THE IMPACT OF TELE-NETWORKING ON RESEARCH*

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It is commonplace that communication technologies are altering the face of research...Networks have become an accepted part of the practice of science. Researchers continue to clamour for network capability, and devour network capacity and services as fast as engineers can deploy them. But there is much more growth and experience to come. We are at an early stage of the learning curve.[1]

Policies that influence the rate of adoption and degree of access to telecommunication channels have profound implications for science. At one extreme, as different scientific disciplines adopt different channels at different rates, the likelihood of cross-disciplinary research decreases and differences in the rate of progress in those disciplines become more obvious ... At the other extreme, adoption of the same telecommunication channels at the same rate promotes the sharing of knowledge, extended research groups, more information transfer, and the rapid diffusion of scientific information - but undermines disciplinary boundaries and reward structures.[2]

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INTRODUCTION

A distinguishing feature of the practice of research in the early 1990s is, it can be argued, the rise of electronic networking. The extraordinary exponential growth of traffic at 300 per cent per year, on AARNet in Australia[3], Internet in the US[4], of JANet in the UK, and of EARN in Continental Europe are now well catalogued.

Electronic networking, or as it is increasingly referred to, tele-networking, relies on the use of computers networked via telecommunications links. Its dramatic development, like many other aspects of the micro-electronics and computing industries, has occurred in an environment marked by intensive competition, non-standardisation, and almost anarchic creativity.

A marked feature of the growth and importance of tele-networking is the extent to which it has been driven by the demands of research itself. There has been a strong linkage between the demands of computer research and capabilities to do more complex and faster calculations and the development of computers to meet these needs. In addition, high speed computation and communication is becoming regarded as an essential tool in an increasingly wide range of research fields. Reflecting this research origin, networking has grown most strongly from the bottom up. Its stimulus has **not** been access to high speed data highways, but the development of local area networks so that researchers could share data and latest progress.

The structure which has facilitated this dramatic growth is, paradoxically, a very

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lack of structure or administrative requirements. It is an international telecommunications service without hierarchical management. Service delivery is achieved not by traditional organisational bureaucracy, but by the building of coordination:

> The rapid growth in EN [Electronic Networks] has been a consequence of almost free connection (local joining costs only), free software and free information from library catalogues, documents and databases around the world - based on a lot of good, simple cooperation. It is the community, the people who occupy this virtual public open space of the Internet, who generate the information and make the facilities so valuable. The network is a global club, a largely self-regulating community of individual users.[5]

Much is promised, and expected, from the development of tele-networking:

> Data communication networks enable scientists to talk with each other, access unique experimental data, share results and publications, and run models on remote supercomputers, all with a speed, capacity and ease that makes possible the posing of new questions and the prospect for new answers. Networks ease research collaboration by removing geographic barriers. They have become an invaluable research tool, opening up new channels of communication and increasing access to research equipment and facilities. Most important, networking is becoming the indispensable foundation for all other use of information technology in research.[6]

However, at this early stage of the development and application of teleresearch there is much experimentation and relatively little empirical or critical analysis. Much of the literature depends on anecdote, speculation, and extremely limited data. The general tone of many reports is of unbounded enthusiasm.

At the same time, there are also frequent expressions of disillusionment and frustration at the many technical and operational barriers that apparently inhibit access to the wonders of tele-networking. Star[7], in her analysis of a network system dedicated to a specific research community, has discovered that relatively few members of a research group are comfortable in using the network tools, and identified many practical barriers to access and effective use.

As one official view puts it:

> Mathematics, computer science, and electrical engineering are probably the best places to look for the impacts of CMC [computer mediated communication] since these fields invented the channel and its eccentricities. For those trained in these fields, the medium is transparent. It allows them to distinguish routine and mundane communication processes from the exceptional or contested ones. **For the majority of us, CMC is both an opportunity and a source of frustration.**[8]

The frustration is perhaps best captured by an anonymous commentator:

> No matter what rhapsodies they write about the Data Superhighway, the technology is still at the stage of hand-cranking the Model-T to start-up and having to make roadside repairs as a daily feature of travel.

The development of electronic networks and their associated services has largely been driven by researchers with a technical interest, who have assumed that an expanded technology of communication and information access must be of unquestioned positive value to the research process. There has been relatively little examination of how and why researchers use electronic networks, or of the dynamics and advantages of tele-networking for research, let alone consideration of the limitations and consequences of intermeshing technological and social networks.

These limitations are reflected in a recent report.

> The information highway involves 'more than just laying down concrete. We need the connecting roads, the highway services, and the transportation functions.' The needed policies and user services should be based on an understanding of researchers' patterns of communication and information seeking and use. There is little empirical evidence, however, about how many researchers are regular users of the existing national network structure, what the vast majority of researchers use networks for, and about how the networks affect their work. Few investigations have focused on the problems faced by both 'high profile' and other users of electronic research networks, or on how researchers are trained to use networks. In addition, little research has been done on major policy issues related to the design and implementation of a national research network.[9].

This paper provides a review of the scant research which has been conducted on the ways in which tele-networking is being used, and may affect the processes of research, and some preliminary data on the operation of tele-networking in Australia.

A TYPOLOGY OF TELE-NETWORKING FOR RESEARCH

Star and Kanifer have introduced the useful distinction in teleresearch between custom software projects which link remote researchers joined by common interests, and tools for browsing. The latter approaches to information location, retrieval and sharing, can be broken down into five categories:

1 Simple hierarchical methods of data access based on underlying directory structures (e.g., Gopher, anonymous FTP);

2 Powerful text and keyword search methods including large-scale fulltext search engines (e.g., WAIS) and keyword search facilities layered upon other information systems (e.g., Veronica and Gopher, Archie and anonymous FTP);

3 Free-form linking schemas that embody hypertext and hypermedia principles (e.g., World Wide Web);

4 News, or bulletin board systems (e.g., Usenet news) which allow groups to carry on multiple, overlapping, freeform conversations asynchronously and over extended periods of time;

5 Electronic mail, which is ideally suited to person-to-person and person-to-people communication, and conversations.[10]

While this is a useful analysis from the network capability perspective, a more useful classification for the purposes of this paper is how researchers use tele-networking. Four distinct categories can be identified:

(i) *Information access* - this is a very common form of teleresearch which is of value to all researchers, regardless of discipline. It enables researchers, from their desk or laboratory to directly search library catalogues and databases and rapidly locate information required for deciding the next step in an experiment or project. It also enables researchers to seek information directly from colleagues around the world, by use of e-mail and bulletin boards.

(ii) *Communication* - research has always thrived on communication, given that the practice of science is inherently a social process; the determination of what is an interesting problem, the identification of new research directions and opportunities, the testing of ideas, the dissemination of results, and the formal refereeing and publication processes all rely critically on communication within the scientific community. It cannot be surprising, then, that a technology which facilitates and expands communication between researchers should be highly used, and prized.

Indeed, network access has quickly become an expectation of researchers. Like the telephone, it is now an expected part of day-to-day science:[11]

> "I live on the Internet"; "the internet is a new nation"; "the laboratory of the 21st century has no walls and no boundaries, but is a virtual community"; "we are all netizens now"; "the vast majority of our communications are by Internet"; "using the net, we can talk back and forth and solve problems, ship data files, write papers together, much more quickly and richer".

E-mail provides the means for easy communication between individuals and research groups, whereas bulletin boards provide the means for communication between individuals and research groups on the one hand and the research community on the other. Transfer of information, be it research results or manuscripts, is facilitated by the file transfer capability.

A particular application of the network communication capabilities is in the dissemination of the results of research. It can be used to communicate rapidly the preliminary results of projects, even experiments. But it is also increasingly used as the channel for submission of manuscripts for formal journal publication. The process of refereeing, editing, revision and proofing can all be carried out using the network. The same capabilities are applicable also to proposal preparation and submission.

(iii) *Collaboration* - electronic networking provides a mechanism for the effective management of research projects and programs, the elements of which are geographically dispersed. It also provides a means for maintenance of a research community, or the rapid establishment of a new one.

> It allows researchers to participate in more, and more diverse, research communities ... Electronic communications allow researchers to juggle more collaborations and keep weak ties active.[12]

A spectacular example of what can be achieved by marshalling the resources of a research community in effective collaboration, in this case by researchers themselves, is provided in Box 1.

However, collaboration has emerged not only by the decentralised actions of individual researchers. The potential for electronic networks to be used as a mechanism to improve the quality and productivity of research has also been an issue of interest to the policy-makers.

> The fusion of computers and electronic communications has the potential to dramatically enhance the output and productivity of US researchers. A major step towards realising that potential can come from combining the interests of the scientific community at large with those of the computer science and engineering community to create integrated, tool-oriented computing and communication systems to support scientific collaboration. Such systems can be called 'collaboratories'.[14]

Box 1 - Factoring the Ninth Fermat[13]

Two mathematicians employed by Bell Communications Research (Bellcore) and Digital Equipment Corporation used electronic mail to recruit computing resources from several hundred researchers from companies, universities, and government laboratories around the world. They asked them to work on solving a large and important mathematical problem, one with practical implications for cryptography. Researchers who volunteered to help were sent a piece of the problem and returned their solutions by electronic mail. All of the partial solutions were then used to construct the final solution. The electronic message announcing the final results contained a charming admission: the two mathematicians who organised the work and constructed the final solution from the pieces returned to them did not even know the names of all of the people who helped them:

We'd like to thank everyone who contributed computing cycles to this project, but I can't: we only have records of the person at each site who installed and managed the code. If you helped us, we'd be delighted to hear from you; please send us your name as you would like it to appear in the final version of the paper. (Manasse, 1990)

In 1989, the US NSF funded the establishment of a number of testbed collaboratories. Custom software systems were developed to meet the specific data-sharing, communication and collaboration needs of each of the selected research communities.

One of these, established as a model collaboratory for the Human Genome Project, was entitled the Worm Community System. It is designed to support the community of some 500 scientists, worldwide, who are sequencing the gene structure and studying other aspects of *c.elegans* - a nematode worm. (See Box 2).

The collaboratory was considered to facilitate research by the following means: improved access to colleagues, powerful dedicated electronic networking, organisation of educational workshops, improved access to data, and provision of tools for collaboration, such as specialist data catalogues, and specialist software tools for planning and management of major international projects.

A remarkable example of the interaction between the application of computer-based analysis to molecular biology and electronic network-based collaboration is provided by the case of automated gene sequencers. (See Box 3).

(iv) *High performance computation and communication (HPCC)* - beyond the applications of tele-networking discussed above, there are aspirations to address previously unresearchable issues using the power of interconnected supercomputers. When the speed of communication becomes comparable with the speed of computation inside a computer the multiple power of these machines can be bought to bear on enormously complex problems.

Box 2 - A Model Collaboratory[15]

The Worm Community System comprises a digital library containing the data of the community of molecular biologists who study the nematode worm Caenorhabditis elegans, which has become a primary model organism in the Human Genome Project, and a software environment that supports interactive manipulation of this library across the Internet. The current library contains a substantial fraction of the extensive knowledge about the worm, including gene descriptions, genetic maps, physical maps, DNA sequences, formal journal literature, informal newsletter literature, and a wide variety of other informal materials. The current environment enables users to browse the library by search and navigation, to examine and analyse selected materials, and then to share composed 'hyperdocuments' within the community. The current prototype is running in some 25 worm laboratories nationwide, and there are already instances of users electronically submitting items to the 'central' information space and having these automatically redistributed to other sites.

There are also a number of data-intensive fields of science, which study phenomena that are remote and inaccessible (e.g., space, ocean depths), or inherently distributed across time and space (e.g., global climate change). Collecting, storing and analysing data and modelling these systems require not only great computational power, but also communication systems that can transfer these enormous packets of information around the world.

Recognition of the strategic significance of this potential capacity has led the governments of the major industrialised nations to invest in the development of HPCC capability. In the US the HPCC program has been formulated in the light of the four broad classes of HPCC applications that have been identified:

- simulation and collaboration in scientific research and engineering;
- embedded systems applications;
- information management; and
- 'grand challenges'.

'Grand challenges' are fundamental problems whose solutions have thus far not been accessible but which are considered to be critical to major future needs. Example of grand challenge issues include:

- climate modelling;
- prediction of earthquakes;
- semiconductor design;
- rational design of pharmaceuticals;
- design of protein structures;
- human genome sequencing;
- magnetic information storage technology; and
- underseas surveillance.

Box 3 - A New Collaboration Every Day: Identifying Human Genes Using Automated Sequences and the Internet[16]

Cloning, sequencing, and characterising the biological function of a gene are long, slow processes requiring many different types of biological expertise. In 1990, J. Craig Venter at the National Institute of Neurological Disorders and Stroke developed a shortcut method for identifying genes: using automated DNA sequencers to sequence a few hundred bases from one end of complementary DNA (cDNA) clone of the gene's messenger RNA (mRNA) transcript. The resulting "expressed sequence tag" (EST) is a unique identifier for the gene. ESTs generated from randomly chosen cDNA clones effectively provide a clone and a partial sequence of a gene in a single experiment. In many cases, the gene family to which a newly cloned gene belongs can be identified by comparing the EST sequence to the known sequences contained in databases such as GenBank. The National Center for Biotechnology Information's "Blast" Internet server and Oak Ridge National Laboratory's GRAIL server are key resources in this analysis process. In the last 2 years, the EST project has published sequences of thousands of human genes, developed a database of sequences and analysis results that is available over the Internet, and provided the clones from which these ESTs were derived to the research community via the American Type Culture Collection. Venter's laboratory, now at the Institute for Genomic Research, is sequencing thousands of new ESTs per month.

Each EST raises the possibility of a new scientific collaboration to characterise the function and assess the biological and medical significance of a new human gene, and hundreds of requests for sequences, data, clones, or additional information have been answered by the laboratory.

In many cases, data and materials are sent for others to pursue independently. Either way the rapid communication facilities provided by the Internet allow quantities of data that could not feasibly be published in print media to be exchanged quickly and efficiently between colleagues around the United States and in many other countries.

The extent of these changes has led some commentators to suggest that the researcher of the near future will need to be equipped with a radically new toolkit (Box 4).

THE EFFECTS OF TELE-NETWORKING ON THE PROCESSES OF RESEARCH

The typical networked scientist uses electronic networks to chat with colleagues across the hall and on the other side of the globe, arrange meetings, distribute conference announcements, share work in progress, get hold of new software, send out preprints, submit proposals, and run a model on a supercomputer in another state. The extent of network use varies; some researchers spend half of their day on the network, while others may use it once a week only to check e-mail.[18]

Box 4 - The Toolkit of the Future[17]

The centrepiece will be the user node in which an electronic laboratory notebook configured similar to a laptop computer (or even smaller) will provide the user with a mobile facility and could contain software and experimental details in a relational data structure, and such data as images of empirical results stored as digitised images in files that can be manipulated and directly compared following computer scaling.

This same electronic notebook will be able to interact with a high-band-width research network which will provide access to other researchers through electronic mail, compound document transfer and direct file access. Moreover, the notebook will also contain information about access to data not necessarily in the notebook at the local site, but rather in a database on a remote computer accessible through the network.

The notebook will be the input/output communication nexus and provide the researcher with information for initiating global database searches or scientific computations. The researcher can select any CPU on the basis of availability on the distributed computing network, or suitability based on computing power, available applications software and database. Such functionality would provide any researcher at any location access to a global collaborative laboratory.

Networks are not, of course, new to research. They have played a vital role in the social control and direction of research, though they have more usually been labelled as 'invisible communities'.

For example, Vinck *et al.*[19] have examined how researchers are mobilised in response to an urgent public health problem, and the forms of self-organisation and directed organisation. They identified four modes of coordination, the form of each of which reflects the structure and logistic needs of the particular issue being researched:

1 Networks having a "data collection structure" where coordination involves management of the circulation of information and publications, and the compilation of databases.

2 The "forum" network provides a means for coordinated interaction between specialist communities, structuring "a scientific community around questions of research, objects of study, methodologies or development of new products."

3 The network based on "thematic partition with harmonisation of research practices" is the "hard network" version of the forum, and commonly partitioned by focus onto particular themes.

4 The network "starred around a central facility" revolves around a central facility such as a reference laboratory, testing centre or major instrument facility.

This analysis clearly indicates that different research communities have different needs for data, instrumentation and communication, and that these needs are largely determined by the nature of the research problem. Hence, tele-networks, to be useful, will need to provide the desired capability, or be tailored to the specific needs of a research community. Simple generic networking or data access may have only limited value.

A small number of significant studies have been conducted, mainly in the US, which shed light on, first, patterns of use of electronic networks, and, secondly, their interaction with the social structures and dynamics of research.

In a study of the social and behavioural considerations underlying the planning for the establishment in the US of NREN (the National Research and Education Network), McClure *et al.*[20] found that current literature and policy statements suffer from "technophoria" in the way in which they extol the virtues of electronic networking They are also commonly incomplete in that they: rarely examine users' problems and frustrations; assume universal access and connectivity; inadequately consider training, education, and retraining issues; collect few data designed to provide an overall picture of the uses and effects of high-speed electronic networks; rarely analyse policy issues and behavioural factors appropriate to a national research network initiative; and assume past experience with networks have prepared policy-makers, network managers, and users to deal with issues and problems from a true integrated, multi-purpose national network.

A range of barriers to effective network operation and use were identified by network users in this study. They included: inadequate education and training; a lack of technical standards; complex or unknown procedures; insufficient or uneven network capacity; unreliability of data transmission and transformation; lack of user-based systems and applications; poor documentation; inadequate directories; insufficient connectivity; technological overkill; uncertainties about network management; and doubts about data security.

In their study of computer-mediated communication, Lievrouw and Carley[21] proposed that scientific communication be viewed as a three-stage cycle of conceptualisation, documentation and popularisation. They argued that electronic networking affects all three stages of the scientific communication process; it expands the group of researchers a scientist may communicate with during the conceptualisation stage and makes this group more homogeneous and long lasting; it increases the use of both formal and informal documentation; and it influences the degree of access to the mass media.

They carried out two surveys of 46 BITNET users, and 35 NSFNET users, respectively. The results reveal it is the promotion and facilitation of collaboration that is regarded as the greatest impact of tele-networking on the research process. With regard to communication, the greatest impact is in broadening the community of scholars. E-mail is by far the most common, and valued use of networking, followed by file transfer, accessing computer resources, and sharing software.

They arrived at some interesting generalisations about the contribution of tele-networking to research, though the empirical and theoretical basis for these claims is limited:

1 Greater reliance on tele-networking expands an individual's spheres of influence;

2 Greater use gives greater access to potential collaborators and pathways for diffusing ideas;

3 The greater the use of tele-networks, the higher the level of knowledge shared with colleagues;

4 Increased network use creates more overlap between the three communication stages;

5 Tele-network reliance leads to an increase in the number of rules to control premature diffusion of information.

Star[22], however, draws attention to the lower entry barrier to the electronic publication of ideas or experimental results. Noting the high level of retractions and corrections on e-mail, she raises the issue of whether the lower barriers to entry produce lower barriers to error, and hence that there is a substantial reduction in quality control of research findings.

In a more detailed study of e-mail use, Carley and Wendt[23] carried out an extensive examination of a small number of artificial intelligence researchers using a specialised language model, Soar. The group already had strong proximity and collegiate ties. On the basis of tracking group members' e-mail for a week, it was found that 60 per cent of the traffic dealt with organisational issues (such as communicating the availability of literature), 20 per cent involved operational issues (how to get rid of a bug), and 20 per cent was essentially social.

They concluded that e-mail was more commonly used to diffuse secondary information rather than primary ideas. Intellectually stimulating ideas are apparently still most likely to be conveyed through face-to-face communication. But once an idea becomes established, e-mail becomes an effective mode of communication. They also note that e-mail does not appear to stimulate new relationships between scholars; instead it enhances existing relationships and proximity ties. It is argued that e-mail, then, has primarily an enhancing effect,

> because it makes it possible to maintain ties with a larger group of colleagues and extends an individual's research group (that is, the group of people with whom an individual interacts regularly and informally, to the point of direct collaboration on specific research projects).

Another study of network impact examined the use by 257 researchers of the commercial SCIENCEnet established to serve the oceanography community[24]. The analysts' assessment was positive:

> Within the SCIENCEnet community of oceanographers, network usage is consistently associated with desirable scientific outcomes. The observed associations do not prove causality, but they do demonstrate that productive scientists use the network more often and for more purposes than unproductive scientists do. SCIENCEnet has become a critical part of the infrastructure of doing ocean science.

In 1992 the Office of Technology Assessment of the US Congress commissioned two studies to examine the impact of tele-networking on research processes. The questions to be examined were[25]:

- How do communication technologies change the way researchers interact with one another - world-wide, nationally, regionally, and locally - and with various other publics?
- What is the evidence that the nature of team-work is changing to accommodate technology?
- While researchers in informal communication networks benefit from quick-circulating ideas, will researchers outside these electronic circles risk lags in access to information?
- What do empirical studies of users and consumers say about the limits of telecommunication: what do electronic bulletin boards and fax transmissions provide?
- Will the need grow for "knowledge brokers" who work at the intersections of scientific specialities and/or intercede between knowledge producers and users?

Lewenstein[26], who was commissioned to conduct a study of the use of computer-mediated communication in the cold fusion research controversy, concluded on the basis of this admittedly special case that researchers create their own idiosyncratic mixes of communication strategies and channels. Further, in accord with the findings of Carley and Wendt, he concluded that:

> CMC does not lead to more collaboration; it is a tool that facilitates existing arrangements. It is also used strategically and idiosyncratically to achieve an individual researcher's objectives. How these technologies support scientific communication, then, must be examined in the context of the individual's regimen of information retrieval, refinement, and transfer.[27]

Heinz, in a more general analysis of the effects of tele-networking, found that it is seen as particularly powerful in increasing access to the research resources of people, information, databases and software. International communication and collaboration in particular are made much easier by tele-networking. However, face-to-face interactions are still regarded as vital.

Other applications included growth of electronic communication to streamline grant management, experimentation by established journals and scientific societies with electronic publishing, a move to comprehensive national databases to deal with proliferating research data (for example the American Physical Societies have argued for a national physics data base as the heart of a world-wide physics information system), remote access to major facilities such as supercomputers and particle accelerators, the creation of new distributed facilities such as the global digital seismology network of the Incorporated Research Institute for Seismology, and finally access to short-life material through companies offering, for example, custom DNA shipped in 24 hours.

Ingvarson *et al.*[28] also raise a series of questions about the impact of teleresearch on the key dynamics of the research process:

- Are libraries going to be less used by researchers?
- Is the role of the research group and supervisor being made less important by networking so that small groups and individuals can be just as effective as large groups?

- What is the status of network-published results and what does it do to traditional publishing?
- Does electronic networking subvert the peer review process and journal reporting?
- How will electronic publication be recognised in peer assessment and promotion?
- Will access to EN expand horizons or facilitate a narrowing into small communities communicating only internally?
- Will access to EN increase or resolve information overload?

In conclusion, it is apparent from these few studies that the technological capabilities, real and potential, of tele-networks, do not automatically translate into more productive, or creative, research. If tele-networking is to achieve its much touted potential, it is essential that it be designed with an understanding of, and a commitment to support, the dynamics and social processes of research in general, and the characteristics of individual disciplines, and problem domains in particular.

ANALYSIS OF TELE-NETWORKING FOR RESEARCH IN AUSTRALIA

A survey of the practice and implications of tele-networking among Australian researchers was made of a sample of 114 researchers active in the use of tele-networking.

The sample comprised 40 per cent from computing sciences, 30 per cent from physical sciences and engineering, 17 per cent from biological and environmental sciences, and 13 per cent from humanities and social sciences. The dominance of computing sciences is to be expected, given that they are the prime developers and users of the technology of tele-networking. Details of methodology are in Appendix 1.

In all, twelve distinct but overlapping applications of tele-networking to research were identified:

E-mail - used extensively as a substitute for previously mailed, and more recently faxed correspondence; commonly contains a mix of progress in research, requests for specific data or technique-related information, drawing attention to new publications, and general network maintenance and social chat. E-mail appears to be particularly valuable to lone researchers who use it to maintain close contact with scholars at other universities and to gain and retain membership of their research club.

E-mail bulletin board - researchers in a particular field establish a bulletin board as a regular means of communication between the individual and the relevant research community. Activities include the sharing of references, conferences, new books, courses, and conduct of long-running seminars. They also post enquiries such as “Has anyone done any work on such-and-such?” or “What’s the best paper to read to get an overview of this approach?”.

File Transfer - electronic files are made available in a public part of the system such that anyone (world-wide) who has an Internet connection can access them.

Database access - the capability to access and search databases - domestic, international, third-party (private sector or government) public access or private restricted access.

Distribution and access to image-based data - distribution and access to geographical information (maps) and image data over computer networks. For example, collaboration between researchers at Monash University and ANU to study NASA's Magellan images of Venus has used AARNet as the main communications conduit for image and program files. A comprehensive set of planetary images is now available directly on line from a NASA computer in the US.

Research teams with geographically separated members - tele-networks can provide the means for far more effectively operating and managing a coherent research team which is scattered around the country. For example, the Australian Geodynamics CRC, which involves groups in Melbourne, Perth, Canberra and other regional centres maintains co-operation between these groups and industry collaborators using AARNet.

Access to remote equipment - the great majority of this use is remote computer access, particularly to supercomputers, whether interstate or overseas. Researchers with very high computation requirements commonly carry out the majority of this component of their research from their offices on supercomputers located in the US, Europe and Japan. There is potential for remote access to other high cost instruments, but this appears to be still in the research stage.[29]

Access to data sources - a number of researchers, particularly in data intensive, high computation fields, regularly access collections of data which are centrally, or non-centrally stored.

Access to libraries - researchers commonly search their own university library catalogue, that of other Australian universities, and specialist collections overseas.

Sharing software - researchers use the electronic network to gain access to software in the public domain, specialist software made available through bulletin boards, and software developed by collaborating groups.

Dissemination of results - there are a number of forms of dissemination of results, distinguished largely by the formal level of quality control; bulletin boards can be used to distribute preliminary results or new findings; moderated news groups rely on electronic posting of an article to a group-appointed news editor, who performs the traditional editorial functions before making it available to the group; formal publication through e-mail journals is now operating in some rapidly moving fields.[30]

Submission of manuscripts - a growing number of traditional journals are encouraging, and in some cases requiring, submission of manuscripts by e-mail.

As well as identifying these types of usage of tele-networking, data were collected on the frequency and value of specific uses, and their effect on research practices. Table 1 and Figure 1 summarise the data on frequency and types of usage of electronic networks. Only 3 of the 55 respondents did not report using e-mail. Almost half of the respondents reported that they used e-mail on an hourly basis, on average; the remainder used it on a daily basis.

Table 1 - Respondents use of Tele-networks

Category of Use (per cent of Respondents Using) n = 53	TOTAL	hourly	daily	weekly	monthly
E-mail	94	41	54	0	0
Bulletin Board	65	0	28	19	19
File Transfer	87	7	23	39	17
Searching DB	63	0	7	19	37
Sharing Software	69	2	13	26	28
Data/Eqpt access	50	2	7	15	26
Computer access	61	15	17	20	9
Dissem. results	70	2	6	32	32
Submit manuscripts	67	0	5	2	59
Libraries	85	2	30	43	11

Other uses reported by more than five-sixths of the respondents were file transfer, and communication to libraries. Approximately two-thirds reported using all the other listed capabilities of electronic networks, with the exception of access to data sources and remote instruments, which only half of the sample reported.

After e-mail, computer access was the only other use by a non-negligible proportion of researchers on an hourly basis. Dominant uses on a daily basis, again after e-mail, were library communication, bulletin boards and file transfer - all activities which could be considered an integral part of the everyday research process. On a weekly basis, library communication, file transfer, and dissemination of preliminary results were the dominant uses. However, monthly frequency of use showed a different pattern, with electronic submission of manuscripts, dissemination of preliminary results (concerned with the outputs of research) and searching of databases the most frequent uses.

An analysis by mode of use presents a complementary picture: the mode of use of e-mail and bulletin boards was daily, file transfer, computer access, library communication and dissemination of preliminary results was weekly, and database searching, software sharing, data access and electronic submission of manuscripts was monthly.

In addition to frequency, respondents were asked to assign a relative value to the various uses of electronic networks. The relative rankings for critical and critical+important+useful are shown in Table 2.

Figure 1. Frequency of Respondents Using Tele-networks

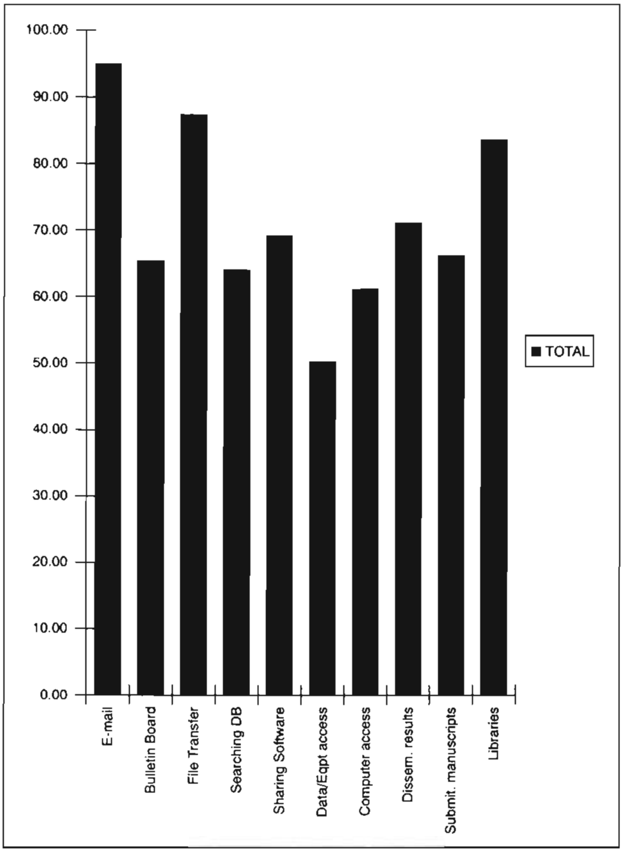

Table 2 - Relative Ranking for Critical, Important and Useful Values

Category of Use	Critical	Critical + Important + Useful
E-mail	1	1
File Transfer	2	2
Searching commercial online databases	5	-
Sharing Software	-	5
Computer Access	3	-
Dissemination of preliminary results	-	4
Communication with library	4	3

This reveals e-mail and file transfer, in that order, being regarded as most valuable across all the measures of positive value; they are generally followed by library communication. However the uses of computer and database access have the characteristic that for some researchers they are critical, but they do not have a high value for the majority. In contrast, few regard sharing software or dissemination of preliminary results as critical, but overall they are rated as having a strongly positive value.

The way in which electronic networks facilitate research was examined through the ranking of a series of potential advantages constructed on the basis of the research and analysis reported above. Table 3 presents the resulting data. The first column of figures in the Table presents the percentage of respondents who gave some positive priority to the corresponding advantage. The second column reports only the number 1 priority choices, and the third column, the sum of priorities 1 and 2.

Table 3 - How Use of Tele-networks Facilitates Research

Category of Facilitation (per cent of Respondents Selecting)	Total	1st priority	1 & 2 priority
Promotes and facilitates collaboration	90	54	70
Allows remote and/or powerful data collection/analysis	39	4	22
Reduces negative effects of remote/small institutions	50	11	30
Improves ability to solve specific research problems	26	2	6
Facilitates resource sharing	56	4	9
Increases productivity	46	6	15
Aids conceptualisation	11	0	2
Improves project administration	19	2	7
Allows participation in international research	52	11	15
Assists project initialisation and proposal development	11	0	4
Enables 'faster' research	26	4	7
Enables a 'larger' research program	26	0	6

The first column shows that the promotion and facilitation of collaboration is regarded as the greatest advantage of the use of electronic networks, with 90 per cent of respondent support. Approximately half of the respondents also saw considerable advantage, in descending order, in facilitation of resource sharing, allowing participation in international research, and reducing the negative effects of remote or small institutions.

The results are even more distinct when only 1st priority ratings are examined. The promotion and facilitation of collaboration is supported by more than half the respondents, and received almost five times as much support as the next categories - allowing participation in international research, and reducing the negative effects of remote or small institutions.

The combination of the 1st and 2nd priority choices also supports the overwhelming importance of the promotion and facilitation of collaboration, followed by reducing the negative effects of remote or small institutions, and allowing remote and/or more powerful data collection/analysis.

This emphasis on the prime value of tele-networking for research being in the promotion and facilitation of research collaboration corresponds with the findings for the oceanography community.[31]

Finally, an assessment of the contribution of access to tele-networks to formation or membership of research networks was made. Given the emphasis placed on collaboration, it would appear reasonable to assume a growth in access to and effectiveness of research networks.

By and large, the data support this view. Of the responses, 62 per cent of researchers considered that use of tele-networks had enabled them to join or establish a national network of researchers. Of those responding positively, just over half were members of a network with no more than 10 members, 35 per cent were members of a network with 11-50 members, and just four respondents were part of a network with more than 50 members.

The data were comparable, but even more positive for international networks. A significant 72 per cent of respondents claimed that use of electronic networks had enabled them to join or establish an international network of researchers. Again, the majority were of modest size - 47 per cent with no more than 10 members, and 22 per cent with 11-50 members. However there was also evidence of membership of larger networks, with 3 respondents being part of a network with 50-100 members, and 7 in networks with more than 150 members.

In summary, the findings of this Australian survey with regard to both type and frequency of usage, and the impact of that usage, are broadly in line with the limited data available from US surveys. For the majority of researchers, the technology is used mostly to improve communication with their research colleagues, and through the ease and immediacy of transfer of information, to provide the basis for research collaboration.

However it is also apparent that the other more specific capabilities of electronic networks, such as access to databases and computer resources, are each important to some groups of researchers. These findings also support other evidence of a growing trend to dissemination of preliminary results, and for the submission of manuscripts, by electronic means.

It is instructive that researchers value access to electronic networks primarily for its capability to promote and facilitate collaboration. Issues of efficiency or increased productivity, even though they undoubtedly result, are not regarded as nearly as important. Rather the technology is prized because of the way in which it supports the normal social processes of research, allowing individuals and groups to link with each other, share information and ideas, and compete for priority.

There is another special group of researchers, whose research programs could not even be envisaged, let alone conducted, without access to high performance computing and communication (HPCC) networks . Their pattern of use of electronic networks is quite different from the 'normal' user. Their special needs also place high demands on the system.

CONCLUSIONS

Some important findings of this preliminary study are that:

- Researchers identify the promotion and facilitation of collaboration as the primary advantage offered by access to electronic networks. In this way, in general it appears that they are predominantly used as an aid to collaboration which has already been established by other means. In simple terms, tele-networking facilitates communication and collaboration when a linkage has been established, but it does not drive collaboration. There is also evidence that it is used more for the communication of secondary, rather than primary information.
- In the sample of researchers studied in this project, particular value was placed on the ability of tele-networks to reduce the disadvantages of working at a smaller, or remote university.
- Different disciplines have different needs and usage patterns for tele-networking. As the US study on 'collaboratories' commented, the development of electronic networking has largely been driven by computer scientists and engineers and hence shaped by their specific and idiosyncratic needs. It is in that sense, a classic case of 'technology push'. Now that advantages are being recognised for many researchers, there is an obvious case for seeking to reshape the operation of the networks who have no specialist expertise in computer and tele-network use, to be more user-friendly and customer-driven.
- Researchers in the data-intensive and computation intensive fields, relying on high performance computation and communication - HPCC, are highly technically proficient, and articulate, about their needs. While there is no doubt that the potential return from investment in HPCC is considerable, so is the cost. In addition, the different needs of the average performance computation and communication - users should not be neglected.
- While electronic networking promises much, occasionally even miracles, the almost universal experience is of frustration, and difficulties in making the system work. Indeed, it is common to encounter expressions of animated delight when a transaction works right the first time. There is quite evidently room for enormous productivity improvement in the use of electronic networks.
- The provision of training in the use of tele-networking is, at best, partial and piecemeal. The majority of researchers, including PhD students, pick up the skills to use Internet themselves, or by discussions with colleagues. A few universities

have provided minimal training courses. Perhaps the most important step in improving the productivity of electronic networking is the provision of appropriate training.

- There is some evidence, and considerable expressions of concern, that the relative ease of access to electronic networking, and the lack of any 'entry qualification' may be reducing the high standards of quality control associated with science. The low entry barrier/low error barrier identified by Star[32] suggests that a not insignificant proportion of the information circulating may not be accurate. However, given that it is predominantly secondary information, there is little evidence, as yet, of a serious challenge to the reliability of findings reported in the major journals.
- No examples of the development of custom software networks specifically for or by Australian research groups have been identified. Australian researchers are members of a range of international (predominantly US-based) netware groups. It has not, apparently, been considered appropriate to originate, or gain the experience of operating, such networks in Australia.

This study has revealed the very considerable contribution that tele-networking can make to research, and the emergence of a series of forms of its use in research. However, the potential is yet to be reached, and there is a need for a considerable improvement in access, user-friendliness and training.

While no panacea, the appropriate provision of tele-networking and development of procedures and protocols for its use could make a significant contribution to the challenging problem of providing an adequate infrastructure, in the expanded university system, to support both research and research training.

There is a need for an active program of development of tele-networking to support collaboration between researchers, and to provide a demonstration of the capabilities and advantages of such a mode of operation. This could include the development and trialing of model custom software networks. The Cooperative Research Centres would be particularly appropriate venues for the exploratory development of advanced teleresearch processes.[33]

Understanding of the ways in which the capabilities of tele-networking can interface with the social dynamics of research is as yet at a very early stage. As the technical power of the networks grow, it will be essential to have a comparable growth in knowledge about how the technology can most effectively be used to assist, and where appropriate transform, research processes.

APPENDIX 1 - METHODOLOGY

The first phase of data collection, after a literature survey had been conducted, entailed approaching all 35 Australian universities and eliciting their support for the project. This was achieved by contacting the Deputy or Pro Vice-Chancellors (Research) of each institution and requesting their assistance in identifying researchers at their institution involved in tele-networking activities. They responded by either identifying relevant researchers and notifying us of their activities, or by passing the request on to appropriate departments.

All but five universities provided responses, though the quality and comprehensiveness of the responses varied considerably. Part of the explanation for this variability in response undoubtedly lay with the priority accorded to the request, part with the available records in each university, and part with varying interpretations of what constituted tele-networking.

Two types of responses were forthcoming. First, as requested, information regarding researchers involved in tele-networking activities, and secondly, information regarding researchers who were researching technologies that could have telerenetwork applications.

A total of 114 researchers who were active in tele-networking were identified by this process. Details of these researchers, including contact details, disciplinary category, and specific research interests have been compiled into a database.

This listing can not be considered as either comprehensive, or necessarily representative. The fact that one university identified 13 researchers, and another only one, is not necessarily indicative of their relative strengths or interests. In addition, the list is undoubtedly biased towards the heavy users of tele-networks. However given the objectives of this study, the latter bias did not seem a disadvantage, and it was this group that was used as the sample to investigate in more detail the current practices, advantages and limitations of tele-network use in research.

A questionnaire was distributed to the 114 teleresearchers listed in the database, with responses invited by either e-mail, fax or mail. In all, 55 useable responses were received in time for analysis, which constitutes a response rate of 48 per cent.

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