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Newly Available Technologies Present Expanding Opportunities for Scientific and Technical Information Exchange

Jean M. Tolzman

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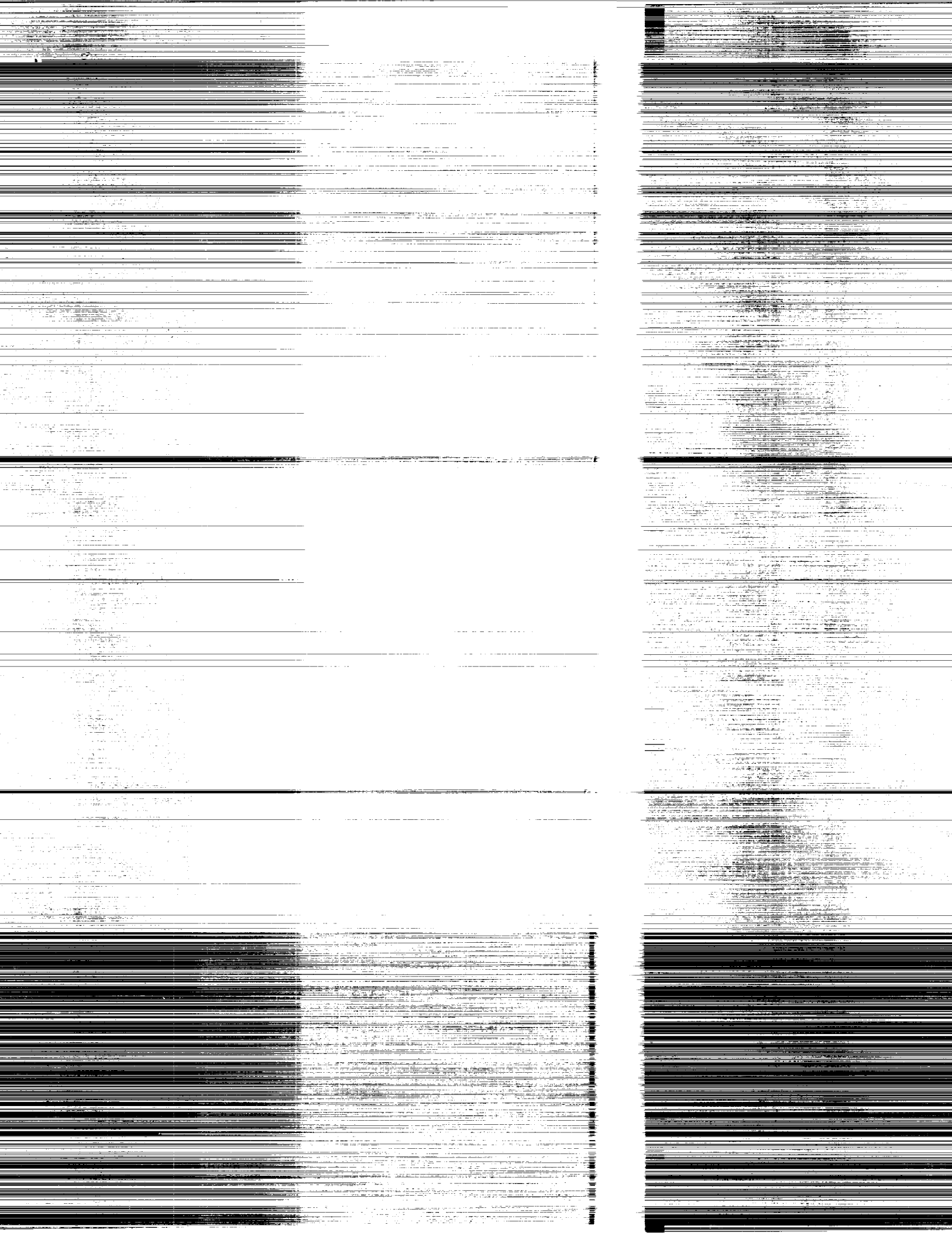
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Space Administration

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1 SUMMARY

The potential for expanded communication among researchers, scholars, and students is supported by growth in the capabilities for electronic communication as well as expanding access to various forms of electronic interchange and computing capabilities. Increased possibilities for information exchange, collegial dialogue, collaboration, and access to remote resources exist as high-speed networks, increasingly powerful workstations, and large, multiuser computational facilities are more frequently linked and more commonly available.

Numerous writers speak of the telecommunications revolution and its impact on the development and dissemination of knowledge and learning. One author offers the phrase "scholarly skywriting" to represent a new form of scientific communication that he envisions using electronic networks. In the United States (U.S.), researchers associated with the National Science Foundation (NSF) are exploring "nationwide collaboratories" and "digital collaboration."

Research supported by the U.S. National Aeronautics and Space Administration (NASA) points to a future where workstations with built-in audio, video monitors, and screen-sharing protocols are used to support collaborations with colleagues located throughout the world. Instruments and sensors located worldwide will produce data streams that will be brought together, analyzed, and distributed as new findings. Researchers will have access to machines that can supply domain-specific information in addition to locator and directory assistance. New forms of electronic journals will emerge and provide opportunities for researchers and scientists to exchange information electronically and interactively in a range of structures and formats.

Ultimately, the wide-scale use of these technologies in the dissemination of research results and the stimulation of collegial dialogue will change the way we represent and express our knowledge of the world. A new paradigm will evolve—perhaps a truly worldwide "invisible college."

2 INTRODUCTION

"We expect the revolution in communications to extend the power of our brains. Its ultimate effect will be the transformation and unification of all techniques for the exchange of ideas and information, of culture and learning. It will not only generate new knowledge, but will supply the means for its world-wide dissemination and absorption."

David Sarnoff, 1891–1971

Founder and President, RCA

Wisdom of Sarnoff and the World of RCA

2.1 A recent U.S. National Academy of Sciences (NAS) report addresses perceived impediments to the pervasive and effective use of information technology in scientific research [NAS89]. Included in a series of recommendations, the

report emphasizes the user's view in the further development and application of information technology to support the envisioned "global research enterprise." Donald N. Langenberg, chair of the panel that produced the report, writes in its preface "...that information technology is of truly enormous importance to the research community, and hence to all humanity, precisely because it has the potential to enhance communication of information and knowledge within that community by orders of magnitude. We can now only dimly perceive what the consequences of that fact may be. That there is a revolution occurring in the creation and dissemination of information, knowledge, and ultimately, understanding is clear to me. It is also clear to me that it is critically important to maintain our commitment to free and unfettered communication as we explore the uses of information technology in the conduct of research."

In this 1989 NAS report, the effects of information technologies not only in facilitating scientific research but also in changing the way that research is performed are summarized and hypothesized. In claiming that we are on the verge of a revolution through the pervasive use of increasingly intelligent and accessible information technologies, the writers of this report examined three particular aspects of scientific research: data collection and analysis; communication and collaboration; and information storage and retrieval. The writers acknowledge that there is a diversity in research methods among different scientific disciplines and the information technologies needed to support these methods. However, among the scientific disciplines, they find sufficient commonality in these three particular groupings of research activities to warrant and focus their examination of information technologies and their potential for impacting and changing the manner in which research is conducted.

2.2 This paper contains discussions of selected current information technology projects, initiatives, and research areas. Those chosen for discussion are only a sampling of those that have or hold the potential for impacting scientific communication and collaboration, the second of the three aspects addressed in the NAS report. Exciting initiatives aimed primarily at the data collection and analysis aspect of research, such as those in electronic scientific visualization, automatic correlation of data sets, and telepresence or virtual reality applications, will be discussed only in terms of their potential for supporting the collaborative efforts of scientists. Yet, while some of the emerging technologies and projects that will be discussed also can influence the exchange of technical information between engineers and technologists, the focus of this paper will be on communication and dissemination in scientific research.

As has been documented in reports by T. Pinelli [PINELLI] and other knowledgeable authorities, the information seeking and use habits, as well as communication habits, of engineers and scientists differ in some important ways.

These differences will not be discussed in this paper. The reader is referred to an issue of *Science & Technology Libraries* (also issued as a monograph) [STEI91], where papers by Pinelli and others examine the information handling differences between scientists and engineers. Additionally, the challenges to communicating through the various languages of the international research community will not be addressed in this paper. This topic deserves substantial treatment and is the subject of a paper by Dr. T. Schneider.

3 TELECOMMUNICATIONS, COMPUTERS, SOFTWARE, DATABASES, AND MULTIMEDIA

The enormous increase throughout the past decade in the availability and power of computational and network resources has provided the basis for a similar increase in the number of scientists and researchers working together without the constraints of geographic distance and time. Facilitated by the use of high-speed networks, increasingly powerful workstations, and multiuser, large computational facilities, collaborative efforts are being undertaken that use distributed and remote data collection devices, advanced analytical and manipulation tools, data and information repositories, and rapid data and idea exchange facilities. With the growing availability and affordability of such capabilities a scientist's "workbench" is envisioned.

3.1 Viewed by many as the world's network of networks, the growth and current size of the Internet is phenomenal. Initially developed as ARPANET in the late 1960s by the U.S. Defense Advanced Research Projects Agency (DARPA), the Internet grew from the four networks connected in the 1960s to 200 interconnected networks by 1985, to 500 interconnected networks in 1989, to the nearly 10,000 networks currently interconnected and collectively referred to as the "NET."

The networks range in size from large international networks with thousands of hosts to small nationally based networks with tens of hosts attached. Table 1 (at right) lists some of the networks and the communities they serve. [CHEN/FOST89 and ALBR/EGRE91] The networks vary not only in size and the communities they serve but also in the access methods and capabilities supported, and the protocols used. However, the use of gateways and routing between the networks is transparent to the user.

Currently the NET connects nearly one million host computers worldwide, where one-third of the host computers are outside the U.S. Recently the number of connected hosts has been growing at the average rate of 15 percent per month. An estimated 10 to 20 million users are serviced through the NET, and this does not include the projected 100,000 U.S. elementary and high schools expected to join the NET in the near future. An estimated 10 terabytes of information monthly moves through just the U.S. national research and education backbone alone. This backbone currently is known as the Interagency Interim National Research and Education Network (IINREN) and can be viewed both as a response to the needs for high-speed interconnected networks as well as an impetus to further networking. NREN has its origin in the High Performance Computing Act signed into law in the U.S. in December 1991. It will build upon and replace Internet whose current backbone transmits at only 45 megabits per second. NREN would transmit at 1.2 gigabits per second. This is the difference between 1,607 text pages per second and 39,000 text pages per second.

3.2 With declining prices for computer hardware and increasing demands for the processing power needed for advanced research, the massively parallel computers known as supercomputers have become more prevalent. Together with the widespread, high-speed connectivity enabled by the NET, remote access to these large-scale machines is available to researchers who can collaborate on research previously not undertaken because of computing constraints. The expansion of this availability and accessibility is a major component of the U.S. High Performance Computing and Communications (HPCC) Program authorized in 1991. [OSTP92]

The performance and availability of machines commonly referred to as mainframes and minicomputers have seen similar growth. Additionally, very large numbers of powerful,

COUNTRY	ORGANIZATION
Australia	SPEARNET
Austria	ACONET; UNA
Denmark	DENET; DUNET
Europe	EARN; EURONET
Finland	FUNET
France	ARISTOTE; REUNIR
Germany	DFN
Greece	ARIADNE
Iceland	ISNET; SURIS
Indonesia	UNINET
International	CERN; CSNET; E-SPAN; EARN; EUNET; INTERNET; NORDUNET; NSFNET
Ireland	HEANET
Italy	CILEA; CINECA; CNR; CSATA; ENEA; INFNET
Netherlands	ERNET; HBONET; PICA; SURF
New Zealand	SPEARNET
Norway	BIBSYS; UNINETT
Portugal	RIUP
Spain	FAENET; IRIS
Sweden	OSINET; SUNET
Switzerland	CHADNET; SWITCH
Turkey	TUVAKA
UK	JANET
USA	BITNET; INTERNET

Table 1. Selected national and international scientific and academic networks.

increasingly easy-to-use workstations are becoming available to researchers in all disciplines. And the more widely available personal computer is becoming steadily more capable. With these increases in processing power come capabilities for machine manipulation of data and information in numerous dimensions and media. This has created many computer-literate people who are growing accustomed to direct access to computing and information resources.

3.3 The performance of the software through which people interact with and instruct computers to operate has advanced but not quite in tandem with computers. Based upon research in computer science, cognitive science, and linguistics, software programs and the processor-controlled machines they direct are becoming increasingly more capable and powerful. Machine intelligence—such as expert systems, voice recognition, speech synthesis, hypertext, imaging, animation, machine vision, simulations, and user interfaces—will be constructed that will enable scientists to navigate through the vast array of data and information resources in standard, intuitive, and consistent ways, collaborate with other scientists, and manipulate and analyze data in ways previously prohibitive in their cost.

The U.S. HPC Program is supporting software development aimed at the following: higher level languages; advanced compiler technology; optimization and parallelization tools; interoperability support; data management; visualization; debugging and analysis; instrumentation; and performance measurement. These developments, along with the more robust standardized software development procedures and packages, will allow researchers to perform statistical analyses on data, compute complex mathematical functions, simplify mathematical expressions, maintain large databases, and assist in search and retrieval of relevant information. Specialized groupware for collaborative work, as well as other software, increasingly will be user centered.

3.4 Vast machine-readable sources of data and information resources already exist and are expanding with newly released research results as well as the retrospective digital conversion of the rich holdings in libraries and information centers. Additionally, with the development of file format and exchange protocols, the databases of experimental data and analyzed results previously known only to the originating research teams are becoming available for remanipulation and alternate analysis.

New initiatives to create collaboratively and dynamically maintained databases that contain all existing knowledge on a particular subject are being undertaken. These subject-specific electronic databases extend beyond the traditional bibliographic or data distinctions of the past. One example is the Human Genome project at the Johns Hopkins Laboratory for Applied Research in Academic Information. Supporters of this project are working to develop an electronic database that holds all scientific information relating to the genome subject and contains raw genetic data, bibliographic information, and communications from editors around the world who have authority to update the database. The database is kept current by continually adding new information as it becomes available. Researchers in the field can search the database directly and their contributions are or will be posted in an unreviewed section of the database. Following peer review and acceptance, the contributions are transferred to the archival section of the database. The database is accessible through the NET.

3.5 Computer- and communications-intensive, multimedia homogenizes and integrates technologies and media. As the capabilities and availability of powerful computers, greater bandwidth communication channels, enabling software and databases, and auxiliary products are emerging, the much-anticipated era of multimedia likely will become a reality. Multimedia supports the integration of text, graphics, audio, image, and video. Supporting applications such as visualization, animation, and authoring systems for complex documents, multimedia offers tremendous potential for creative and productive exchange of information as well as the generation of new information. The technology also will support hypermedia, a word that encompasses hypertext, hyperlinks, and all other nonsequential navigation and access techniques. Current applications of hypermedia in scientific and technical information are discussed in a recent article by Kaye and Kuhn. [KAYE/KUHN92]

As a visionary of future electronic journals, L. Seiler [SEIL89] postulates on the following scenario using multimedia: "The hypermediated electronic journal article would be accessed from a color display with a resolution equal to that of a glossy magazine. The viewer will read the article or have the computer read it aloud. It could include text, sound, still [pictures], and moving images. Viewers who wanted to read material from a reference could activate their light bar, highlight the reference, and have the computer use a link to the electronic library [to] find and display the full text of the referenced article, movie, soundtrack, personal correspondence, or dataset."

4 SCIENTIFIC COMMUNICATION

Examinations into the communication needs of scholars and projections for changes in forms and processes are not new. [NATI79] Periodically, special task forces and projects are established to examine the productivity of government-funded scientific research. [OTA91, SST92] Inevitably these examinations include a review of communication needs, methods, and forms. However, with the emergence of the integration of capabilities discussed above not only is the U.S. government, including the Congress, looking into the productivity of scientific research, but also numerous independent projects and organizations are emerging to examine ways to facilitate researchers' application of newly available technologies. Below is a brief sampling of them.

4.1 The Coalition for Networked Information (CNI), sponsored by ARL, CAUSE, and EDUCOM, has as its mission statement: "...to promote the creation of and access to information resources in networked environments in order to enrich scholarship and to enhance intellectual productivity."

4.2 The Internet Society was founded this year as an international organization for standards establishment, coordination, and promotion of Internet use and applications. The Society maintains a list of Internet service providers around the world.

4.3 With partial funding from the NSF's Program on Ethics and Values Studies in Science and Technology, a joint project has been undertaken by the CNI and the Science, Technology, and Public Policy Program at Harvard University's John F. Kennedy School of Government. The goal of this Information Infrastructure Project is to assist groups, such as research teams and academic and professional societies, in establishing appropriate policies and practices for the new forms of scholarly communication that are expected to arise

on interconnected networks. A recent draft background paper [KAHI92] identifies six issues to be addressed, including joint authorship and ownership, rights in computer conferencing, derivative and iterative works, control of dissemination, site licensing, and international access.

4.4 Established in 1988, the Scholarly Communications Project of Virginia Polytechnic Institute and State University has been examining the practical aspects of electronic communication of scholarly information. As a working demonstration of the concept of electronic, scholarly, peer-reviewed journals marketed and distributed via electronic networks, the Scholarly Communications Project currently publishes the *Journal of the International Academy of Hospitality Research*.

4.5 In addition to the projects and organizations cited above as involved in examining potentials for new forms of scholarly communication, numerous writers and speakers are addressing perceived issues and anticipated changes and impacts. A thoughtful article by A. Okerson, Director for the Office of Scientific and Academic Publishing for the Association of Research Libraries, reflects on rapidly evolving changes in scholarly, including scientific, communication. [OKER91] In her article she reviews current trends in electronic scholarly publishing and projects a likely future. In this probable future she sees the traditional paper scholarly journal as minimally supplemented, and possibly replaced, through electronic media. She concludes that this evolution will not only include a change in media from paper to electronic, but that it is likely to create forms of scholarly discourse that are distinctly different from those in place over the last 200 years.

Another provocative and prolific writer, S. Harnad, has published numerous articles relating to his research in the field of cognitive science as well as on scholarly communication. [HARN91] Based upon his recent experiences using electronic discussion groups on the NET and in co-editing the electronic journal *Psychology*, where a practice called "open peer commentary" encourages collegial dialog, Harnad forecasts revolutionary changes in scholarly communication. Harnad's ideas merge together current informal and formal scientific communication forms into a process he calls "scholarly skywriting" [HARN90]. Using the high speed of the NET together with committed scientists and peer reviewers, authoring scientists post their current ideas and findings to the NET where they are peer-reviewed within hours and feedback is provided back to the author. While Harnad admits that this process primarily facilitates the initial phases of research, in a forthcoming article in *College & Research Libraries* he promises to defend his position that the process will effectively replace the traditional formal method of paper-based, peer-reviewed journals.

5 INFORMAL COMMUNICATION

In exchanging data, resources, ideas, and information through informal means, scientists engage in collegial and collaborative ways. Writing in 1990, R. Larsen sees the growing availability of the NET together with increasingly powerful machines and capabilities, complimented by vast data and information resources, as the basis for the future "colibratory." [LARS90] His vision is shared by P. Denning [DENN89] as he anticipates the ubiquitous and pervasive "Worldnet." Denning sees general implications for the NASA-conducted Telescience Testbed Pilot Program that studies interactions with remote instruments supplying data

streams to collaborating researchers. [LEIN89b] And the U.S. NSF has articulated a research agenda for a national "collaboratory" through which scientists at remote laboratories could collaborate interactively using advanced workstations with audio and video capabilities and screen sharing programs transmitting nearly interactively between distant locations. [LEDE89] Although such concepts and the resources upon which they are predicated are not yet available outside pilot applications, commonly available electronic capabilities on the NET are supporting informal scientific communication today. These are discussed briefly below.

Some of the same technologies discussed in this paper are being implemented to support distance learning programs in education as well as to improve the flexibility and effectiveness of education programs at all levels of current educational systems. [EDUCAT] The U.S. HPCC Program is encouraging the U.S. education system to use the technologies that support advanced scientific research. The communication and machine simulation and visualization applications developed for scientific research are not only being used to link researchers, educators, and learners, but also are being tailored to help teachers and students to understand scientific methodologies and specific concepts. [OSTP92]

5.1 Electronic mail (e-mail), bulletin board systems (BBSs), file transfer, and discussion groups are rapidly replacing many of the functions of conventional letters, telephone calls, personal visits, "snail mail," paper newsletters, catalogs, information lists, and meetings/conferences in facilitating informal scientific communication. The use of e-mail currently accounts for the majority of transactions on the NET. It provides the conduit not only for personal and office correspondence, but also for access to stored documents. Increasingly, scientists are using e-mail to assist in global, collaborative research experiments, especially for functions such as scheduling experiments and other logistics.

Electronic BBSs are used to present lists of professional opportunities and meetings and to direct users to researchers and experts. File transfer capabilities provide software and data distribution over the NET. More than a thousand scholarly electronic discussion groups (also referred to as listservs or computer conferences) exist on the NET. Some are moderated, others are not. These electronic group discussions provide focus for electronic discussion of specific topics of interest to those who subscribe or participate. Once registered, subscribers automatically receive all messages sent to the discussion group. As larger bandwidths are made available in the communications channels of the NET, full-motion videoconferencing will be available to support multimedia information interchange among a group of participants interactively.

5.2 The great lexicographer, Dr. Samuel Johnson, said, "Knowledge is of two kinds: We know a subject ourselves, or we know where we can find information upon it." Centuries later, with the volume of published scientific literature doubling each decade, knowing where to find information and obtaining relevant information in a useful form is increasingly complex and perhaps no longer within the reach of individuals. Information access is a challenge that will be met with increasingly sophisticated electronic tools. These tools will be built using research currently being conducted in expert systems, artificial knowledge, neural networks, semantic networks, nonsemantic retrieval networks, etc.

These information tools will use the catalogs and directories already emerging on the NET. More than a thousand library catalogs currently are available over the NET. Commercial information service providers, such as Dialog, currently make their services available through the NET. And government information services such as NASA/RECON and ESA/IRS are available through the NET. Additional directories of resources exist and are being expanded for enhanced access to the array of data and information.

An intriguing concept for mediating the vast, and ever-growing, data and information resources available on the NET recently has been proffered by Vincent Cerf, current president of the recently established Corporation for National Research Initiatives. The concept calls for development and implementation of "knowbots" (short for knowledge collecting robots). Also known as "data drones" or "intelligent agents," knowbots are computer programs designed to self-navigate throughout networks such as the NET. They are designed not only to search unattended for information in a single network, but using their underlying knowledge bases, will travel from network to network and "clone themselves, transport other knowbots, and respond to requests from each other." [MCCA92]

5.3 An ever-expanding wealth of material is disseminated and delivered through the NET. In addition to access to traditional bibliographic information services, several initiatives in electronic document delivery are being deployed on the NET or in local- and wide-area networks. Some of these are identified below.

Earlier this year the Elsevier Science Publishing Company, Inc., the largest English-language research publisher, announced a project called The University Licensing Program (TULIP). Through the TULIP project, Elsevier will distribute 42 of its materials science journals electronically over the NET to approximately 15 universities. The project has been touted as the first to provide copyrighted, published information over the NET.

NASA is coordinating the Study of Electronic Literature for Astronomical Research (STELAR) project. Through this project, NASA scientists and information professionals, scientific societies, and journal publishers jointly are exploring the use of the NET to provide sophisticated search, retrieval, and electronic access to articles in leading refereed journals in astronomy. By late 1992, a file server at Engineering Information, Inc., will begin electronic document delivery over the NET. OCLC, FAXON, and others also are examining technical and legal issues to full document delivery over the NET.

Some pioneering projects currently are under way that use campus-wide networks for information dissemination. The Chemistry Online Retrieval Experiment (CORE) project currently being conducted at Cornell University is a collaborative effort between the American Chemical Society (ACS), Bellcore, Chemical Abstracts Service, Cornell University, and OCLC. In this project, both the text and the graphics of articles appearing in the 20 journals published by ACS are provided over the campus network. Users interactions with retrieval and display are being carefully studied. Carnegie Mellon University is conducting Project Mercury. This project has as its goal the ready delivery of information to the desktop of each student and faculty member.

At AT&T Bell Laboratories, the RightPages electronic library prototype is taking advantage of fast hardware, multimedia workstations, and broadband networks to make scientific and technical journals available over a network for users at AT&T Bell Laboratories. The State University of New York (SUNY) plans to begin construction of a digital library next year. The digital library would be made available over the NET to the 65 campuses in the SUNY system. These developments are not limited to the U.S. The Bibliothèque Nationale is a national initiative in France. One of its objectives is to centralize library material and make it available electronically.

6 FORMAL COMMUNICATION

The first scientific journals, the *Journal des Scavans* and the *Philosophical Transactions of the Royal Society*, appeared in 1665 and supplanted the existing practices for scientific communication, which relied on correspondence, exchange of personal reports of experiments and findings, and private printing. Throughout the intervening 327 years, the scientific journal has operated as the primary repository of research findings as well as the primary channel of communication in science.

There are many other types of formal written communication in scientific disciplines. These include the preprint, conference proceedings, technical report, dissertation or thesis, monograph, popular journal, and newsletters. In addition, there are variances in preference and emphasis among the different scientific disciplines for certain types of communication. For instance, B. Cronin [CRON82] indicates that in many humanities and social science disciplines the publication of a monograph is viewed as a more important potential contribution to knowledge than the publication of an article in a refereed journal. The opposite emphasis appears to operate in the disciplines of natural and applied sciences. However, in general the refereed journal is the most accepted type of publication within the scientific community [ALLE91] and will be the focus of this brief discussion of formal scientific communication.

6.1 Several unsuccessful efforts to create new formats and types of journals are discussed in an article by A. Piternick. [PITE89] Since Piternick's article was published in 1989, several electronic journals have become available over the NET. Although these electronic journals currently do not include color or graphics, future electronic journals likely will include charts, graphs, tables, illustrations, and scientific notation along with text. Both economics and technological developments likely also will permit future electronic journals to include data files, analytical tools such as algorithms for solving equations, motion simulations, and video and sound.

The Association of Research Libraries (ARL) has issued a directory that details the electronic journals and newsletters that currently are available through the NET. The directory lists 36 active electronic journals, of which 10 are recorded as refereed journals. Extracting selected information from this directory, Table 2 (on next three pages) was prepared.

Plans for other, new electronic journals have been announced, including the NSF's Electronic Journal of Scientific Database Research and the American Association for the Advancement of Science's (AAAS) Online Journal of Current Clinical Trials. Also, the American Mathematical Society (AMS) recently announced development plans for a model electronic journal. This model will use NET databases

JOURNAL	SUBJECT MATTER	SUBSCRIPTION INFORMATION
Art Com	Contemporary art and new communication technologies.	WELL - Enter g acen at the Ok: prompt USENET - alt.artcom
ArtsNet Review	An Australian magazine dedicated to contemporary cross-cultural, arts and electronic networking issues.	Send e-mail to suephil@peg.pegasus.oz.au with subscription request.
Bryn Mawr Classical Review	Electronic book review journal.	Send e-mail to mailserv@brynmawr.bitnet or to mailserv@brynmawr.edu with the text SUBSCRIBE BMCR-L.
CATALYST*	The Community Services Catalyst is a refereed electronic journal serving community college educators.	Send e-mail to listserv@vtvm1.bitnet or listserv@vtvm1.cc.vt.edu with the text SUBSCRIBE CATALYST Subscriber's Name.
CONTENTS	CONTENTS, the Religious Studies Publications Journal, is an electronic serial for religious studies.	Send e-mail to listserv@uottawa.bitnet or listserv@acadvm1.uottawa.ca with the text SUBSCRIBE CONTENTS Subscriber's Name.
CORE	An electronic literary journal for short fiction, poetry, and networks.	Send e-mail to core-journal@eff.org with subscription request.
DargonZine	Dargon Project fiction anthology.	Send e-mail to white@duvm.bitnet with subscription request and Userid and Subscriber's Name.
DEOSNEWS	The Distance Education Online Symposium.	
DISTED	DISTED, the Online Journal of Distance Education and Communication, is interested in projects concerned with overcoming geographic, cultural, and socioeconomic barriers in education through the use of electronic communication.	Send e-mail to listserv@uwavm.bitnet with the text SUB DISTED Subscriber's Name
EJournal*	A peer-reviewed, academic electronic journal concerned with the implications of electronic documents and networks.	Send e-mail to listserv@albnyvm1 with the text SUB EJRNLS Subscriber's Name.
EJASA	The Electronic Journal of the Astronomical Society of the Atlantic dedicated to the advancement of amateur and professional astronomy and space exploration.	USENET - sci.astro
EJC/REC*	The Electronic Journal of Communication/ La Revue Electronique de Communication is dedicated to communication theory, research, practice, and policy.	Send e-mail to comserve@rpiacs.bitnet or comserve@vm.eecs.rpi.edu with the text JOIN EJCRC Subscriber's Name.
Fineart Forum	A moderated electronic newsletter covering all applications of science and technology to the contemporary arts and music.	Send e-mail to fast@garnet.berkeley.edu or fast@ucbgarne.bitnet with the text SUB FINE-ART Subscriber's e-mail address, full name, and postal address.
Flora Online*	Peer-reviewed electronic journal for systematic botany. Includes original data-intensive studies or original programs dealing with botanical topics.	Anonymous FTP at huh.harvard.edu or electronic BBS at 716/896-7581 (8-N-1).

* Indicates a peer-reviewed journal.

Source: Directory of Electronic Journals and Newsletters; compiled by Michael Strangelove (441495@acadvm1.uottawa.ca)

Table 2. More than 35 electronic journals are available over the NET.

JOURNAL	SUBJECT MATTER	SUBSCRIPTION INFORMATION
Intertext	Intertext, an electronic fiction digest, is a bimonthly magazine devoted to the publication of quality fiction.	Send e-mail to jsnell@ucsd.edu with subscription request and specify ASCII or PostScript.
IOUDAIOS Review	A serial electronic journal of the international electronic forum for scholarship on Early Judaism and Christian Origins. It uses a simplified SGML system to facilitate electronic distribution.	Send e-mail to listserv@yorkvm1.bitnet or listserv@vm1.yorku.ca with the text SUB IOUDAIOS Subscriber's Name
Issues in Science and Technology Librarianship	A publication of the Science and Technology Section of the Association of College and Research Libraries, American Library Association, that is dedicated to topics relevant to science and technology librarianship.	Send e-mail to acrlsts@hal.unm.edu with a subscription request.
JIAHR*	The Journal of the International Academy of Hospitality Research contains refereed articles on basic and applied research in all aspects of hospitality and tourism.	Contact the editor and publisher at jahred@vtvm1.bitnet or jahred@vtvm1.cc.vt.edu (Price: \$30 per year for institutions, \$20 for individuals, \$10 for students).
JTE	The Journal of Technology Education provides an electronic forum for scholarly discussion on topics relating to technology education (that is, the "industrial arts").	Send e-mail to listserv@vtvm1.cc.vt.edu with the text JTE-L.
LIBRES	The Library and Information Science Research Electronic Conference (LIBRES) is an electronic journal designed to foster library and information science research and support the development of its knowledge base.	Send e-mail to listserv@kentvm.bitnet or listserve@kentvm.kent.edu with the text SUB LIBRES Subscriber's Name.
MeckJournal	A monthly electronic journal from Meckler Publishing, MeckJournal contains editorials, late-breaking news, and feature articles published in any of Meckler's 14 technology-related periodicals.	Send e-mail to meckler@jvnc.net with the text Subscribe MeckJournal Userid.
New Horizons in Adult Education*	New Horizons in Adult Education is a refereed electronic journal devoted to research within adult education and related fields.	Send e-mail to aednet@suvvm.bitnet or aednet.suvvm.acs.syr.edu with a subscription request and Userid and Subscriber's name.
OFFLINE	OFFLINE began as a service of the Computer Assisted Research Group of the Society of Biblical Literature, but it attempts to cover more widely the actual and potential use of computers in religious studies in general.	To retrieve a list of files, send e-mail to listserv@brownvm1.bitnet with the text GET HUMANIST FILELIST.
PACSNEWS	PACSNEWS, the Public-Access Computer Systems News, is a copyrighted electronic newsletter that contains brief news items about end-user computer systems in libraries.	To retrieve an issue, send e-mail to listserv@uhupvm1.bitnet or listserv@uhupvm1.uh.edu with the text GET PACSNEWS V?N? F=MAIL, where ? is the appropriate issue volume (1 or 2) and number (1 through 12).

* Indicates a peer-reviewed journal.

Source: Directory of Electronic Journals and Newsletters; compiled by Michael Strangelove (441495@acadvm1.uottawa.ca)

JOURNAL	SUBJECT MATTER	SUBSCRIPTION INFORMATION
PACS Review	The Public-Access Computer Systems Review is a refereed electronic journal about end-user computer systems in libraries. It covers such topics as CD-ROM databases, electronic publishing, expert systems, and hypertext programs.	Send e-mail to listserv@uhupvm1.bitnet or listserv@uhupvm1.uh.edu with the text SUBSCRIBE PACS-L Subscriber's Name.
PostModern Culture*	An electronic journal of interdisciplinary studies that publishes analytical essays and reviews as well as video scripts and other new literary forms.	Send e-mail to listserv@ncsuvvm.bitnet or listserv@ncsuvvm.cc.mcsu.edu with the text SUB PMC-LIST Subscriber's Name.
PSYCOLOQUY*	PSYCOLOQUY is a refereed electronic journal sponsored by the American Psychological Association's Science Directorate and Office of Publication and Communication. PSYCOLOQUY published brief reports of ideas and findings in all areas of psychology and its related fields.	Send e-mail to listserv@pucc.bitnet or listserv@pucc.princeton.edu with the text SUB PSYC Subscriber's Name
Quanta	Quanta, the electronic magazine of Science Fiction and Fantasy, publishes fiction by amateur and professional authors. Quanta is available for downloading in either PostScript or ASCII format.	For PostScript subscription, send e-mail to quanta+requests-postscript@andrew.bitnet or quanta+requests-postscript@andrew.cmu.edu ; For ASCII subscription, send e-mail to quanta+requests-ascii@andrew.bitnet or quanta+requests-ascii@andrew.cmu.edu
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TeXMaG	TeXMaG is a monthly electronic magazine published by the Academic Computing Services of Texas A&M University.	Send e-mail to listserv@uicvm.bitnet or listserv@uicvm.uic.edu with the text SUBS TEXMAG-L Subscriber's Name.
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Source: Directory of Electronic Journals and Newsletters; compiled by Michael Strangelove (441495@acadvm1.uottawa.ca)

and utilities exclusively to support manuscript preparation, editorial processing, revision control, peer review, peer commentary, production, and distribution. Approximately 90 newsletter titles are listed in the ARL directory as available over the NET. In addition to the traditional printed version of this directory, an electronic version is maintained and is available on the NET.

6.2 Arguments abound regarding likely electronic journal concepts and forms. And several writers suggest that the current printed forms of scholarly journals and evolving, electronic forms will coexist for at least the next decade or perhaps into the foreseeable future. [GARF91] What does not seem to be denied is that access and delivery will be electronic, and that a virtual "electronic library" will unfold.

Approaches to concepts of the electronic journal range from mere duplication of current printed journal formats in an electronically accessible form available through the NET to more revolutionary concepts such as S. Harnad's "scholarly skywriting" concept. [HARN90] Within this range, some writers call for the replacement of the category called "journal" with a category called "electronic archives." The envisioned electronic archives would retain selected characteristics of current printed journals, such as editorial boards and peer review, but use technology to offer retrieval features for accessing a single article as well as a related body of literature, for placing comments and rebuttals to individual articles within the electronic archive, and for automatically notifying users of new additions to the archive that are likely to be of interest to them. [HARR91]

Writing in the journal *Academic Computing* [SEIL89], L. Seiler contemplates altered forms for scholarly communication. After claiming that the scholarly journal will not retain its current format, Seiler explores the constraints of the current format and offers suggested electronic alternatives that are likely to better serve the interests of scholarship. She argues that "journals will change because the information scholars produce is not limited to what the print medium can encompass. Movies, video and audio tapes, and numerical databases are essential materials for scholarly investigation but are beyond what the print medium by itself can address." In her view the formal scholarly communication of the future will consist of hypermediated electronic journal articles accessed from high-resolution color display devices. Before concluding the article, Seiler presents a wide-ranging discussion of the probable repercussions of this revolutionary change in communication forms.

6.3 Entire books have been written on the subject of peer review in science. Nearly every article or report that examines the future of scientific communication or the future of scholarly journals addresses the topic, although in varying degrees. And while many writers claim that the existing process used to conduct peer review is plagued with bias, delays, errors, and inconsistencies, for the majority of these writers, peer review is essential to assure a level of quality in formal journal publication. In considering the viability of peer review, little differentiation is made between the printed and electronic formats of reviewed journals.

In a recent journal article [LIPE91], R. Lipetz argues against the abandonment of peer reviewing. He anticipates a future in which emerging technologies can be used to assist reviewers in their work, making them more productive and effective. In *Scientific Literacy and the Myth of the Scientific Method* [BUAE92], author H. Bauer suggests that "even moderately successful scientists learn to adjust to the predictability and mediocrity of peer review." In a book entitled *Peerless Science* [CHUB/HACK90], Chubin and Hackett disparage the dearth of legitimate studies of the journal peer review process. They argue that the process as it is presently practiced is subject to contradictory, and often conflicting, forces. They view peer review as "shamelessly secretive, elitist, and oligarchic—as is science itself." A practice that Chubin and Hackett encourage as a workable alternative to current journal peer review methods is the "open peer commentary," also promulgated by Harnad [HARN91].

In considering what she views as the inevitable replacement of printed scholarly journals with electronic forms, Seiler [SEIL89] discusses the provisions needed for the electronic environment. She does not criticize current peer review practices, but does raise questions about the means for distinguishing between information on the NET that has been quality-assured, such as refereed articles, and information available on the NET that is not constrained, such as e-mail, BBSs, and discussion groups/conferences. She notes that a common user interface could likely obscure the relative quality of various units of information.

7 CHALLENGES

The challenges to the pervasive and effective use of information technology in scientific communication can be characterized as financial, technical, legal, political, social, and operational. Table 3 (at right) provides a listing of challenges in each of these categories.

8 WORLDWIDE SCIENTIFIC "INVISIBLE COLLEGE" PARADIGM

Will the paradigms of informal and formal communication among scientists change with the pervasive use of integrated and advanced information technologies? According to many writers it is inevitable that they will. However, the speed of such paradigm shifts and the success of specific innovations will be dependent upon the recognition among developers of innovative tools and media of the variations among different

CATEGORY	CHALLENGES
Financial	<ul style="list-style-type: none"> • Accounting and charging for use of licensed products, databases, and information resources • Cost recovery for network, computing, and information services • Economic models • Resource sharing • Global market
Technical	<ul style="list-style-type: none"> • Appropriate standards for network-accessible information • Responsibility for network management and operations • Software interchange capability • Access to large-scale databases • Improved user-level tools • Preservation and citation conventions • Authentication
Legal	<ul style="list-style-type: none"> • Licensing provisions for network and information resources • Intellectual property rights and fair use • Privacy and security considerations
Political	<ul style="list-style-type: none"> • Appropriate science research funding and evaluation • Monitoring national social agenda • Network funding, privatization/commercialization • Global relations
Social	<ul style="list-style-type: none"> • New forms of communication and relating among individuals and groups • Equity in access to information and resources • Technology transfer
Operational	<ul style="list-style-type: none"> • Service to a growing community of non-expert users • Directories for locating computing, data, and information resources • Avoiding information pollution • System reliability • Availability of skilled workforce

Table 3. Challenges to the pervasive and effective use of information technology.

scientific disciplines in their social practices and their needs for information and communication. Successful innovation will be user-centered.

8.1 Emerging themselves in this century in pursuit of a recognized distinct subdiscipline, researchers in the sociology of science have been studying and documenting the various social practices among scientists in general as well as among specific scientific disciplines. And while there certainly is not consensus among these researchers regarding the complex dimensions of human communication, whether formal or informal, among scientists, some views have achieved popular appeal as well as academic acceptance. One of these accepted views was first documented by Derek Price in his now famous books entitled *Science Since Babylon*, published in 1961, and *Little Science, Big Science*, first published in 1963. Masterful in his use of vivid metaphors, Price revived the 17th century term "invisible college" to characterize the informal networks of communication and collaboration among scientists. Many of Price's early observations and interpretations have been confirmed and extended by the studies of Crane [CRAN72] and Mullins [MULL73] and further explored in hundreds of articles and monographs. [CHUB83]

Whether Price's phrase "invisible college" or the phrases "reference group" or "cultural circle" are used, respected sociologists of science [CHUB85; CRAN72; KUHN70; MERT73; MULL73; MULK91; PRIC61; PRIC63; and PRIC/BEAV83] argue convincingly that scientists engage in informal communications with individuals whom they trust to be effective assessors of and advisors for their research. Regarding formal communication, the sociologists of science view that scientists publish formally to register their discoveries, to garner recognition for their work, and to satisfy institutional requirements for appointments, tenure, and funding. Paradigms for scientific communication, including current ones as well as those hypothesized for the future, must acknowledge these underlying general motivations for communication in science.

8.2 The envisioned global research enterprise using interconnected information technologies is likely not only to make scientific research more productive but to make more visible and accessible both the informal and formal communications between scientists, creating a worldwide "invisible college." In the process, the number of members in each scientist's trusted reference group could expand, and could even include trusted machines, as the envisioned "intelligent agents" or "software mediators" become fully known.

The total of both anticipated and unanticipated change is often referred to as a "revolution" with far-reaching effects comparable to those introduced by the discovery of fire, the development of human language, and the construction of the printing press. Often without specifics regarding the changes resulting from this most recent revolution, the changes frequently are characterized as of great magnitude and deeply altering our lives and societies.

No doubt exists that the new and emerging electronic technologies will challenge existing paradigms and even produce new ones based upon an increasingly global scientific research enterprise. But the speed with which the paradigms might change will be influenced by the financial, technical, politico-social, and legal concerns cited by so many of the writers who are examining both the facilitators and the im-

pediments to more productive scientific research and knowledge development.

What is obvious is that scientists, academic/professional societies, and the institutions funding research, along with librarians/information professionals, are challenging commercial publishers for more economic, efficient, and effective scientific information communication and exchange. Researchers, research organizations, and societies increasingly are recognizing that they, and not commercial publishers, are both the generators and the controllers of quality scientific information and literature.

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