers must be able to confer, analyze preliminary data, develop hypotheses, perform additional experiments, and think together in a very dynamic, exploratory fashion.

Complicating the process even further is the fact that the collaborative part of research can be intermittent. A scientist may take six months to build a new piece of equipment and only then be ready to collaborate. Collaborative tools need to be simple so that once people are trained to use them, they do not forget everything by the time they are ready to collaborate.

When we started developing the EMSL collaboratory about five years ago, we first interviewed researchers in the laboratories to understand their needs. This information enabled us to divide collaborations into four general types that involve different modes of communication. The first is peer to peer, in which two people work in the same discipline, often wanting joint remote access to an instrument to obtain raw data. The second, mentor-student collaboration, requires much more interaction. One person often demonstrates a technique as the other watches and then observes as the other tries to replicate it. Interdisciplinary research, a third type, entails many of the same interactions as mentor-student collaborations. Each participant brings a certain base of knowledge to the experiment. As the participants work together, each becomes the student of the other in their respective fields. The final form of collaboration involves what I call producer-consumer work, in which people performing the experiment are looking for results and nothing more. A biologist may not want to know how a specific research technique such as mass spectroscopy works, nor do they want to operate such an instrument remotely. They may simply want their collaborator to determine a protein's sequence for them. Thinking about collaboration in these terms helps us understand what tools—remote instrument control, conferencing, whiteboards, electronic notebooks—will be most helpful for a particular group.

To create a collaboratory involving EMSL's nuclear magnetic resonance (NMR) facility, we initially provided basic tools, including video conferencing, whiteboards, and an electronic notebook to one group studying the three-dimensional structure of a particular protein. We also gave the remote researcher access to the NMR spectrometer control software via the Internet, allowing him to run experiments remotely. While we did not have to change the spectrometer software to do this (it uses the X-Windows protocol), we did have to deploy additional software that encrypted all communications between NMR spectrometer and remote user to ensure that unauthorized users could not gain control of the spectrometer.

We watched how this group collaborated over the Internet and then started looking at what else we could do to help them. We saw that the researchers were using a very tedious process to share the experiment parameters (nearly 20 pages of voltages, frequencies, time delays, amplifier settings, etc., that a local researcher would usually print a copy of). They would save the parameters as a text file, open the Web browser, log-in to the notebook, upload the text file, and then view it as one long scrollable page. We made this much easier by writing software that allowed the parameters to be sent to the notebook directly from the instrument control software at the click of a button, with no need to start a browser or go through the notebook log-in screen. We also designed an extension to the notebook that allows users to easily search for a given parameter. Rather than scrolling through pages of text, users can now type in the first couple of letters of a parameter name, or choose one from a list, and see its value in a simple text box. By making these changes it became easier for both the local and the remote researchers to work on the electronic notebook than on paper.

Another enhancement we made involved integrating Java software developed at the European Molecular Biology Laboratory (EMBL) that can display Brookhaven Protein Databank files as three-dimensional molecules into the electronic notebook. As the group analyzed its NMR data, the researchers proposed protein structures that were consistent with the data. At first, the researchers exchanged these files as text in the notebook—as columns of numbers representing the X, Y, and Z coordinates of all the atoms in the molecule. Obviously these numbers are much more difficult to interpret than a three-dimensional rendering of the molecule. Integrating the EMBL software into the notebook made it possible to view the protein structure, rotate the molecule, query bond links and angles, and so forth, without having to use any other applications. These enhancements make it easy for participants to go from the experiment to the collaboration and back. Collaboration becomes more informal and more integral to the experiment rather than being a separate laborious task that can be delayed or forgotten. Collaboration occurs as part of the research rather than through a report after the experiment is done.

While using appropriate technologies and integrating collaboration tools into the experimental process are important aspects of making collaboratory interactions successful, we also need to consider the effects of these technologies and collaboratory practices on the personnel and organizations involved. For example, today an experimentalist must be a machinist, a pump mechanic, a laser technician, a chemist, and a grant writer to be successful. In collaboratories these jobs can be separated, with individuals specializing in each area and sharing their expertise. For example, in collaborative high-energy physics projects, engineers build advanced light sources and then chemists use those light sources to perform experiments. With collaboratories this type of specialization may occur more frequently, on smaller instruments—at a finer scale—than it does now.

Conversely, collaboratories will allow individuals to expand their range of collaborations more widely as well. Today, chemists who study a molecule and have questions about it that cannot be answered using the instruments available in their own laboratory often have to wait for someone else with the appropriate instrumentation to see the questions in the literature and try to answer them. Researchers have no ability to pursue interesting questions regarding a chemical system through a series of experiments unless they can buy or build all the necessary instruments. Collaboratories will allow researchers to quickly obtain temporary access to additional resources, speeding the pace of scientific progress.

At an institutional level, although one institution might not be able to afford a state-of-the-art spectrometer, four together could obtain one and give everyone equal access to a more capable resource. Institutions can also assemble a scientific "SWAT team" to tackle a new problem—composed of, say, a geochemist, a chemist, a physicist, and some computer people—without having to build a facility and wrangle participants away from their home institutions before work can begin. Participants can rapidly form an "Institute for the Study of X" by repurposing facilities at six different sites. Such an institute can be exactly what the users want and need.

Collaboratories may prove particularly important in bringing scientists at small undergraduate-only institutions back into mainstream research. While researchers at these institutions would never be able to obtain startup funds to build half-million-dollar-plus instruments to work with undergraduates, collaboratories will allow them to use instruments at other locations. Access to remote peers will be just as important as access to instruments. It can be very difficult to stay current in a two-person chemistry department; having remote colleagues who are easily accessible over the Internet could help tackle scientific problems, stimulate discussions, and provide an informal way to get peer review comments.

Collaboratories will allow students to participate in experiments more readily than they can today. Undergraduates will be able to join research teams via collaboratories throughout the year, gaining experiences that are available today only through a limited number of short "summer" fellowships. Increased communication between researchers, students, and educators may also help improve the linkage between formal classroom studies and research experiences.

These examples are meant to show that, in addition to deploying collaboration technologies, we will have to rethink the way we do scientific research and change some of our processes, policies, and expectations to realize the promise of collaboratories. The EMSL collaboratory's logo is a mathematical puzzle with three rings that cannot be pulled apart—yet without the third ring, any two of them will slide apart easily. The whole is more than the sum of the parts. The same metaphor applies to collaboratories. They require some technology and sociology to make possible collaboration among specialists in different disciplines. The result is something new and far greater than the individual components.

THE DOE 2000 PROJECT

MARY ANNE SCOTT
U.S. DEPARTMENT OF ENERGY,
OFFICE OF ADVANCED SCIENTIFIC COMPUTING

Collaboratories are limited only by our imaginations and the time technology takes to advance enough to fulfill that vision. Electronic collaboration is not only an important research tool; it can also leverage resources in today's constrained R&D environment. The U.S. Department of Energy's DOE 2000 Project has therefore been fostering specific collaboratories as well as funding research on networking and communications technologies essential to support collaborations. We are still building the foundations.

Just over three years ago, DOE decided that some collaboration tools were mature enough to warrant a focused program: it was time to put them in the hands of scientists to determine what works and what doesn't. The measure of success would be a positive impact on the way science is done and what it accomplishes. Our hope was that collaboratories would enable scientists to perform research that was impossible before.

The DOE 2000 program was funded in fiscal year 1997. Because collaboratories are aimed at linking people, computers, data, and facilities, the program was designed to reveal how all of these elements could contribute to a wide range of R&D and applications.

The program has three parts. First, there are the R&D projects on advanced computing software tools. These projects use research in applied mathematics and computer science to develop an integrated set of high-performance tools that can simulate complex systems in various disciplines. The intent is that these tools will remain in use over many generations of computer hardware. These tools will represent complex geometries, solve diverse equations, simplify the execution of codes assembled of modules written in different languages, evaluate and enhance the performance of applications codes, and dynamically steer calculations—for example, changing the convergence threshold of a module.

The second part of the program funds a mix of short and long-term R&D on tools for making collaboratories themselves possible. Again, we take the results of fundamental research, this time in computer science and networking, and develop an integrated set of tools to enable scientists to remotely access and control facilities and share data and information in real time. Specific projects include:

- Defining and demonstrating security architecture based on Public Key Infrastructure (PKI) that can protect proprietary data and hence make such data remotely accessible. The same architecture will be designed to provide remote access to those authorized to operate experimental devices.
- Development of differentiated services within the research network that will provide reserved bandwidth to support applications requiring sustained bandwidth.
- Developing a prototype modular electronic notebook that can be used in a number of desktop computer environments. This notebook will enable scientists to design experimental procedures jointly and share their data from scientific instruments.
- Developing such tools as video conferences to manage distributed collaborations. These tools range from those that allow "whoever is speaking" to have "the floor" to those that allow a meeting leader to control the floor.
- Developing advanced techniques for managing the electronic record of the collaboration—that is, the creation of persistent representations of sessions and people that include audio/video, electronic notebooks, and electronic whiteboards.
- Exploring such techniques as virtual reality that enable large groups to work together effectively at a distance.
- A collaborative framework for pursuing these projects will allow all of the tools to interoperate.

The third and most important part of the DOE 2000 program is pilot collaboratories, in which we test, validate, and apply the tools we have developed in partnership with other programs in the Division of Energy Research and other DOE offices. DOE 2000 now maintains two pilot projects:

1. The Materials Microcharacterization Collaboratory (MMC) is a partnership between DOE's Office of Basic Energy Sciences and Office of Energy Efficiency and Renewable Energy to provide remote access to facilities that perform electron-beam microcharacterization of materials. Its goal is to furnish a common interface to remote users, both novice and advanced. The facilities, which are unique but complementary, are located at Oak Ridge National Laboratory (ORNL), Lawrence Berkeley National Laboratory (LBNL), Argonne National Laboratory (ANL), the National Institute of Standards and Technology, and the University of Illinois.

2. The Diesel Combustion Collaboratory (DCC) is a partnership to develop the next generation of clean diesel engines. This collaboration brings together the same three divisions of DOE plus researchers at three U.S. manufacturers of diesel engines and Sandia National Laboratory, Lawrence Livermore National Laboratory, LBNL, and the University of Wisconsin. These pilot

projects use tools developed under the DOE 2000 program as well as those available commercially.

Brian Toner, who runs a small research laboratory for surface studies in the Physics Department at the University of Wisconsin in Milwaukee, is a participant. He is developing bioremediation methods for cleaning up transition metal actinide pollutants and has done microscopy work at several locations, including LBNL. About four years ago a group from LBNL asked whether he was interested in participating in Distributed Collaborative Experiment Environments, a program that would enable him to use the Advanced Light Source (ALS) to run his experiment remotely. The ALS lends itself especially well to a remote collaborative environment or virtual laboratory, having been designed to support remote collaborations and operations as technology advances to make this possible.

Dr. Toner was initially skeptical but decided to become part of the team for two years. It didn't take long for him to become an advocate. Today the SpectroMicroscopy facility at the Advanced Light Source (ALS) Beamline 7 enables a large and geographically distributed collaboration, part of a rapidly expanding user community, to make analytical use of synchrotron radiation. Dr. Toner now does his research without leaving Milwaukee, although his graduate students travel to the facility to set up new experiments. Funding for the original project has expired, but Dr. Toner maintains his participation because the ALS tools have changed the way he does his research.

ALS Beamline 7 was designed to provide spatially resolved chemical information at lengths from below 1 micron to the atomic scale, in the case of photoelectron diffraction structural imaging. The facility's capabilities are beyond those of any other in the world, with the possible exception of one or two sites with similar soft x-ray undulator beamlines. Because of the unique capabilities of these instruments, the SpectroMicroscopy Project was conceived from the outset as a rather large collaboration. These machines represent a substantial investment in training, staffing, time, and travel costs, so plainly the success of the collaboratory would have far-reaching implications for users of the SpectroMicroscopy facility, ALS, and synchrotron radiation sources in general.

In the other pilot project, Chaitanya Narula, a research scientist at Ford Research Laboratory in Dearborn, Michigan, is trying to find new catalysts to reduce NO_x emissions from diesel engine exhausts. The platinum (Pt) clusters (the catalyst) are supported on titania (TiO_2) particles. To be effective, the Pt clusters should be small and uniformly distributed on the TiO_2 (titania) particles, which should also be as small as possible. But were they? Ford sent a sample to ORNL's High-Temperature Materials Laboratory to be examined on its electron microscope.

Dr. Narula didn't have to leave his office to get the answer because he can use his PC and the Internet to control the microscope at ORNL remotely and also to obtain advice from ORNL microscopy experts. When he examined the results, he found that the platinum clusters were 2 to 5 nanometers in size and not uniformly distributed, while the TiO_2 particles averaged 20 to 50 nm in diameter. So it was back to the drawing board. Dr. Narula tried a different processing technique and sent a new sample to ORNL within a week. Ford and ORNL researchers examined the new samples together across the Internet. This time the platinum clusters were uniformly distributed and only 0.5 to 1 nm in diameter on TiO_2 particles that were 5 to 10 nm in diameter.

Dr. Narula still needed to find out if the clusters were really platinum. The sample was forwarded to ANL, another member of the DOE 2000 project. Using the Advanced Analytical Microscope at ANL and a three-way telepresence session, participants confirmed that the particles were indeed platinum. All of this was accomplished in a few short weeks rather than months as would normally be required.

The Diesel Combustion Collaboratory (DCC) provides another example of a successful electronic collaboration. For a dozen or so years the major U.S. diesel manufacturers have teamed with laboratory researchers in precompetitive research to understand how to design better diesel engines. The agreements they are working under call for quarterly meetings in which experimentalists and modelers discuss progress and analyze results with representatives from the manufacturers. The problem is that the emission standards of the U.S. Environmental Protection Agency are very stringent, and manufacturers are hard pressed to meet them. The goal for the DCC is to use collaborative technologies to speed up the process whereby the experimentalists and modelers agree on how to improve engine design. Toward that end, a group is working on such tools as Web-accessible data archives, with the appropriate security, and remote execution of computational models.

Early on in the collaboratory, at one of the quarterly review meetings, a representative from Cummins Engine Company showed a slide comparing his analysis with the latest data from a Sandia National Laboratory experiment. The Sandia experimentalist, John Dec, immediately asked, "Where did you get that? That looks just like my slide." The Cummins engineer had taken advantage of the collaboratory's newly installed shared work space to download an electronic version of the slide without having to bother Dr. Dec. This is a simple example, but it illustrates how such techniques save time and effort.

Dr. Dec may have been surprised the first time he saw his data being reused, but he has many reasons to be pleased with similar capabilities. He has generated more than 35 gigabytes of experimental data over the past few years from his combustion rig, but proprietary software, obsolete hardware, and other factors have made simply collecting that information in a form that could be analyzed time consuming. The collaboratory has provided a secure data archive to replace this outmoded approach. Dr. Dec can now access his data from any location with a Web browser instead of making a trip to the laboratory.

Of course, protecting proprietary information in this environment is very important, and new security mechanisms being developed on this project are addressing this issue. For example, the image library used by researchers in the DCC is protected by a software implementation of a policy-based access system—the Akenti Policy Engine—that uses public-key-based authentication coupled with secure communications.

Instead of sending massive amounts of data to individual routers, the Internet's Multicast Backbone, Mbone for short, routes real-time communications over the Net by distributing and replicating the data stream only as needed, thus efficiently distributing data packets without congesting any single route. Mbone was created by Van Jacobson of LBNL; Steve Deering, then of Xerox Corporation's Palo Alto Research Center; and Steve Casner of the University of Southern California. Mbone technology was used to establish the first multicast video and audio link to the South Pole—between the LBNL and scientists at the U.S. Amundsen-Scott Station—in early April 1998. Mbone video conferencing tools, developed by Van Jacobson and Steve McCanne at LBNL, exchange live sound and pictures between remote locations far less expensively than any other method. This link is permanent, although it works only when a satellite is in the right position. The connection allows scientists in the Antarctic and the United States to jointly manage and work on the Antarctic Muon and Neutrino Detector Array, which uses instrument probes thousands of meters deep in boreholes in the polar ice.

When this link was initiated, school children also got into the act. Real-time interaction via Mbone between students in the United States and researchers at the South Pole was featured in "Live from the Poles," an hour-long television special produced by the National Aeronautics and Space Administration's Passport to Knowledge project. This project, distributed by almost 300 public television stations across the nation and by NASA-TV, is just one example of what this technology has to offer education. Schools everywhere can interact with astronomers at mountain-top observatories, biologists in the rain forest, geologists on the slopes of live volcanoes, oceanographers under the sea, and astronauts aboard the Space Station.

In 1997 one of the members of the MMC, Edgar Voelkl, visited his hometown of Regensburg, Germany, to attend a conference. The conference organizer became quite excited when Edgar suggested operating his U.S.-based electron microscope remotely during the program. Edgar also encountered a lot of skepticism, but he didn't let it influence his plans. The local newspaper announced the remote operation as one of two highlights of the upcoming meeting: "World premier at the university: A highly sophisticated instrument in the American Oak Ridge (Tennessee) will be operated live through the Internet."

On the night of the session the lecture hall was almost filled. It was obvious that many came to scoff, but it was all in vain. Toward the end of Edgar's talk, the connection to ORNL was established and the microscope was used to remotely obtain high-resolution images of gold particles. Astigmatism and focus were corrected live, and the final image was downloaded to a laptop in Regensburg. The connection was great—throughput of greater than one image per second. The outcome of the session exceeded expectations and surely converted many skeptics that night.

Several factors helped things go so well. The location had good network connectivity: the University of Regensburg is part of a 225 megabytes/second ring that includes the Universities of Nürnburg, Berlin, and Frankfurt. Frankfurt maintains a direct connection into the Energy Sciences Network in the United States, the research network serving DOE scientists to which ORNL is connected via a T-3 link. However, good connections do not necessarily ensure that applications run as expected when these networks become congested. That's why at DOE we are continuing to work on providing differentiated services—or quality of service, to use a more commonly used term—to provide scientists the means to access sustained bandwidth when needed.

As you can see from these examples, the DOE 2000 program has made progress toward the goal of enabling scientists and engineers to interact as if they were physically collocated—sharing data, high-performance computing systems, and instrumentation independent of location. Tools are becoming available, but issues remain, such as hardening these tools, providing interoperability, and assuring availability across a wide variety of platforms.

DISSEMINATING ENERGY INFORMATION

RALPH L. SCOTT
U.S. DEPARTMENT OF ENERGY,
OFFICE OF SCIENCE AND TECHNOLOGY INFORMATION

A well-educated populace, a collaborative mindset, high-quality and readily available information, and collaborative tools and technology are variables in the equation underlying the nation's long-term economic health and development. The U.S. Department of Energy (DOE) is using electronic tools to bring scientific and technical information to the desktops of researchers and the homes of the U.S. public, thereby fueling collaboration and long-term prosperity. These efforts are occurring within DOE's Office of Science and Technology Information, which has existed for some 51 years. Its job, ever since the Manhattan Project, has primarily been to pull together information that DOE researchers have generated and make it available to the public in a way that contributes to research and economic development.

Clearly, the DOE as a whole is in the information business. The results of the R&D programs it funds are its principal product. Research begins with a determination of the scientific holes that need to be filled. Performing that research and reporting it to the science and technology community allow its members to build on the results for the public's benefit.

The process of disseminating results from DOE's R&D programs has proved difficult. The agency originally used microfiche and 35 mm films to share information. It has also created libraries and organized conferences, but we also believe collaboration is imperative. Toward that end we are desperately trying to lead the Department into the information age to ensure that energy-related information, from outside sources as well as DOE, is directly available to the community.

We are creating a virtual library that we believe will significantly aid the worldwide research community. The basic element of this library is the Energy Files, which will provide the foundation of a National Library of Energy Science and Technology. Energy Files provides one-stop access to some 400 information repositories at DOE laboratories and international sites gleaned from exchange agreements with over 120 different countries. We have also created Open-Net, which makes declassified information from the department's nuclear weapons programs available to the public.

Users of Energy Files can search the full text of electronic journals, citations, and preprints as well as energy engineering standards and databases. The system also provides information on regulatory issues. Energy Files sees substantial use, receiving about 70,000 hits a month. Over 70 percent of these queries come from outside the government, attesting to the depth of public interest. Machine translation turns literature in 10 foreign languages into English. We are also working on push technology. When a user enters a topic of interest, he or she is notified electronically if more information becomes available on the Web.

The Information Bridge, a key aspect of the Energy Files, is a unique Web site that includes 28,000 energy-related full-text reports totaling some 2 million pages. Users can search this collection to find reports containing information of interest and gain access to—and download—those pages. This Web site is growing: the legacy collection dates from January 1974, but the full collection will eventually encompass material from the early 1940s—a formidable information resource.

DOE has made the Information Bridge publicly available through a collaborative effort with the U.S. Government Printing Office. Use of the bridge requires no passwords or registration. The agency is now working with several publishers, including *Science* magazine, to provide hyperlinks to the full-texts of electronic journals devoted to energy R&D, including references listed in the articles. We are working to make the search engine as effective as possible by incorporating new scientific terms as they come into use.

The site also includes R&D summaries that enable users to find out about more than 15,000 active DOE projects and locate someone with whom to discuss the research. This site records some 800 hits daily. The overall goal is to put a comprehensive source of energy-related information at people's fingertips to support the collaborative mindset central to scientific work in the next century.

INTERNATIONAL COLLABORATION

S. YONA ETTINGER
U.S.-ISRAEL BINATIONAL SCIENCE FOUNDATION

In the 1960s and the 1970s a great deal of research was performed which showed that, when laboratories were spaced as little as 100 feet apart, effective communication between them was almost nil. The collaboratories concept offers a unique solution to this problem: it reduces the distance between laboratories to practically zero, thereby increasing effective communication almost to infinity.

The collaboratory endeavor can be especially conducive to interdisciplinary research. The revolutionary changes in the field of life sciences, for example, have incorporated biology more deeply into the wider frame of natural sciences and provoked far-reaching developments in other disciplines. These results have produced new interdisciplinary areas of research such as neuroscience, molecular biology, and environmental studies.

To make significant contributions and achieve breakthroughs in these subjects, cooperation is required among scientists in fields as diverse as physics, psychology, and atmospheric research. However, when interdisciplinary research groups form, they are often criticized for doing research that lacks depth and comprehensiveness. I believe that collaboratories can provide a solution to this problem because they enable experts to join forces in tackling an interdisciplinary topic without compromising the quality of the research.

Experiences at the U.S.-Israel Binational Science Foundation (BSF) entailing international collaboration bear this out. The BSF was established in 1972 by the governments of the United States and Israel to promote and support cooperation between U.S. and Israeli scientists and technologists. Progress achieved by jointly acquiring, analyzing, and using data benefited both partners while saving time and money. The BSF today supports about 3,000 joint research projects manifested through various modes of collaboration. But a collaboratory taking advantage of the high-resolution communications network has now opened even broader opportunities for international collaboration with even greater benefits. One such cooperative research project with multidisciplinary ramifications was pursued by the Department of Chemical Engineering at the University of Minnesota and the Technion in Israel. The study focused on microstructure in gelling and solidifying complex liquids—a basic research project that also sheds light on the formation of gall bladder stones.

Besides tapping the expertise and facilities available in their own departments, the researchers jointly used a cryotunneling electron microscopy facility at the Weitzman Institute in Israel, a scanning electron microscope in Minnesota, and laser scanning imaging facilities in the Biology Department of the Technion. This collaboration in diagnostic techniques elevated the quality of the research and its anticipated results. As was pointed out by a referee for the project, "The structural determination techniques are all at the absolute cutting edge of current research." These techniques would not have been possible without the multinational collaboration and the collaboratory.

Another example entailed cooperation among three groups studying phase transitions in layered and random systems. The experimental work was performed at the Massachusetts Institute of Technology, while the complementary theoretical work was divided between the University of Pennsylvania and Tel Aviv University. An intensive electronic communication between these teams generated 15 joint publications in four years, 13 of which appeared in *Physics Review* and *Physics Review Letters*—testimony to the synergistic outcome of research involving complementary disciplines and to the viability of the collaboratory concept. Without daily interaction among the three laboratories, I doubt if they could have been so productive.

A final example concerns a cooperative project between Haifa University in Israel and the State University of New York at Stony Brook to investigate the morphology of sign languages used in the United States and Israel. Sign languages are of special interest to cognitive psychology because they provide a natural laboratory for studying the organization and structure of language. The collaboratory concept can provide a new dimension to this endeavor by expanding the program to other sign languages practiced in many different countries. Ultimately, this multinational research could provide a better understanding of linguistic similarities and differences that could elucidate the well-known difficulties that deaf people experience in acquiring spoken language and perhaps also produce a blueprint for an international sign language.

So collaboratories are indeed an important vehicle for providing new opportunities and opening new frontiers in research. However, key impediments threaten to hamper such efforts. For example, the growing commercial interest in biotechnology and its applications has focused awareness of intellectual property rights in the scientific community worldwide.

Protection of intellectual property rights has a chilling effect on the free exchange of information and research findings and may prevent the fluent operation of collaboratories. In fact, intellectual property restrictions might take an even stricter form in cases of international collaboration. This trend will undermine everyone's results because cutting-edge accomplishments in both basic and applied research have repeatedly been shown to be crucial to the success of high-tech industries, especially for biotechnology and chemical industries.

In a recent study titled *The Increasing Linkage Between U.S. Technology and Public*

Science[3] the contribution of public science to industrial technology is examined. In particular, the authors traced the number of citations of scientific research papers in industry's patent applications. They found that on average 73 percent of the papers cited by U.S. industry patents came from the public science domain. Only 27 percent were authored by industrial scientists. Furthermore, reliance of the biomedical and chemical industries on public science was much more intense. In biomedicine some 17,000 citations were reviewed—12,700 were generated by universities; 3,400 by national laboratories; and 900 by industry.

Expanding the collaboratory program to include international collaboration will help foster first-rate research. Collaboratories can play a crucial role in ensuring the accuracy of data and thus elevate quality in scientific discovery while providing unique opportunities in education. Collaboratories can also provide a tremendous opportunity for small countries to participate in large science projects and make significant contributions to creative state-of-the-art research. For example, in medical training, many schools face difficulties in providing students will real-life experience with rare diseases. An international data bank could be used to develop simulation systems that give medical students hands-on experience. Collaboratory cooperation could also prove essential by allowing institutions to share information and provide real-time professional consultation and thus improve diagnosis and treatment. In short, collaboratories provide fertile ground to enable laboratories with complementary expertise and mutual interests to share information and coordinate research plans irrespective of geographic distance.

[3] F. Naim, K.S. Hamilton, and D. Olivast, *The Increasing Linkage Between U.S. Technology and Public Science*, Chi Research, Inc., Haddon Heights, N.J., Research Policy Report 932, 1997.

FROM COLLABORATION TO COLLABORATORY

JOHN W. JOST
INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY

The International Union of Pure and Applied Chemistry was founded on collaborations. Begun in 1919, the IUPAC produces standards and recommendations on nomenclature, symbols, terminology, and analytical procedures used in chemical research. The IUPAC encompasses some 1,000 people working on different projects, in groups of 2 to 20 scientists scattered around the world. More than half of all these people are in the United States or Europe. But the Union also includes collaborators in many other parts of the world, such as India, Pakistan, Argentina, Japan, and Australia, who can find it difficult to participate physically in IUPAC projects.

The normal method for producing standards hasn't changed for the past 80 years. A proposed standard is drafted and then circulated for comment. The proposal is annotated and rewritten. There are more comments. Then there is a meeting and discussion. Then someone thinks about the standard again and there are more comments. Two years later there is another meeting and so on. E-mail has accelerated this process but only a little.

What we really need are tools that will allow participants to do joint authoring. Although joint authoring is a standard part of science, when the point of a document is in the details regarding the physical appearance of the text, small complications such as different fonts can be very frustrating. Even when the collaborators are all using the same version of a program, what appears on the screen, or is printed, can vary unpredictably. Even recommending a particular font for a specific symbol can cause problems. It can be difficult to specify these things unambiguously. When you send an e-mail attachment—and you are lucky if it arrives in one piece—your collaborator is likely to receive a document with symbols that are not those you intended. What you designated as specific symbols may, on someone else's machine, appear as something else. Realizing what is happening and dealing with it can consume an inordinate amount of time. The result is that we still rely on paper to provide the baseline for discussions of a manuscript.

All of this is frustrating and very low tech. We are not talking about steering a radio telescope or obtaining the correct settings on a gigahertz spectrometer. We are dealing with silly things like fonts, mail attachments, and symbols. Tools that can solve these silly problems should be available on the Web. We cannot expect everyone who wants to participate in a project to change their software setup just to work on a particular project. People in such places as Zimbabwe want to participate but don't always have access to the latest commercial software. Everyone wants participation from as many parts of the world as possible, so we need to reduce the barriers.

The bottom line is that organizations such as IUPAC need compatible, fundamental tools that will enhance collaboration by creating collaboratories. Before we worry about high-speed, real-time, full-motion video connections, some thought should be given to fundamental joint authoring tools that allow people to reliably see and edit a document from any computer on the Internet.

ADVANCING RESEARCH IN NORTH CAROLINA

JANE SMITH PATTERSON
NORTH CAROLINA BOARD OF SCIENCE AND TECHNOLOGY

The Board of Science and Technology was first established in 1963 to encourage, promote, and support scientific, engineering, and industrial research applications in North Carolina. The Board works to investigate new areas of emerging science and technology and conducts studies on the competitiveness of state industry and research institutions in these fields. The Board, whose members are drawn from universities, research institutions, industry, and government, also works with the State General Assembly and the governor to put into place the infrastructure that keeps North Carolina on the cutting edge of science and technology. A critical mission for the Board under Governor Hunt has been to strengthen our research and education base and thus increase the flow of research from universities to corporations and the commercial marketplace. Building collaborative partnerships with access to information and communication networks has offered new opportunities in education, research, and economic development.

The Board played a significant role in building the North Carolina information highway, which is making this conference possible. Some 1,400 high-speed wide-area networks now operate off this information highway, which has also made possible 38,000 video sessions over the last four years. With the network available to them, students at the high schools for science and mathematics have participated in chemistry experiments with scientists across the state.

To support scientific research, the board also initiated projects such as MCNC (Microelectronics Center of North Carolina), the North Carolina Biotechnology Center, and the Technology Development Authority. We are now working to set up the Alliance for Competitive Technology, which will utilize technology and develop strategic industrial plans.

Because electronic collaborations are so important to these projects and the overall research process, we hope to actively foster collaboratories. We might, for example, encourage the new president of the University of North Carolina system to establish a technical cyber "SWAT team" to enable universities to join collaboratories. The Board could also encourage the institutions in the Research Triangle to participate in collaboratories. We hope, in fact, that the Board will agree to build collaboratories linking North Carolina universities with federal agencies and national laboratories in other states. I think it is important to harness the collaboratory concept to further not only chemical, biological, and technological research but also research involving the humanities.

The Board realizes that making the collaboratory concept work requires not only enthusiastic scientists, but also adequate funding, especially for the underlying technology. The Board could therefore play an important role by funding research on the technologies that enable collaboratories and allow them to work effectively. Our next technological focus, building the H.320 platform—a standards-based video platform—will enable different sites to participate in full-motion video conferences even more easily than they can today. Eventually, participation in video conferences and other forms of online collaborative research will entail simply picking up the phone or checking your computer. We, however, must try to move more quickly from the technology available today to desktop facility for researchers.

The press often portrays members of the research community as isolated scientists engaged in obscure pursuits. Therefore, I also see an important role for the Board of Science and Technology in educating the public and the press about the practical payoffs from collaboratories. Finally, the Board might investigate the complex intellectual property concerns that arise as collaboratories bring together public and private entities to perform joint research. The Board has already investigated intellectual property concerns with a similar science and technology board in Germany.

Although we are only beginning to exploit the potential of advanced communication technology in research, my hope is that this conference has convinced participants that the more they use these tools, the more they become invisible. Users who take full advantage of interactive electronic tools can pursue innovative research and obtain far-reaching results that would otherwise not have been possible. Ultimately, it enables us to shorten the cycle time of scientific discovery and product commercialization for the competitive growth of our economy.

APPENDIX A

WORKSHOP AGENDA

Wednesday, August 12, 1998

10:00	Introductions Panelists Facilitators	Jane Smith Patterson, N.C. Board of Science & Technology
10:10	Improving Research Capabilities Though Collaboratories	William A. Wulf National Academy of Engineering
10:30	Tools for Collaboration	James D. Myers Pacific Northwest National Laboratory
10:45	Discussions with Participating Sites	
11:00	Break	
11:05	The DOE 2000 Project	Mary Anne Scott [Washington Site] U.S. Department of Energy
	Disseminating Energy Information	Ralph L. Scott U.S. Department of Energy
11:40	International Collaboration	S. Yona Ettinger U.S.-Israel Binational Science Foundation
	From Collaboration to Collaboratory	John W. Jost International Union of Pure and Applied Chemistry

12:00	Advancing Research in North Carolina	Jane Smith Patterson N.C. Board of Science & Technology
12:10	Questions from Participating Sites Marye Anne Fox, North Carolina State University Site Johannes Boehme, Wake Forest University Site Charles Putman, Duke University Site John Toole, Washington, D.C. Site William Glaze, University of North Carolina at Chapel Hill Site	
1:00	Summary	William A. Wulf National Academy of Engineering
1:10	Follow-up Steps	Jane Smith Patterson N.C. Board of Science & Technology
1:15	Adjourn	

Site addresses:

- University of North Carolina at Chapel Hill, School of Public Health—Mayes Telecommunications Center, 231 Rosenau Hall, Chapel Hill
- Duke University—130A North Building, Durham
- Wake Forest University, Bowman-Gray School of Medicine—Teleconference Center MRI Building, Winston-Salem
- North Carolina State University—107 Park Shops, Raleigh
- Centers for Disease Control and Prevention—Hubert H. Humphrey Building, 200 Independence Avenue, S.W., Room 745G, Washington, D.C.

APPENDIX B

BIOGRAPHIES OF PANELISTS AND FACILITATORS

Panelists

Jane Smith Patterson is the Senior Advisor for Science and Technology and Director of the Office for Technology in the administration of Governor James B. Hunt, Jr. of North Carolina. During Governor Hunt's first two terms, Ms. Patterson served as Secretary of Administration. Over the next six years, she worked in private industry as a Vice President of ITT Network Systems Group, of ITT Alcatel and Alcatel, NA. She was recruited by University of North Carolina, Wilmington to serve as Interim Vice Chancellor, where she oversaw reorganization and creation of a new Vice Chancellorship for Extended Education and Public Service. In 1993, Governor Hunt appointed her to serve as his Chief Advisor for Policy, Budget and Technology. Ms. Patterson's career has concentrated on the areas of information technology infrastructure and its impact on the operations of government, industry, and education. She has consulted with more than 20 countries worldwide and 38 states relating to the design and execution of information networks. She has been the major visionary and leader in the development and implementation of the North Carolina Information Highway. Ms. Smith Patterson was a 1996 National Information Infrastructure Awards finalist and winner of the Federal Government Computing Council's Open Systems Interoperability Award in 1997.

William A. Wulf is President of the National Academy of Engineering and Vice Chair of the National Research Council, the principal operating arm of the National Academies of Sciences and Engineering. He is on leave from the University of Virginia, Charlottesville, where he is AT&T Professor of Engineering and Applied Sciences. Among his activities at the University are a complete revision of the undergraduate computer science curriculum, research on computer architecture and computer security, and an effort to assist research scholars in exploitation of information technology. Dr. Wulf has had a distinguished professional career which includes serving as Assistant Director of the National Science Foundation; Chair and Chief Executive Officer of Tartan Laboratories, Inc., Pittsburgh; and Professor of Computer Science at Carnegie Mellon University, Pittsburgh. He is the author of more than 80 papers and technical reports. He has written three books and holds one U.S. patent.

James D. Myers is Senior Research Scientist and Collaboratory Project Leader in the Computing and Information Sciences Department at the Environmental Molecular Science Laboratory (EMSL), a division of the Pacific Northwest National Laboratory (PNNL). He is principal investigator on the DOE 2000 Collaboratory and internally funded projects to design, develop, deploy, and understand the use of scientific collaboratories. Dr. Myers has experience in object-oriented software design, distributed computing, network and World Wide Web communications, collaborative groupware systems, scientific visualization, and hardware interfacing, and is one of the developers of the EMSL real-time collaboration, electronic notebook, and NMR Virtual Facility software. His team is now deploying this software to allow external researchers to run experiments on the EMSL's instruments remotely (and securely) and participate fully in all data acquisition and analysis tasks without requiring a visit to the laboratory. Dr. Myers is also developing the concept of a collaboratory for undergraduate research and education with Dr. Norman Chonacky of Evergreen State College and collaborators at PNNL and 7 northwest academic institutions. He is a 1996–97 Associated Western Universities Distinguished Lecturer and was nominated for a 1997 Presidential Young Investigator award. He received his Ph.D. in physical chemistry from the University of California, Berkeley.

Mary Anne Scott is Program Manager in the Office of Computational and Technology Research, Division of Energy Research at the Department of Energy. Over the past three years she has been responsible for a program that is developing technologies that enhance ability of scientists to work collaboratively, improve the ease with which they are able to model complex scientific problems, and provide remote access to experimental facilities and other DOE resources. This program is producing Advanced Computing Software and Collaboratory Tools which are being used in Scientific Application Pilots and Collaboratory Pilots—they are also being made available to the general scientific community. Under the Next Generation Internet Initiative activities within DOE, she has program responsibilities for applications. These are revolutionary applications that require high bandwidth and services not available in today's Internet and that will be used to demonstrate the integration of advanced networking with the application technologies.

Ralph L. Scott is Assistant Manager for the Department of Energy's Office of Scientific and Technical Information (OSTI). He has also worked as a scientist and manager of environment, safety, and health, and fossil fuel technology commercialization programs. He has advanced degrees and has also received numerous awards for academic as well as professional achievement. Some of his current major activities include: Bringing Electronic Journals to the Desktop; History of Human Radiation Experimentation; and Declassification Review. Previously, he served as OSTI's Assistant Manager for Technology Systems Management where he was responsible for all computing, telecommunication, software, printing, publishing, and microfiche operations.

S. Yona Ettinger is currently the Executive Director of the U.S.-Israel Binational Science Foundation (BSF). Between 1992 and 1996, Dr. Ettinger was the Minister-Counselor for Science and Technology at the Embassy of Israel in Washington, D.C. Prior to his appointment to that position, he served as the Director General of the Israeli Atomic Energy Commission from 1987 to 1992. From 1981 to 1986, Dr. Ettinger was the Head of the Physics Division at Rafael A.D.A. in Haifa, Israel, where he also served as Chief Engineer from 1960 to 1975. From 1975 to 1979, he held the position of Director General at the Soreq Nuclear Research Center at Yavneh. He has sat on several international delegations including the Israel-Jordan Bilateral Negotiations on Water, Energy and the Environment and the U.S.-Israel-Jordan Joint Expert Group on Cooperative Research in Science, Technology and Education. Dr. Ettinger has received several awards and has published in scientific and engineering journals.

John W. Jost is Executive Director of the International Union of Pure and Applied Chemistry (IUPAC), an international, scientific, non-governmental objective body that addresses global issues involving the chemical sciences. IUPAC's international secretariat is located in Research Triangle Park, North Carolina, recently relocated from Oxford, England. Dr. Jost was previously with Unocal, a large international oil company, where he served as Senior Vice President for Administration, President of Unocal Process Technology and Licensing, and Vice President of the Fred L. Hartley Research Center. He received Bachelors and Masters degrees in chemistry from Columbia University, obtained his Ph.D. in physical chemistry from the State University of New York in Stony Brook in 1971, and performed postdoctoral research at the University of California, Berkeley.

Facilitators

Marye Anne Fox is Chancellor of the North Carolina State University. Previously she served as Vice President for Research and the M. June and J. Virgil Waggoner Regents Chair in Chemistry at the University of Texas at Austin. Her most recent research activities include organic photochemistry, electrochemistry, and physical organic mechanisms. She is a former Associate Editor of the *Journal of the American Chemical Society*. She was also the Director for the Center for Fast Kinetics Research, Vice Chairman of the National Science Board, and a member of the Task Force on Alternative Futures for the Department of Energy National Laboratories, Galvin Committee. Dr. Fox is a member of the National Academy of Sciences and serves on several NAS committees, including the NAS Council Executive Committee and the Committee on Science, Engineering, and Public Policy. She is an NAS Councilor, a former member of the Commission on Physical Sciences, Mathematics, and Applications, and has served on the Committee on Criteria for Federal Support of Research and Development. She received a Ph.D. in organic chemistry from Dartmouth College.

Johannes M. Boehme has a broad educational and professional background that has provided him with expertise not only in the medical specialty of radiology but also in business and computer applications related to the field. Dr. Boehme is currently an Associate Professor of Radiology (Computer Science), the Associate Director for Administration in the Division of Radiological Sciences, and the Associate Dean for Academic Computing and Information Science at Wake Forest University School of Medicine. Dr. Boehme is also an adjunct Professor of Business at the Babcock Graduate School of Management at Wake Forest University. At the state and national level, Dr. Boehme was a co-investigator on the National Telecommunications and Information Administration (NTIA) grant, a member of the Technical Advisory Committee for the TeleQuest Teleradiology System, and a board member for the North Carolina GigaNet Initiative and Internet 2 Projects. He is co-author of 20 books chapters, more than 17 journal articles, and a dozen abstracts and pamphlets. His research interests include the design, coordination, and implementation of clinical computer operations, with particular emphasis on integration strategies for computerized patient management information, including hospital information systems, radiology information systems, and picture archiving and communications systems.

William H. Glaze is Director of the Carolina Environmental Program and Professor at the University of North Carolina School of Public Health. Until 1997, Dr. Glaze was Chair of the Department of Environmental Science and Engineering at the University of North Carolina, Chapel Hill. Previously, Dr. Glaze was Director of the Environmental Science and Engineering Program at University of California, Los Angeles and has also served on the faculty of the University of Texas at Dallas and the University of North Texas. He has served as a member of the Science Committee of the Environmental Management Advisory Board for the U.S. Department of Energy; Environmental Engineering Committee and Drinking Water Subcommittee; the Division Review Committee of the Chemical Science and Technology Division of Los Alamos National Laboratory; and has served as former Chairman of the Committee on Water Treatment Chemicals at the National Research Council, National Academy of Sciences. Dr. Glaze is currently a Consultant to the Executive Committee of the U.S. EPA Advisory Board and a member of the American Chemical Society Task Force on Environmental Research.

John C. Toole is Deputy Director at the National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign. Mr. Toole joined the NCSA senior management team in August 1997 and oversees the technical operation and coordination of National Computational Science Alliance teams throughout the United States. Before coming to NCSA, Mr. Toole was Director of the National Coordination Office (NCO) for Computing, Information, and Communications and Chair of the Computing, Information, and Communications R&D Subcommittee of the Committee on Computing, Information, and Communications (CCIC) of the National Science and Technology Council. Mr. Toole retired from the U.S. Air Force in 1994 after more than 22 years of service. Prior to being selected as Director of the NCO, he spent 10 years with the Defense Advanced Research Projects Agency, serving as Program Manager, Deputy Office Director, and Acting Office Director of Research in Computing Systems and Technology. The National Center for Supercomputing Applications is the leading-edge site for the National Computational Science Alliance. The Alliance partnership is funded by the National Science Foundation to advance computational infrastructure for the 21st century; it includes more than 50 academic, government and industry research partners from across the United States.

Charles E. Putman is Senior Vice President for Research Administration and Policy at Duke University in Durham, North Carolina. He is also the James B. Duke Professor of Radiology and Professor of Medicine at Duke Medical Center. Dr. Putman received his medical degree from the University of Texas, Galveston and completed residency in Radiology at the University of California in San Francisco. In 1973, Dr. Putman was appointed to the faculty of Yale University School of Medicine as Assistant Professor in both radiology and internal medicine. He was made Chief of Chest Radiology the following year and then served as Clinical Director of Diagnostic Radiology. In 1977, he joined the faculty of Duke University medical School as Professor and Chairman in the Department of Radiology. He was appointed Vice Chancellor for Health Affairs, Vice Provost in 1985, and Dean of the School of Medicine the following year. He also served as Executive Vice President of Administration from 1990 to 1995. Dr. Putman was elected to the Institute of Medicine in 1987. He serves on the Executive Committees of the North Carolina Board of Science and Technology, the Research Triangle Foundation, and the Research Triangle Institute. He is Vice Chairman of the North Carolina Biotechnology Center and Chairman of the Board of the Microelectronics Center of North Carolina.

Norman L. Christensen, Jr. is Dean of the Nicholas School of Environment and Professor of Ecology at Duke University. He received his B.A. and M.A. in biology from California State University, Fresno and his Ph.D. in biology from University of California, Santa Barbara. Dr. Christensen is interested in the effects of disturbance on the structure and function of populations and communities. His ongoing studies include an analysis of patterns of forest development following cropland abandonment as they are affected by environment, stand history, and plant demographic patterns. This research focuses on the historical data sets and resources of the Duke Forest. He is also conducting research on the southeastern coastal plain and western Sierra Nevada focused on a comparison of biogeochemical and community responses to varying fire regimes. These studies are aimed at an understanding of the evolutionary and ecosystem consequences of fire and the application of such information in the development of wilderness management and policy protocols. In addition, Dr. Christensen is conducting research on the use of remote sensing systems, such as synthetic aperture radar, to evaluate long-term changes in forest ecosystems.

APPENDIX C

NORTH CAROLINA BOARD OF SCIENCE AND TECHNOLOGY

The North Carolina General Assembly established the North Carolina Board of Science and Technology in 1963 during Governor Sanford's administration. The board is charged with the following responsibilities:

- To identify, and to support and foster the identification of important research needs of both public and private agencies, institutions, and organizations in North Carolina;
- To make recommendations concerning policies, procedures, organizational structures, and financial requirements that will promote effective use of scientific and technological resources in fulfilling the research needs identified;
- To allocate funds available to the Board to support research projects, to purchase research equipment and supplies, to construct or modify research facilities, to employ consultants, and for other purposes necessary or appropriate in discharging the duties of the Board.

A critical mission for the Board is to increase the flow of research out of universities and private companies in North Carolina and into the commercial marketplace. Building collaborative research partnerships between university researchers and private companies is a fundamental step toward commercialization of an applied research activity. The Board does not run programs but rather serves as a catalyst for projects. When a project is acceptable to the general assembly and the governor, then it is spun out of the Board either on a self-sustaining basis or for some other group to run. Currently, Governor James B. Hunt Jr. chairs the nineteen-member Board of Science and Technology. The members on the Board include individuals representing major universities, research institutions, private industry, and government.

1997-1998 Membership Roster

Governor James B. Hunt, Jr., *Chair*
Office of the Governor, North Carolina

Norman R. Cohen, *Vice-Chair*
Director
UNITEC

Robert P. Annechiarico
Director of Research Computing
Department of Public Health Sciences
Wake Forest University

David E. Benevides
Communications and Public Affairs Manager
IBM

James N. Brown
Chief Scientist, Electronic Systems
Research Triangle Institute, *Retired*

Mary Dell Chilton
Senior Staff Scientist
Novartis Seeds, Inc.

Katie G. Dorsett, *Ex-Officio*
Secretary
North Carolina Department of Administration

Charles E. Hamner
President
North Carolina Biotechnology Center

William R. Kress
President
MCNC

Thomas J. Meyer
Vice Chancellor for Graduate Studies and Research
Kenan Professor of Chemistry
University of North Carolina at Chapel Hill

Charles G. Moreland
Vice Chancellor for Research, Outreach & Extension
North Carolina State University

Freda Nicholson
President and CEO
Discovery Place, Inc.

Jane Smith Patterson
Senior Advisor for Science and Technology
Office of the Governor, North Carolina

Earnestine Psalmonds
Vice Chancellor for Research
North Carolina A&T State University

Charles Putman
Senior Vice President Research, Administration & Policy
Duke University

Ravindra P. Sinha
Chairman
Department of Geosciences
Elizabeth City State University

Larry W. Watson
Associate Professor
Mathematics and Science Education
North Carolina State University

John E. Weems
President
Meredith College

APPENDIX D

COMMITTEES OF THE NATIONAL RESEARCH COUNCIL

Office of International Affairs
Division for International Organizations and Academy Cooperation

The National Academy of Sciences (NAS), the National Academy of Engineering (NAE), and the National Research Council (NRC) have a record of accomplishments in the international arena and have been leaders in encouraging and fostering international cooperation in research. The NAS complex brings to its international programs unique strengths, including access to a comprehensive range of interdisciplinary expertise and world-recognized quality and credibility. Its leadership in providing high-level, independent advice to the U.S. government makes it well situated to be a non-partisan voice for international cooperation and an active participant in global scientific affairs. Membership in international organizations, such as the International Council for Science (ICSU) and its member Unions, is a significant responsibility the institution has accepted as a service to the concerned U.S. scientific communities. Through its association with these international organizations, the Academy has facilitated participation in a broad range of collaborative research and information-sharing activities. These programs have advanced national interests as well as global science. The Office of International Affairs, Division for International Organizations and Academy Cooperation (IOAC) of the NRC serves as the focal point for the activities of the U.S. National Committee for the International Union of Biochemistry and Molecular Biology and the U.S. National Committee for the International Union of Pure and Applied Chemistry.

U.S. National Committee for the International Union of Biochemistry and Molecular Biology

The U.S. National Committee for the International Union of Biochemistry and Molecular Biology (USNC/IUBMB) represents the interests of U.S. biochemists and molecular biologists in international issues, promotes the advancement of the sciences of biochemistry and molecular biology, and helps to facilitate communication among scientists internationally. The programs of the USNC/IUBMB also emphasize the overlapping interests of academia, industry, and governments to stimulate worldwide capacity building efforts in the United States and other countries.

1998 Membership Roster

Bettie Sue Masters, *Chair*
Department of Biochemistry
University of Texas, Health Science Center at San Antonio

Gregory Petsko, *Vice-Chair*
Rosenstiel Basic Medical Science Research Center
Brandeis University

Don M. Carlson
Department of Molecular and Cell Biology
University of California, Davis

Richard W. Hanson
School of Medicine
Case Western Reserve University

George L. Kenyon
Dean, College of Pharmacy
University of Michigan

Rowena Matthews
Biophysics Research Division
University of Michigan

Cecil B. Pickett
Executive Vice President
Schering-Plough Research Institute

George Stark
Chairman
Cleveland Clinic Foundation

Jack E. Dixon, *Ex-Officio*
Department of Biological Chemistry
University of Michigan

Jack F. Kirsch, *Ex-Officio*
Department of Molecular & Cell Biology
University of California, Berkeley

U.S. National Committee for the International Union of Pure and Applied Chemistry

The International Union of Pure and Applied Chemistry (IUPAC) serves to build global interaction among research communities and promote advances in chemical sciences and technology at the international level. In the past several years, the U.S. National Committee (USNC) for IUPAC has played an important role in "restructuring" IUPAC by setting a vision for reforms. Now the Union is strategically positioned to address relevant international issues in a timely, cost-effective manner. To define the relevant issues to be addressed, the USNC is reaching out to the professional societies and organizations for their input. By rebuilding the channels of communications, the committee will seek the involvement of the U.S. chemical communities to prioritize the international issues of concern and evoke a dialog to establish priority areas. The USNC/IUPAC projects also include the Young Observer Program, which seeks participation of outstanding young chemists in IUPAC committees, and the Company Associates Program, which involves the U.S. chemical companies.

1998 Membership Roster

Slayton A. Evans Jr., *Chair*
Department of Chemistry
University of North Carolina

D.H. Michael Bowen, *Vice-Chair*
American Chemical Society (*retired*)

Ned D. Heindel
Department of Chemistry
Lehigh University

Michael Jaffe
Research Division
Hoechst Celanese (*retired*)

Parry M. Norling
Central Research and Development
E.I. duPont de Nemours & Co., Inc.

Jeanne Pemberton
Department of Chemistry
University of Arizona

Edwin P. Przybylowicz
Eastman Kodak Company (*retired*)

Elsa Reichmanis
Research Department
Lucent Technologies, Bell Laboratories

Geraldine S. Richmond
Department of Chemistry
University of Oregon

Peter J. Stang
Department of Chemistry
University of Utah

Joann Sullivan
Office of Research and Development
Medical University of South Carolina

APPENDIX E

WORKSHOP PARTICIPANTS

Jon S. Abramson
Department of Pediatrics
Wake Forest University

Roger Akers
Department of Epidemiology
University of North Carolina at Chapel Hill

Pablo Amor
Counselor, Science, Technology & Education
European Union Delegation of the European Commission

Robert Annechiarico
Director of Research Computing
Department of Public Health Science
Wake Forest University

Roger Austin
Department of Bio-organic Chemistry
Research Triangle Institute

Jerry Bernholc
Department of Physics
North Carolina State University

Amar Bhat
Fogarty International Center
National Institutes of Health

Edward Bilicki
North Carolina State University

Peter Blair
Director
The Sigma Xi Center

Alan Blatecky
Vice President, Information Technology Division
MCNC
Research Triangle Park, North Carolina

Margaret Boccieri
Associate Director
North Carolina Board of Science and Technology
Office of the Governor
State of North Carolina

Johannes M. Boehme
Associate Dean, Academic Computing and Information Science
Bowman Gray School of Medicine
Wake Forest University

Wendy Boss
Department of Botany
North Carolina State University

Dennis Brown
Department of Biochemistry
North Carolina State University

Frances E. Carr
Senior Advisor for Research
U.S. Agency for International Development

Ivy Carroll
Vice President
Research Triangle Institute

Norman L. Christensen, Jr.
Dean, Nicholas School of Environment
Duke University

Margaret M.L. Chu
Office of Research and Development
National Institutes of Health

Joseph Clark
Office of the Executive Director
American Chemical Society

Daniel Comins
Department of Chemistry
North Carolina State University

Doug Crawford-Brown
Department of Environmental Sciences and Engineering
University of North Carolina at Chapel Hill

Alvin Crumbliss
Department of Chemistry
Duke University

Alvin Cruze
Executive Vice President
Research Triangle Institute

Douglas Darr
Director, Business Technology Development
North Carolina Biotechnology Center

Sheila David
The Heinz Center for Science, Economics, & the Environment
Washington, D.C.

Audrey DeNazelle
University of North Carolina at Chapel Hill

Joseph Desimone
Department of Chemistry
University of North Carolina at Chapel Hill

Prasun Dewan
Department of Computer Science
University of North Carolina at Chapel Hill

Stephen M. Downs
Division of Medical Computing and Informatics, School of Medicine
University of North Carolina at Chapel Hill

Peter Einaudi
University of North Carolina at Chapel Hill

S. Yona Ettinger
Executive Director
U.S.-Israel Binational Science Foundation

Slayton Evans
Department of Chemistry
University of North Carolina at Chapel Hill

Frederick Ferguson
Director of Center for Aerospace Engineering
North Carolina A&T State University

Greg Forest
Department of Mathematics
University of North Carolina at Chapel Hill

Raymond Fornes
Department of Physical Sciences Research
North Carolina State University

Donald Fox
Department of Environmental Sciences and Engineering
University of North Carolina at Chapel Hill

Marye Anne Fox
Chancellor
North Carolina State University

Eric Frey
Department of Biomedical Engineering
University of North Carolina at Chapel Hill

Kenneth Galluppi
Carolina Environmental Program
University of North Carolina at Chapel Hill

William H. Glaze
Director, Carolina Environmental Program
University of North Carolina at Chapel Hill

John Hardin
Assistant Vice President for Research
University of North Carolina at Chapel Hill

David Havri
University of North Carolina at Chapel Hill

Ned D. Heindel
Department of Chemistry
Lehigh University

Frances Hess
Carolina Environmental Program
University of North Carolina at Chapel Hill

Janice M. Hicks
Department of Chemistry
Georgetown University

Brian Hoffman
Department of Chemistry
Northwestern University

Michael Jaffe
Department of Chemistry
Rutgers University

Melvin Johnson
Associate Vice Chancellor, Academic Affairs
North Carolina A&T State University

Timothy Johnson
Department of Biomedical Engineering and Medicine
University of North Carolina at Chapel Hill

John W. Jost
Executive Director
International Union of Pure and Applied Chemistry

Rudy Juliano
Department of Pharmacology
Medical School
University of North Carolina at Chapel Hill

Stephen H. Koslow
Associate Director
National Institute of Mental Health
National Institutes of Health

Louis Kucera
Department of Microbiology
Wake Forest University

Hiram Larew
Bureau for Policy
U.S. Agency for International Development

Thomas Lehman
Assistant Editor ES&T
Department of Environmental Sciences and Engineering
University of North Carolina at Chapel Hill

Irving Lerch
Director, International Affairs
American Physical Society

Michael Levy
Department of Microbiology, Pathology & Parasitology
North Carolina State University

Jonathan Lindsey
Department of Chemistry
North Carolina State University

Richard Linton
Department of Chemistry
University of North Carolina at Chapel Hill

R. Wayne Litaker
Department of Molecular Biology and Biotechnology
University of North Carolina at Chapel Hill

Mark Lively
Department of Biochemistry
Wake Forest University

Steve Lommel
Assistant Dean for Research, Agricultural & Life Sciences
North Carolina State University

Robert Lowman
Associate Vice Provost
Research Services
University of North Carolina at Chapel Hill

Trudy Mackay
Department of Genetics
North Carolina State University

Thomas Malone
Chief Scientist
The Sigma Xi Center

Wayne Mascarella
Center for Organic and Medicinal Chemistry
Research Triangle Institute

Bettie Sue Masters
Department of Biochemistry
The University of Texas, Health Science Center at San Antonio

Stephen McGregor
Associate Director for Spatial Analysis
Carolina Population Center

Andrew Medina-Marino
Executive Director
Journal of Young Investigators

Thomas Miller
College of Engineering, Dean's Office
North Carolina State University

Charles G. Moreland
Vice Chancellor for Research, Outreach & Extension
North Carolina State University

Thomas Moss
Government-University-Industry Roundtable
National Academy of Sciences

Merrit Mulman
North Carolina Israel Partnership

Christopher K. Murphy
Board on Chemical Sciences & Technology
National Research Council

James Murrell
Academic Technology & Networking Services
University of North Carolina at Chapel Hill

James D. Myers
Environmental Molecular Sciences Laboratory
Pacific Northwest National Laboratory

Edward Noga
Companion Animal & Special Species Medicine
North Carolina State University

Cary Nourie
North Carolina Board of Science and Technology
Office of the Governor
State of North Carolina

Robert Osteryoung
Department of Chemistry
North Carolina State University

Eui Park
Department of Industrial Engineering
North Carolina A&T State University

Jane Smith Patterson
Senior Advisor to the Governor for Science & Technology
State of North Carolina

Rowena Peacock
Director, Systems Management
National Science Foundation

John Penick
Department of Math, Science & Technology Information
North Carolina State University

Len Pietrafesa
Department of Marine, Earth, and Atmospheric Sciences
North Carolina State University

Ernestine Psalmonds
Vice Chancellor for Research
North Carolina A&T State University

Charles E. Putman
Senior Vice President for Research Administration & Policy
Duke University

Mary Anne Scott
Office of Advanced Scientific Computing
Department of Energy

Ralph L. Scott
Office of Science & Technology Information
U.S. Department of Energy

Yoram Shapira
Embassy of Israel

Thomas Shay
Department of Marine Sciences
Carolina Environmental Program
University of North Carolina at Chapel Hill

James Siedow
Dean, Faculty Development
Duke University

Robert Silvia
North Carolina State University

John Simon
Department of Chemistry
Duke University

James Smith
Department of Physiology/Pharmacology
Wake Forest University

Dixie E. Snider
Associate Director for Science
Centers for Disease Control and Prevention

Eileen Soo
Department of Computer Science
University of North Carolina at Chapel Hill

Eric B. Steel
Program Office
National Institute of Standards & Technology

Marcia Steinberg
Division of Molecular and Cellular Biosciences
National Science Foundation

Russell Taylor
Department of Computer Science
University of North Carolina at Chapel Hill

John C. Toole
National Computational Science Alliance
University of Illinois at Champaign-Urbana

John Tucker
Board of Mathematical Sciences
National Research Council

Russel Van Wyk
Assistant Dean, College of Arts and Sciences
University of North Carolina

Sheila Vrana
Research Development
Wake Forest University

Sean Washburn
Department of Physics-Astronomy
University of North Carolina at Chapel Hill

Bruce Weir
Department of Statistics
North Carolina State University

Mike Whangbo
Department of Chemistry
North Carolina State University

Wendy White
Office of International Affairs
National Research Council

Jerry Whitten
Dean, Physical & Mathematical Sciences
North Carolina State University

Walter Wiebe
Concurrent Technology Corporation
North Carolina State University

Alex Williamson
Department of Chemistry
North Carolina A&T State University

Warren Wogan
Department of Mathematics
University of North Carolina

Tamae Maeda Wong
Office of International Affairs
National Research Council

Annette Wright
Interim Associate Director
Office of Economic Development
University of North Carolina at Chapel Hill

William A. Wulf
President
National Academy of Engineering