

Changing Patterns of Communication Among Scientists In an Era of "Telescience"

Leah A. Lievrouw and Kathleen Carley

ABSTRACT. *In a work environment filled with computers, telephones, fax machines, and other telecommunications equipment, scientists can engage in a new way of conducting their research: telescience. Telescience, a term that originated at NASA, is defined as the existence of geographically dispersed, intensely communicative research groups and collaborators, electronic journals, and teleconferences. The concept seems to be a natural outgrowth of the development of "big science" in the postwar era—only now, instead of an increase in the number of journal articles or organized scientific meetings, there is an increase in the amount of interpersonal interaction facilitated by the new electronic infrastructure. It is not yet clear that telescience will become the mode in most scholarly disciplines, for a number of economic and cultural reasons. However, where it does appear, it may emerge at different rates in different disciplines as the nature and needs of those specialties encourage the differential adoption of the various telecommunications technologies. In this article, the communication processes and structures that are typical of scientific activity are summarized according to a three-stage communication cycle. In addition, the factors that affect scientists' choices of both conventional and newer telecommunication channels are discussed, as well as the barriers that may prevent them from adopting or using such channels. Finally, the potential behavioral, social, and policy implications of the growth of telescience are reviewed, especially in the social context of the contemporary research university.*

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Introduction

In a work environment filled with computers, telephones, fax machines, and other telecommunications equipment, scientists can engage in a new way of conducting their research: *telescience*. *Telescience* is a term that originated at NASA, defined as the existence of geographically dispersed, intensely communicative research groups and collaborators, electronic journals, and teleconferences (Aborn 1988). Will telescience emerge in all disciplines? Perhaps not, but where it does appear, it will emerge at different rates in different disciplines as the nature and needs of their specialties encourage the differential adoption of the various telecommunications technologies.

Communication among scientists is widely recognized as the key to the development of new ideas and to the success of individual scientists who work with those ideas (Crane 1972; Frydol & DeGreve 1986; Pollock & Nelson 1970). The increasing communication activity of scientists was documented thirty years ago by Derek Price, who equated the growth of numbers of documents and conferences with the rise of "big science" in the US (Price 1963). In certain respects the growth of telescience echoes this theme, but on an even larger scale, as communication channels like electronic mail, voice mail, and fax have the potential to transcend institutional, disciplinary, and even national boundaries.

Accordingly, the technological channels that scientists choose to help them interact profoundly affect the nature of that interaction; as Price (1963, 1965) points out, communication is a fundamental element of the social/technological context of "big science". This view has been reflected in recent studies of new communication media. Electronic mail, for example, has been studied extensively with respect to its acceptance by communicators and its ability to break down geographic or social boundaries (Freeman 1984; Hiltz 1984; Kiesler *et al.* 1984; Sproull & Kiesler 1986). Electronic mail has also been shown to facilitate other common types of scientific communication, such as the development of panels for conferences (Lievrouw 1989), group coordination (Carley & Wendt 1989; Rice 1984), and interpersonal communication (Rice 1980; Rice & Case 1983; Kerr & Hiltz 1982). Other telecommunications channels have been even less frequently studied with respect to their impacts on science. However, a need remains for the formulation of a more general theory of the effect of telecommunications technologies on scientific communication that is consistent with the contemporary understanding of telecommunication technologies in society generally.

In this paper the types of communication processes and structures that characterize science and the factors that influence scientists' choices of both conventional and newer telecommunications channels are reviewed. We propose a number of likely "scenarios" about how communication may evolve, and the rate at which telescience is likely to develop in certain fields, given the communication channel mixes that its members tend to adopt. Finally, we examine the potential behavioral, social, and policy implications

that may stem from the growing use of telecommunications channels in science and suggest directions for continued research in this area.

Communication Processes and Structures in Science

Scientific communication is characterized in general by its distinctive types of communication structures and processes. We define the *communication process* as any activity or behavior that facilitates the construction and sharing of meaning among individuals, that they consider to be the most useful or appropriate in a given situation (for example, the presentation of research findings, collaboration, the founding and growth of institutions, the conduct of "normal science" within a Kuhnian paradigm). A communication structure, on the other hand, is the set of relationships among individuals who are linked by the meanings they construct and share, for example, the research front, invisible college, extended research group (Rogers & Kincaid 1981; Lievrouw & Finn 1990).¹

Scientific activity can be viewed as a communication cycle having three progressive stages: conceptualization, documentation, and popularization

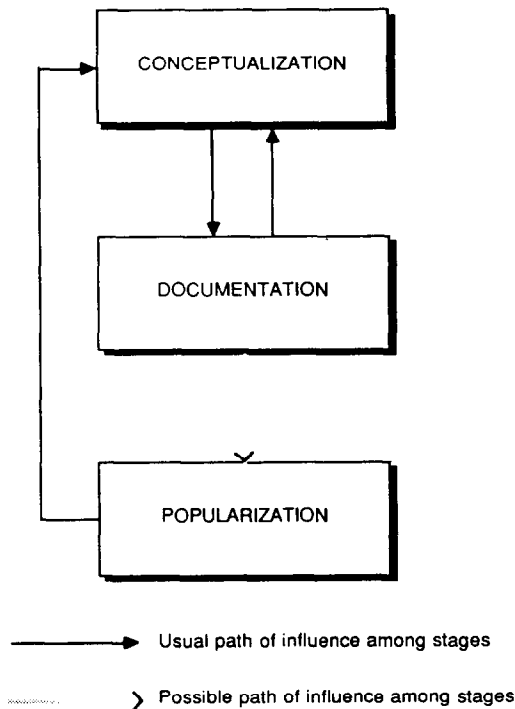


FIGURE 1. The Scientific Communication Style

(see Figure 1 and Table 1). Ultimately, the cycle enhances the credibility of certain scientific ideas and diminishes the credibility of other ideas, and so scientists' desires to advance or promote their ideas is, we believe, a major motive force for the evolution of a scientific specialty through the communication stages. Today, telecommunications technologies have the potential to change the structures and processes of communication that have been typical of conventional science (*i.e.*, nontelescience). They are reviewed briefly below.

TABLE 1. The Cycle of Scientific Communication Using Conventional Communication Channels

Cycle Stage	Characteristics	Comm. Structures	Comm. Processes
CONCEPTUALIZATION	Shared knowledge, concerns, methods; common discourse; a single shared paradigm; extensive, specialized shared vocabulary; socially/culturally homogeneous & cohesive; informal, frequent & extensive contact.	Collaborative pairs; mentor-student groups; research fronts; small interpersonal network (<100 members) of a single cluster or clique.	Interpersonal communication; dyadic or small group interaction; hallway chats; working group meetings.
DOCUMENTATION	Shared knowledge, methods, discourse; multiple paradigms; formal communication channels (<i>e.g.</i> meetings, journals); less frequent, more formal contact; socially/culturally heterogeneous, less cohesive; less shared vocabulary.	Professional groups; special interest groups; university departments; research laboratories; multiple clique-and-liaison network structures; special interest groups; invisible colleges.	Formal communication; documented messages; gatekeeping (<i>e.g.</i> journal editing); awards; stylized, rule-bound communication (<i>e.g.</i> publication style); conference presentation; scholarly publications.
POPULARIZATION	Broad knowledge base; little or no common vocabulary, except key terms or "buzz words" (<i>e.g.</i> "cold fusion," "superconductivity"); little or no social cohesion; extreme heterogeneity.	Mass audience; third-party intermediaries (<i>e.g.</i> , publishers, agents, interviewers, etc.), scientist becomes isolated, or single liaison to many diverse cliques.	Cultural interaction; highly formalized (<i>e.g.</i> mass media programs).

Stage 1: Conceptualization

Communication structures at the conceptualization stage are traditionally composed of individuals who share a great deal of both scientific and social information. For example, scientists who explore a problem or “brainstorm” typically share common substantive concerns, methodologies, and/or discourse. In the strongest sense, they share a scientific paradigm. Communication structures at this stage are usually informal and facilitate interpersonal interaction. Accordingly, groups at the conceptualization stage are typically small (from two to perhaps a dozen people) (Kraut *et al.*, in press). Examples of scientific communication structures at the conceptualization stage that do not employ telecommunications channels include the isolated scientist, the research front or group, the collaborative dyad, the mentor-student pair, and the laboratory.

Similarly, communication processes at the conceptualization stage are ordinarily characterized by face-to-face interpersonal interaction among close collaborators or other trusted colleagues. For example, as innovative researchers refine and promote their ideas with one another they often joke, try out ideas and presentation devices, “hack out” ideas, and “shoot the bull.” Communication occurs directly in predominantly informal, one-on-one or small group exchanges such as working lunches, working-group or laboratory meetings, or hallway chats. In most cases, such interaction requires the geographic proximity of the scientists who are involved (Kraut *et al.*, 1990). This proximity and certain interpersonal ties, such as mentor-student relationships, help to coordinate the diffusion of new information among a small coterie of colleagues (Barnlund & Harland 1963).

Usually, such communication processes are relatively brief (lasting a few months, for example, to several years) and produce work on a single grant, scholarly paper, or book. Simultaneous collaborative work on several related grants or papers, or long-term, multiple-project collaborations are less common.

Stage 2: Documentation

Documentation differs from conceptualization in that communication structures are typically composed of scientists who share a great amount of scientific information, but little social information. They share common substantive concerns, methodologies, and styles of communication, but may or may not agree on a single scientific paradigm. Sometimes scientists divide themselves into camps or clusters according to their differing paradigms or “schools,” which are often referred to as invisible colleges (Crane 1972).

In addition, certain scientists act as bridges or liaisons among the camps.² Such cluster-and-liaison structures may inhibit the richness of interpersonal interaction that is possible at this stage.² Structures tend to be larger, more formal, and more diverse than those at the conceptualization stage (*e.g.*, pro-

professional organizations or interest groups, invisible colleges, disciplines, sub-disciplines, university and college departments).

Communication processes at the documentation stage are more formal and produce a documented record of a coherent body of research. They include gatekeeping (e.g., journal editing or publication of scholarly papers and books), preprint exchange, and paper presentation at conferences. Greater constraints are placed on the communication of ideas (Lindsey 1978; Morgan 1985). Because the scientist must conform to the conventions of publishing or other media channels at this stage, documents are produced that follow stylistic conventions that limit direct contact with the audience (Edge 1977, 1979). The formal nature of the communication structures (e.g., professional societies) and processes (e.g., publishing, especially of general-interest journals) during the documentation stage tends to direct the diffusion of new information (Carley, in press). In short, at this stage documents are produced, and the innovative scientist's audience becomes a larger group of informed sympathizers and critics.

Stage 3: Popularization

In a nonteleience research environment, the ideas that have been circulated at the conceptualization stage and then recorded at the documentation stage are sometimes communicated even further, *i.e.*, to the general public, in the popularization stage.³ Cold fusion and superconductivity are examples of such popularized ideas. Scientific ideas can become part of public discourse via channels as diverse as news reporting, public policy decisions, awards and their attendant publicity, technology transfer, or marketing.

The most important communication structure at this stage is the general public, defined as individuals within the same society who share relatively little specific (scientific or social) information, but who do share a common culture. The general public may in turn contain many significant subgroups, such as readers of a particular magazine, Republicans, or working women. Compared to communication structures at the conceptualization and documentation stages, the structures at the popularization stage are extremely large and diffuse, ranging from thousands to possibly millions of people.

Communication processes at this stage tend to encourage the acculturation of ideas by accelerating the development of institutions or awards, introducing new words into the language, or encouraging new kinds of social behavior as a result of scientific innovations or ideas. For example, special institutes may evolve; some scientists may be recognized with special awards (e.g., the Nobel Prizes); or new terms like *superconductor*, *cholesterol*, or *chaos* may become part of the everyday language of the lay audience.

In addition, at this stage there is even more social distance between the innovative scientist and his/her audience, which can no longer be reached

by simple one-on-one interpersonal messages or by the publication of journal articles to be read by a small group of colleagues. Rather, third parties (e.g., reporters, publishers, talk show hosts, agents) become intermediaries or brokers of the scientific information that reaches the public by creating a concrete representation of the abstract scientific idea for the lay audience (Lievrouw 1990). Therefore, the scientist's contact with the audience(s) at the popularization stage is relatively impersonal, because it is shaped by a complex structure of information "middlemen."

In addition to these effects, popularization guides the subsequent evolution of newer concepts, generating successive rounds of ideas and interpersonal exchange among scientists as the communication cycle begins again. The popularization of an idea may also influence the agendas of public policymakers who fund future research.⁴

Summary: The Scientific Communication Cycle

The point was made earlier that scientists can enhance their professional reputations and credibility by extending their "spheres of influence" throughout the cycle of communication (although, as noted above, in some cases popularization may paradoxically compromise a scholar's credibility among his/her colleagues). An individual's *sphere of influence* is the set of people who are influenced by his/her ideas. As the sphere extends, the number of people involved, the geographic area covered, the intensity of communication relations or processes, and the time frame of interaction all enlarge correspondingly. The following trends, then, characterize the scientific communication cycle:

- Communication structures become larger, progressing from dyads, to groups where it is possible to know most if not all members, to structures coordinated by third-party intermediaries.
- Communication structures become increasingly isolating from the point of view of the individual scholar; that is, both the physical and the social distances between the scientist and his/her audience(s) increase as the communication structures grow.
- The level or thoroughness of knowledge shared by the communicating scientists decreases.
- The constraints on the content of communication increase.
- Communication processes change from informal to formal to cultural in scope.
- Progressively shorter, simpler, and less frequent messages are exchanged.

It is important to remember that scientists can advance their ideas and careers only if their colleagues (or the public) find their ideas credible. Although credibility is by no means the sole driver of scientific research, scientists' communicative behavior certainly depends on the acceptance and encouragement of their

colleagues. Science is essentially a communicative enterprise, and a scientist's success requires that he/she have access to the appropriate communication channels, which are open only to credible (*i.e.*, legitimate) researchers.⁵

This is a separate issue from the validity of the truth claim of any particular idea. Because it is difficult to demonstrate the truth of any particular scientific finding, the criterion that must be applied is how useful other scholars have found the scientist's work to be, regardless of its absolute "truth" value (this criterion is used, for example, in most bibliometric analyses of scientific publications).

Choosing Communication Channels in Science

In most scientific specialties today, telecommunications channels do not dominate the communication process. However, as telecommunication technologies become more common in science we expect communication patterns to change, because the specific communication channels that scientists adopt influence their effective spheres of influence. In turn, the channels that the scientist adopts and uses depend on the scientist's perception of the appropriate sphere to be influenced, and will affect the size and character of his/her sphere accordingly. Therefore, it is necessary to examine the factors which affect the adoption and use of communication channels, including telecommunications channels.

Adoption vs Use

There is a distinction to be drawn between the adoption of a communication channel and its use. *Adoption* is the initial acceptance of a communication channel by organizations (or sometimes by individuals). Adoption is generally an institutional function, in which affiliated scientists may or may not participate. The *use* of a channel, on the other hand, is up to the individual scientist, whose decision may be influenced by whether administrators have the inclination and/or the means to adopt it. If they do not, or if they adopt unpopular channels, individual scientists may react by adopting their preferred channels at their own expense (*e.g.*, personal computers and modems), which may not coordinate with the technological choices made elsewhere in the institution. Or these dissatisfied researchers may relocate to institutions that have more desirable technological/communication facilities. Clearly, the relationship between institutional adoption and individual use of communication technologies in science is pivotal, and merits more extensive study.⁶

Variables Affecting Adoption and Use

Several variables influence the adoption and use of a communication channel: (1) the nature of the field, (2) the purpose of communication, (3) the pro-

cesses of communication, and (4) the characteristics of the channel. The nature of the field is defined as the individual scientist's perception of both the character of the knowledge being produced and the cultural/technological climate in which it is produced. Scientists' perceptions will tend to change over time based on the nature of the research being performed; the rate and nature of change of innovation in the field; the geographic spread of the interacting scientists; the cost of equipment; and so forth.

The *purpose of communication* is defined as the intent of the communicator. Purpose incorporates timeliness, or how fast the information should diffuse (*i.e.*, whether the information is dated); breadth, or how many people need the information; and whether scientists share the information freely across disciplinary lines or keep it within their own specialties.

The *processes of communication* were defined earlier as any activity or behavior that the individual scientist considers most useful or appropriate in a given situation and that facilitates the construction and sharing of meaning (for example, speaking face to face with a colleague or with students in a classroom; handwriting a note *versus* writing a text on a personal computer). Note that communication processes serve a dual purpose in that they both influence scientists' channel choices and are themselves influenced by those choices.

The *characteristics of the communication channel* are those features that permit particular communication processes to occur: for example, the channel's ability to permit synchronous interaction; the speed of message transmission; its ability to record transmitted information; bandwidth; ease of use; and whether the channel is an exclusive source of valuable or timely information. Furthermore, channel characteristics can be either *desirable* to researchers or actually *available* to them. Availability is defined as whether a channel is currently in use by members of a given scientific field: that is, the real access that researchers in a field have to the channel, not just whether the technology is commercially available. Availability therefore affects the real use of one communication channel versus another.⁷

For example, a university campus with an ubiquitous, "free," and easy-to-use internal computer network will tend to encourage scientists to use that channel, while a more conventional institution with only a rotary-dial telephone system will encourage its scientists to use the phone. Obviously, however, the second institution may be prevented from using another university's voice mail system if it requires touch-tone phones for access to a central computer system. Indeed, the availability of a given technology at some institutions and not at others will tend to inhibit or limit those institutions' potential communication links. The pattern of relationships among these variables is illustrated in Figure 2.

The model in Figure 2 can be viewed as a kind of open system. Certain elements outside the system (such as prevailing economic conditions in society at large, or the technological feasibility of some channel features versus others) may influence the total system or variables within it. However, even

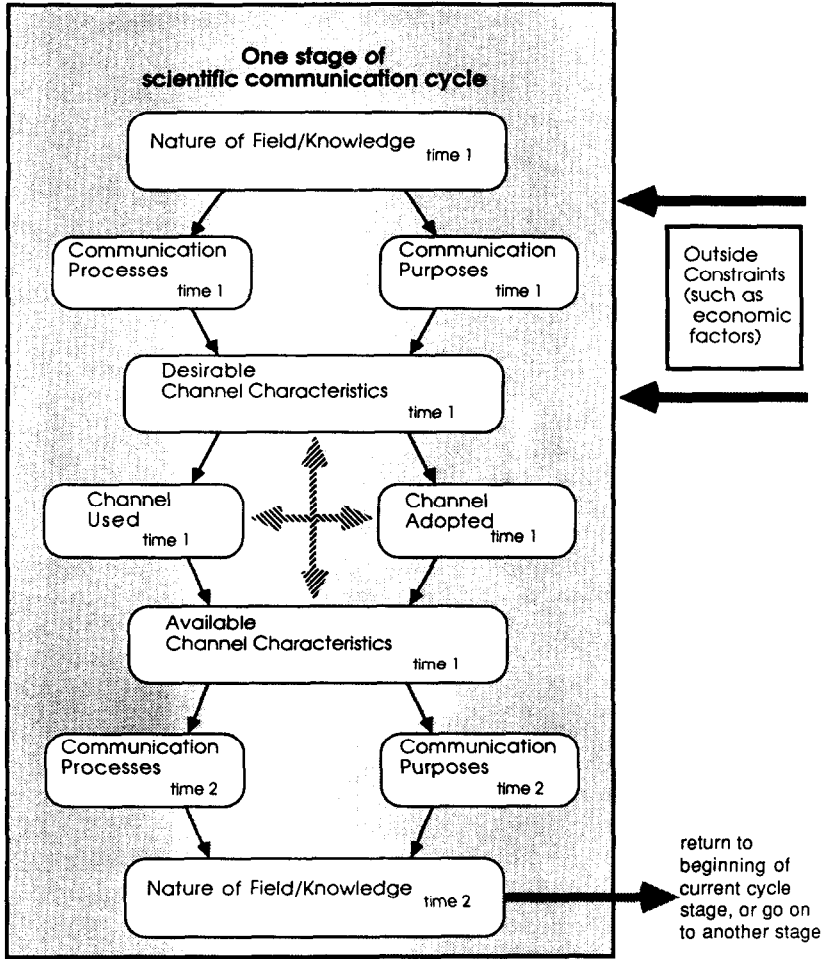


FIGURE 2. Factors Affecting Communication Channel Choices in Science

if contingencies color scientists' perceptions of their fields, the perceptions themselves are better predictors of communication behavior (including channel adoption/use). The field-scale processes of the scientific communication cycle are related to the individual-scale communication behavior of individual scientists.

The first important feature of the illustration in Figure 2 is its recursive-ness. As individuals' perceptions of their field change over time, those individuals tend to employ different communication processes, purposes, and channels. Therefore, the system is constantly changing; the "top" and "bottom" of the figure portray the "beginning" and "end" of a loop, respectively.

Following the path from the top to the bottom of the figure, we begin with the nature of the field as a scientist might perceive it at time 1. Let us suppose that this is the beginning of a conceptualization stage for the scientist. His/her perception at this point has a strong influence on both the communication processes and purposes that will seem most useful or appropriate. We have indicated this influence by showing arrows pointing from nature of field_{time 1} to communication processes_{time 1} and communication purposes_{time 1}.

Next, the communication processes and purposes identified by the scientist at time 1 influence the kinds of communication channel characteristics that he/she will find most desirable. These desirable characteristics in turn affect both channel adoption and use. The hatched-line arrow loop between desirable and available channel characteristics indicates that the desirability of a channel characteristic will enhance its value and increase the likelihood of its availability. Correspondingly, the more widely available a channel characteristic is, the more desirable it becomes, and so forth. There is another hatched-line arrow loop between channels used and channels adopted, which indicates that there is a similar relationship between channel use and adoption.

The combination of channels that are used and adopted, then, influences the next element of the system, the channels that are actually available. It is roughly at this point that we cross over from time 1 to time 2 and return to communication processes and purposes, which are now largely determined by the available channel characteristics. Finally, the communication processes and purposes identified by the scientist at time 2 (given the channels that are actually available) will tend to modify his/her perceptions of the nature of the field, creating a "new" field at time 2.⁸

If the scientist's perceptions change sufficiently between times 1 and 2, he/she may move ahead to the documentation stage and begin to record ideas or findings. The whole system then begins again, either as an iteration of conceptualization, or as a progression from conceptualization to documentation and back again. Less frequently, there may be a progression from documentation to popularization, or from popularization back to conceptualization. Either way, the system continues to "loop" or "spiral" through the stages of scientific communication as the specialty evolves, grows, or declines.

Scientific Communication Using Telecommunications Channels: Scenarios for "Telescience"

What happens to scientific communication when scientists begin using telecommunication technologies? One major effect may be that they will practice scientific inquiry differently from other scientists, assuming that (1) telecommunication channels enlarge the individual's potential sphere of

Table 2. The Cycle of Scientific Communication With Increased Access to Telecommunications Channels

Cycle Stage	Characteristics	Comm. Structures	Comm. Processes
CONCEPTUALIZATION	Increased shared knowledge, methods; Increased social and cultural homogeneity; Increased contact between all collaborators; Cross-disciplinary research discouraged between researchers using different channel mixes	Extended research groups; Cross-university mentor-student groups; Larger, more dispersed interpersonal networks; Group membership may be limited by access to certain channels	Informal intergroup communication; Semi-formal communication; Self publication
DOCUMENTATION	Increase in shared scientific knowledge; Telescientists may progress faster than other scientists	Larger groups; More reciprocated communication; Group membership may be limited by access to certain channels	Semi-formal communication; Increased formality; Parallel publication
POPULARIZATION	Increase in shared cultural knowledge; Telescientists' ideas may be popularized faster	Group membership may be limited by access to certain channels	Increased audience participation

influence, because (2) telecommunication channels enhance the individual's ability to communicate with groups, and (3) the technology underlying telecommunication channels is rapidly changing. (Several possible changes are summarized in Table 2).

Stage I: Conceptualization

During the conceptualization stage, extended research groups may form that are larger, more homogeneous in terms of shared knowledge or specialization, and that last longer than research groups that rely on more conventional communication channels. As more fields become "telescience," the distinctions among the three stages of scientific communication will begin to blur. Telecommunications channels can be more flexible and quicker than conventional communication channels; that is, they facilitate both one-to-one interaction and one-to-many interaction, and they are fast. Such networks have the potential of becoming much larger than the interpersonal networks that have characterized the conceptualization stage in the past. Indeed, an invisible college that depends on acquaintance and face-to-face interaction can probably grow no larger than about 100 people, while an

electronic invisible college could be much larger (e.g., those among artificial intelligence researchers using the ARPANET) (Butler 1989). The informal quality of communication at this stage will be preserved for the most part, but this informality will extend across greater geographic space and more scientists, as it will be encouraged by the use of telephone calls, electronic mail, fax, and so forth. In short, tele-science may increase *both* the size and the intimacy of interpersonal interaction groups among scientists, a situation that would seem paradoxical in a research environment dominated by conventional communication channels.

The increased size of such collaborative groups may foster more communication that has both formal and informal characteristics (e.g., technical reports, self-published proceedings of working group meetings, and so on). Research groups that communicate via telecommunications channels involve greater numbers of collaborators than were previously thought practical (Bierly 1988; Rainwater & Smeeding 1988). For example, Carley and Wendt (1988) discuss the power of electronic mail to promote extended research groups (working groups much larger in size than traditional groups, which rarely contain more than ten people).

In addition, the adoption/use of particular channels may affect the intellectual "territories" claimed by various subfields. Certain channels may either break down or reinforce the social and intellectual barriers that already exist among fields—for example, the longstanding chasm in communication between the sciences and the humanities. Scholars who use similar communication channels should find it easier to cross disciplinary boundaries than those who use different channels: it is easier for sociologists to communicate with experimental psychologists via the telephone, electronic mail, or fax, for example, than it is for members of one group to have papers accepted at the other group's annual meetings or to publish in their journals. Most telecommunications channels also facilitate interpersonal interaction, which is essential at the earliest stages of idea development, *i.e.*, during conceptualization.⁹

Conversely, some problems may emerge with the use of new channels. Scientists may find that they collaborate only with others who have access to the same types of channels that they do, thereby reducing the chances for collaboration and interdisciplinary research among fields with different channels.

Stage 2: Documentation

If the increased use of telecommunications channels fosters the formation of larger, yet less diverse communication structures, and if increased communication structure size and message frequency promote formality, communication structures and processes are likely to become even more formal in the documentation stage than they have been via conventional communication channels. The size and formality of structures in the documentation stage

may depend ultimately on which mix of channels a given specialty adopts.¹⁰ When telecommunication channels are adopted and used, however, the ease of sending documents electronically may encourage more frequent distribution, resulting in the circulation of more documents than was practical using print and physical distribution systems alone.

Conventional channels (*e.g.*, scientific journals) may also be able to enhance the speed and breadth of diffusion of their information by augmenting their services with more sophisticated computer-based cross-indexing systems. The major vendors and brokers of such services today, such as DIALOG, the *Science Citation Index* or *Index Medicus*, are fairly comprehensive but are difficult to search. Search intermediaries (*i.e.*, librarians specially trained to search bibliographic databases) may help some users, but many scientists find it difficult to explain their needs clearly to the intermediary and may not want to learn to do complex searching themselves. In this case, two heads may not be better than one. By the same token, some channels (*e.g.*, print journals) may find wider audiences by offering their contents in several different media simultaneously (online, microforms, optical disc, and print, for example), with corresponding price schedules for users in remote or developing areas (*cf.* Saracevic 1988).

Another result may be the proliferation of less formal documents, such as on-line newsletters and electronic bulletin boards that are widely distributed. Other new communication forms may also evolve, including electronic journals, electronic libraries, and more transparent and sophisticated means of cross-indexing among journals. Such new forms, however, may be resisted or rejected outright by scientists who may fear that they weaken disciplinary boundaries and are not rewarded as well as traditional forms of publishing.

The new forms may also create problems with parallel publication (for example, the IEEE provides both electronic and paper versions of their journals). Even though the same material appears at the same time in both telecommunication channels and traditional channels, scientists using telecommunication channels may be able to receive and respond to new information more quickly than scholars relying on traditional print channels. Consequently, differences in channel mixes from field to field will tend to create differences in the rate of progress in those fields.

Stage 3: Popularization

In the popularization stage, fields with very different channel mixes may experience different degrees of access to popular or mass media. That is, some fields might find it easier to popularize their research findings than others. Scientists who understand the power of telecommunications media may in fact enjoy a better "window" to the public. Furthermore, the high degree of visibility afforded the "telescience" will have a pronounced effect on its funding, especially from public sources, placing its concerns on the

public agenda, and helping to insure its support. This seems to be one concern underlying recent federal initiatives to expand large computer-based communication networks among research universities, private research organizations, and government agencies that sponsor research (Jennings *et al.* 1986).

Differences in the public visibility, and therefore, in the apparent importance, of various fields may occur according to the communication channels they employ. For example, the current public support for superconducting materials and supercomputing/mathematical complexity research (*e.g.*, fractal geometry) can be compared with the relative lack of public support for the supercollider particle accelerator that has recently been awarded to the state of Texas. While superconducting materials research has enjoyed great media support in the form of speeches by former President Reagan, public television specials, and news coverage, theoretical physicists have in general had very little contact with the American mass public in recent years. As a result, when seven states became "finalists" for the location of the new supercollider, several of them withdrew for lack of popular support among their citizens.¹¹

Some Generalizations About Telescience

We can condense the various propositions contained in Tables 1 and 2 into a few main generalizations that illustrate the differences between conventional scientific communication and scientific communication using telecommunications channels, or "telescience":

- The more a scientist relies on telecommunications channels, the larger his/her potential sphere of influence.
- The more a scientist relies on telecommunications channels, the greater is his/her access to potential collaborators and to pathways for the diffusion of ideas.
- The more a scientist relies on telecommunications channels, the greater the level or thoroughness of knowledge that he/she shares with colleagues.
- Scientists who rely heavily on telecommunications channels tend to send more messages than scientists using conventional channels.
- Increased reliance on telecommunications channels increases the degree of overlap among the three stages of scientific communication.
- Increased reliance on telecommunications channels leads to an increase in the number of policies and norms that are implemented to prevent or control the "premature" diffusion of information.

These generalizations are reflected in the differences between Figure 3A and Figure 3B. In conventional science, conceptualization is the smallest block because it involves only a few interacting scientists (with an upper limit of about 100). The size of the group increases in the documentation

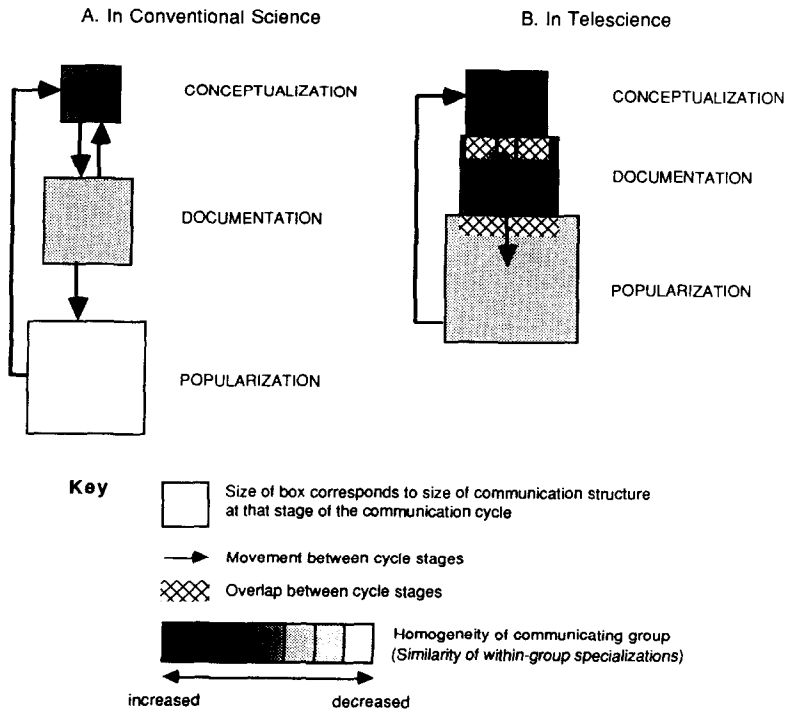


FIGURE 3. Changing Relationships Among Communication Cycle Stages With the Introduction of Telecommunications Channels

stage because publications and other documents have a greater potential “reach” or distribution than the interpersonal contacts of any single individual. If the cycle continues into popularization, the potential audience (the general public) is larger still. If popularization fosters conceptualization again, the group size drops back to the original limit of 100 or less. Also, the transitions or overlaps between the stages tend to be discrete in conventional science: face-to-face communication is replaced by the journal article, which may be replaced in turn by the talk show interview or the trade book for the mass audience. It is relatively simple to tell where one stage leaves off and another begins, based on the channels of communication that are employed.

With the introduction of telecommunication channels, the stages are more similar in size, though the clearest difference is at the conceptualization stage, which is considerably enlarged (Figure 3B). In addition, the boundaries between the stages are no longer discrete. For example, a scientist’s electronic mail message (which may be intended for interpersonal contact with one or two other colleagues, but which can be copied and relayed to others like a document) could belong in either the conceptualization or documentation stages. Or, the line between documentation

and popularization may be blurred when a journal article containing the important results of a new drug study is "leaked" ahead of its publication date in the press (indeed, the *New England Journal of Medicine* and the *Journal of the American Medical Association* have had such problems with this that they now attempt to put release dates on their information, and tend not to release their information to news organizations that violate this rule).

Telescience and 'Big Science': Directions for Future Research

The development of any field into a "telescience" depends entirely on the mix of communication channels that institutions and scientists adopt and use, so policies that affect the availability of certain channels will have an enormous impact on whether telescience can actually emerge in a field. However, research on communication in science has been somewhat limited. Communication researchers seemed to lose interest in scientific communication in the mid-1960s, though sociologists of science continued to pursue social structural and what they termed "sociology of knowledge" issues (Lievrouw 1988). Several questions remain to be addressed, however, especially as scientific communication comes to rely more and more on telecommunications technologies.

One area of immediate importance is the issue of funding for research centers vs the funding of individual principal investigators as the mechanism of research support, especially from public sources. Is the use of telecommunication channels sufficient to ensure the success of geographically-dispersed research "centers" (such as shared supercomputing facilities)? It is still an open question whether distributed communication systems can take the place of physical proximity in science, if "big science" is to survive as a productive organizational scheme for research.

Another critical issue is cross-disciplinary collaboration. Multidisciplinary research is an ideal that has been realized only rarely in American science. There is evidence that the overlap of knowledge bases in science is tending to increase (cf. the "maps" of scientific literature generated by the Institute for Scientific Information; Small & Garfield 1985), but "normal science" is still typically conducted within narrow disciplinary boundaries. Will telescience promote cross-disciplinary work and help to reduce redundant efforts? Is there a need for more informed "translators" who can identify similar concepts that go by different names in different specialties? Will policies that promote telescience (*i.e.*, funding for telecommunications links, increased travel, visiting professorships) increase fruitful collaboration in the future? Or will some specialties retrench in an effort to preserve their disciplinary "turf" and institutional power in the face of such changes?

A neglected area of research that might illuminate some of the questions presented here is the history of communication channels in science. Historians of science have provided some excellent documentation of the rise of more conventional communication structures like the specialty society, the departmental organization of universities, and the rise of specialized research journals. However, especially in the American context, it might be asked how the introduction of the telegraph, and then of the telephone, helped inventor-based "little science" to become "big science" in the post-war era.¹² Furthermore, how have air travel; computer bulletin boards, conferences, and mail; and the enormous success of bibliographic databases changed scientific research behavior in the context of "big science"? Have different communication channels had different impacts on specialties as they evolved? Historically, has science become more personal, less formal, as a result of the introduction of interactive telecommunications channels? These questions could be answered by a more rigorous program of historical research into the patterns of communication in science.

Another area of concern is the analysis of communication networks in science, whether within or across specialties, and how links in such networks change over time and are affected by what communication channels are used. This is a notoriously difficult research task to undertake, even for one-shot studies of single disciplines or research groups. Yet, this information would be invaluable to policymakers trying to understand the production of new knowledge over time. The issue of communication networks is also related to the development of valid and reliable indicators of scientific activity and productivity, which continue to be highly problematic.

To close, then, measurements must be devised that reveal the relationships among the variables that lead to the spread of telescience. The rapid rate of change in modern scientific research requires that communication in science continue to be investigated for clues to its future directions. In addition, 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 (which in turn affect future funding decisions and may even hasten the relative decline of nontele-science disciplines). 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. Whether advances in telecommunication technologies will encourage more universal adoption policies remains to be seen. However, such advances alone will not remedy such gaps. Policy decisions that are made today regarding communication channels will continue to affect the conduct of science and the questions scientists will ask in the future.

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Notes

1. This definition of communication structure is based on the notion of social structure as the set of relationships among individuals advanced by network theorists (White, Boorman and Brieger, 1976; Boorman and White, 1976; Burt and Minor, 1983), coupled with the constructivist notion that individuals are linked by shared knowledge or shared meanings (Carley, 1986; Carley, in press[a]).
2. However, the role of the liaison has been widely studied as a "weak tie" with a considerable degree of power to link disparate groups (cf. Granovetter, 1973). Such liaisons may also act as migrants from other scientific fields, bringing with them new ideas. Therefore, they are often harbingers of change and innovation (cf. Edge and Mulkay, 1976).
3. A number of social studies of science have focused on the phenomenon of popularization. For recent examples, see Kidd (1989), Lievrouw (1990), Gieryn (1989), and Studer and Chubin (1980).
4. Ironically, successful communication in the third stage has often alienated scientists from their original colleagues, who may view the scientist's public success as "selling out." For a more thorough discussion of such "visible scientists," see Goodell (1979).
5. For example, in the case of publishing, credibility is typically established through the citation of certain other researchers' work (Gilbert and Mulkay, 1984).
6. For a discussion of this relationship in organizations generally, see Finn and Lievrouw (1989).
7. Telecommunications channel characteristics are themselves the object of an extensive body of literature, as reviewed by Rice (1980) and Steinfield (1986). See also Lievrouw and Finn (1990).
8. For a thorough exploration of scientists' changing perceptions of their fields as a result of the introduction of telecommunications technologies, see Hiltz (1984).
9. Note that telecommunication channels and their introduction into specific social contexts are not monolithic or deterministic, nor are they implemented uniformly across settings. Thus, the control issue raised by Beniger (1988), which is essentially one of centralization versus decentralization as the future of tele-science, is perhaps too simplistic. The introduction of telecommunication channels may have very eclectic results.
10. We wish to reemphasize that the communication channel mix is considered here to be characterized by "interactive" telecommunications channels, those that simulate or augment interpersonal feedback. There is evidence that other kinds of channels (e.g., online indexing or other information systems) foster more heterogeneity or cross-disciplinary communication, in the form of the citation of journal articles.
11. It is also probable that from a public relations standpoint, the private organizations involved in materials research (Bell Labs, for example) have been more than willing to publicize the importance of their findings.
12. Ironically, the telephone is perhaps the most influential—and yet, the least-studied—of the telecommunications channels that scientists and other scholars use. Most of the channels discussed in the present paper are new, but the telephone has been used in research settings since its inception and could reasonably be considered a "conventional" channel of communication in science. This tends to confound the distinction being made here between "tele-science" and "conventional" science, but because of the scarcity of research findings on telephone use among scientists or other scholars, we continue to classify the telephone as one of the less-understood "new" media.

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