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2 Cyberscience: The Age of Digitized Collaboration?

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Since the early 1980s, the scholarly community has been witnessing a considerable increase in the use of information and communication technologies (ICTs). The networked personal computer, e-mail, the Internet, off- and online databases, the World Wide Web, electronic publications, discussion lists and newsgroups, electronic conferences, digital libraries, and "knowbots" are but a few of the trends that increasingly influence the daily work of the scientific community. As opposed to "traditional" science and research, which is done without networked computers, *cyberscience* designates the use of these ICT-based applications and services for scientific purposes. The increasing use of ICT in academia had, has, and will have manifold impacts on academic institutions, the daily work of researchers, the science publication system, and last but not least, the substance of research. This chapter, which examines many of these issues, is based on a major project on cyberscience that investigated how ICT affects the organization, practice, and products of science (Nentwich 2003; the study's conceptual framework is described in Nentwich 2005).

In this chapter, I first discuss the notion of cyberscience as opposed to related notions (such as e-Science). Following that, I present and examine in more detail the results of my research on collaboration among scholars and scientists in the age of cyberscience. This includes the following topics: results from a cross-disciplinary comparison; the impact of ICT on the spatial layout of research; the promises and limits of virtual conferencing; the increase of collaboration and the emergence of new collaboration patterns; and new infrastructure requirements. In my concluding remarks, I address the often-heard idea of the dematerialization of research.

What Is Cyberscience?

During the last decade, we have been flooded by various expressions with prefixes abbreviating "electronic," such as "e-" (e.g., e-mail or e-conferencing) or just a simple "e" immediately before the main word (eCommerce). Similarly, the prefix "i" or "i-"

as an abbreviation for "Internet" (iContent) or "intelligent" (iForms), "o" or "o-" for "online," and the use of the special character "@," originally defined to distinguish between the user name and the server in e-mail addresses, all became popular (br@instorming). Wherever the new media and in particular the Internet is involved, a number of other letters such as "i" or "w" in a similar form—that is, with a thin line around it—are also used. Also "tele" can be seen quite frequently (like in "teleteaching"), meaning that the new word has to do with an activity performed from a distance. Finally, the prefix "cyber," as an abbreviation of "(related to) cyberspace," is similarly widespread (e.g., "cyberlaw"). While these prefixes are often used to make something old look more modern (especially in advertisements), their use can be justifiable in terms of writing economy—that is, with a view to abbreviate a whole concept. It is this latter purpose that allows me to elaborate on the notion of cyberscience. To the best of my knowledge, this term was first used in academic research by Paul Wouters (1996) as well as in a brief article by Uwe Jochum and Gerhard Wagner (1996), and then in a short chapter on "a day in the life of a cyberscientist" by Paul Thagard (2001), and since 1999, by this author. A session organized by Wouters at the joint conference of the Society for the Social Studies of Science and the European Association for the Study of Science and Technology held in Vienna in 2000 was also called Cyberscience. In addition, the term is frequently used on the Internet for a variety of purposes (thousands of hits resulted from a simple Google search), mainly by commercial enterprises to praise products such as software and publications. The word cyberscience is appearing in venues ranging from information gateways to e-magazines, and from school Web sites to sites containing complex, 3-D images of scientific research. The term has crept into journalism, although with a less precise meaning (see, e.g., Bernhofer 2001). With the publication of my book *Cyberscience: Research in the Age of the Internet* (Nentwich 2003), the notion seems to be used more widely in academic discourse.

I use the term *cyberscience* to designate the application as well as potential future development of ICTs and services in academia. As opposed to so-called traditional science, which does not use networked computers, I define cyberscience as all scholarly and scientific research activities in the virtual space generated by the networked computers and advanced ICT. Just as cyberspace means "the virtual space created by electronic networks" (Gresham 1994, 37), cyberscience is what researchers do in cyberspace. Thus, cyberscience comprises everything related to academia that takes place in this new type of space. Traditional academics traveled in either "thought spaces"—that is, in the world of thinking and ideas—or real places. Cyberscientists, by contrast, spend time not only in these places but also in new virtual spaces. For example, information rooms spread out before them via online databases; they meet and communicate electronically with fellow researchers in chat rooms or on discussion lists; they utilize digital libraries that deliver documents in bits and bytes; and they participate in virtual institutes that enable collaboration among researchers spread around the globe. Cyberscience technologies help to transcend real space.

It is the strong relationship between these technologies and space that makes it advisable not to use just the prefix "e" for electronic, as in "eScience" or "e-Science." These notions are used, among others, by the European Commission (2002, 6) in the context of the development of high-speed research networks and in a number of programs such as those in the United Kingdom and Germany that aim at financing grid technology. Similarly, "telescience" (as used by Carley and Wendt 1991; Lievrouw and Carley 1991; Walsh 1997) and "tele-communicative science" (Stichweh 1989; my translation) are too narrow, as my subject is not only about doing things from a distance but also about working with local people in a new mode. "E-mail science," a notion put forward by Bruce Lewenstein (1995), is also much too narrow, as is another recent addition to this babel of expressions, "digital academe," used by William Dutton and Brian Loader (2002). The latter phrase understands academe in a much narrower sense than I do here—namely, focusing on higher education and learning, and not on science and research. The point is that the new science is taking place in a new space, cyberspace, which can be reached via telecommunication. The connotations of cyber are more appropriate in these contexts, since cyberscience is about more than electronic ways of doing science.

The notion of cyberscience does not encompass all aspects having to do with the use of electronic means. In particular, it does not include the use of stand-alone computers as tools for modeling or computing, or other forms of nonnetworked data production and processing such as artificial intelligence. Furthermore, cyberscience is not the study of the cyberspace but of science and research *in* cyberspace, or termed differently, under cyberspace conditions. In other words, what I call cyberscience is mainly the use of computer-mediated communication (CMC) over computer networks (Walsh and Roselle 1999, 50).

If this chapter were written in German, a tricky problem with terminology would not have arisen. The English term *science*, when standing alone, primarily refers to the natural sciences. The study of cyberscience, however, encompasses all the various sciences, including the social sciences and humanities. English seems to have no straightforward, unambiguous shorthand to include all these fields. *Academia* normally refers to the world inside universities. *Scholarship* is mainly used with reference to the humanities. Perhaps the notion of *research* covers most aspects of my topic. Yet even the word *research* is often connected to the activities going on in laboratories (as in the notion of "research and development"). Whenever I use the term *science* (including cyberscience) and *scientific*, I refer not only to the natural sciences but also the broad panoply encompassed by the German meaning of the words.

Cybercollaboration

Cyberscience facilitates the establishment of networks at both the individual and macro level. In particular, ICT removes spatial barriers to the establishment and maintenance of social networks. Among the manifold issues of interest in the context of collaboration among scientists and academics in cyberspace are the following questions: Is cybercollaboration a cross-disciplinary phenomenon? What impact on the spatial layout of research can we expect to result from cyberscience? What are the promises and limits of virtual conferencing? Does cyberscience support the increase and development of new patterns of collaboration? How can we prepare the information infrastructure for cyberscience? This section examines specific results that relate to these questions. I begin with an overview of the study on which these findings are based.

Cybercollaboration across Academic Disciplines

My primary method of data collection was semistructured, in-depth interviews with fifty active junior- and senior-level researchers from thirteen disciplines who were located in Austria, Germany, and the Netherlands. The interviews, which were conducted during 2002, lasted from one to two hours, and focused on researchers' experiences with, among other cyberscience features, extended research groups and virtual institutes. While extended research groups work together on the basis of ICT e-conferencing, groupware, e-mail, and e-lists) for a single project or a series of them, virtual institutes go one step further by establishing some sort of institutional infrastructure stretching beyond projects, and collaboratories provide for remote access to laboratories. What all three forms—extended research groups, virtual institutes, and collaboratories—have in common is that they are (looser or denser) organizations without any, or only a small, home base in the real world, instead mainly existing as a network of researchers based in many different locations. In addition to the interviews with researchers, I collected cross-disciplinary data on the above topics through an extensive Internet search and in-depth investigation of the literature.[1] I also tested many e-tools (in particular e-conferencing) and conducted informal interviews with other experts, such as librarians, computer experts, and publishers.

At the time of the interviews, researchers in many fields were not aware of the concept of virtual institutes; nevertheless, there are a few genuine examples. So far, the best examples of virtual institutes in my sample of disciplines and subdisciplines are to be found in cultural studies and economics. There are also instances of collaboratories in the medical sector, such as in AIDS research (chapters 13 and 19, this volume). In five other areas—European studies, North American history, technology studies, applied linguistics, and information technology law—the experts reported the beginnings of such virtual entities. The funding agencies in particular, but not only the European Commission, are increasingly asking that project Web sites feature interim results and facilitate group communication. We may call these project networks, or extended work groups, an early stage of a virtual institute as they often carry over to successive projects and maintain a continued presence on the Internet, as is common, for instance, in high-energy physics. In the science disciplines under closer inspection here, I did not find any genuine example of a collaboratory in a narrow sense—that is, one that included collaboration in a remote virtual and/or physical laboratory space. Even the high-energy physicists do not work from a distance with the CERN facilities when they are at their home institutes (although they build stable project networks). Instead, they download files from the CERN servers in order to work with them in their home offices and travel in person to the experimental infrastructure. In sum, genuine virtual research organizations are not yet widespread, although there are a number of cases that come close (see also chapter 1, this volume).

By contrast, in many academic fields, working cooperatively from a distance is done on a daily basis. Specialized software, often called groupware, facilitates this. Yet with the exception of three subdisciplines in my sample, such tools are not used on a regular basis. The exceptions are in the fields of the social science studies of technology, molecular oncology, and high-energy physics. Even in these three fields, the experts' answer to how frequently groupware was used was ''sometimes.'' Nonetheless, of the sample of fifty researchers, some of them reported at least limited experience with groupware. In addition to the fields listed above, those with experience came from regional economics, theoretical physics, applied linguistics, analytic philosophy, Pacific studies, information law, and tax law. Most interviewees, however, were unfamiliar with the term groupware.

The underlying reality probably differs from what interviewees reported. E-mail with attachments as well as shared access to dedicated directories on an institution's file server, which allows for the exchange of and access to common files, sometimes simultaneously, are quite common for many researchers. Hence, a lot of cooperation is actually going on in science and research with the help of electronic means. It is simply not known as groupware, and is less sophisticatedly organized. Furthermore, it seems that proper groupware is increasingly used in international and interdisciplinary projects, such as within the European Union research framework.

E-conferencing, with or without video transmissions, is still unusual in all disciplines. Except for some researchers from subfields in medicine, physics, sociology, and history, interviewees reported only experimenting with e-conferencing. High-energy physicists use videoconferencing, a telephone and satellite-based service, and North American historians use Internet-based e-conferencing on an almost-regular basis. In medicine, it was reported that conferences increasingly offer online access to parts of the event via live streaming. These conferences, sponsored by the pharmaceutical industry, have a physical venue. In most cases the online access is not synchronous and interactive, but the remote auditorium provides the opportunity by e-mail or through a Web form to post comments that will later be added to the respective page of the conference Web site. Asynchronicity and only partial interactivity seem to be the case in those other disciplines with at least some online events, too. Most personal experiences with Webcam-based communication took place in connection with teleteaching experiments or in the private domain.

The most frequent reason given by interviewees for this state of affairs is that they love to travel, and yet do not want to miss the opportunity for socializing, making new contacts, and so on. Furthermore, researchers often noted the (still) poor quality of Internet-based ''Net meetings'' coupled with the (still) high prices of both the infrastructure and the telecommunication fees for the available professional videoconferencing services. At the same time, the respondents pointed to decreasing travel budgets, and hence they saw some real potential for e-services' use in smaller workshop-type project meetings—while acknowledging that the use of the telephone, in most cases, is a good alternative to meeting in person.

All in all, collaboratories, virtual institutes, groupware, and e-conferencing are still the exception rather than the rule, but they are growing in importance. Therefore, in the following sections I consider the potential and possible consequences of these organizational forms and technologies.

The Impact of ICT on the Spatial Layout of Research

As I have defined cyberscience in relation to activities in a new kind of space, cyberspace, the use of networked computers obviously has the potential to affect spatiality in academia. Scholars may break free from spatial limitations to a considerable extent. Through telecommuting, the resources in the scholars' offices may be used even if the researcher is not present physically (telework). Online access to remote digital libraries with e-journals and access to various online databases may reduce the need to have a physical library close by. Extended research groups may cooperate in a virtual environment (e.g., in a collaboratory) while meeting only occasionally. Groupware applications may support this joint research, and virtual or e-conferences may take place on a larger scale, as I discuss in more detail later in this chapter.

By diminishing the importance of space, cyberscience may have a considerable impact on the way that research will be done in the not-so-distant future: multiauthorship may increase, oral scientific discourse might be replaced by written procedures, and scientific communities may be more fragmented (i.e., specialized but more interconnected worldwide). Further, research infrastructure requirements may shift, and this may alter the positioning of more peripheral research.

It can be shown that the spatial layout of academia is changing profoundly. An overall conclusion is that space—that is, the geographic distance between researchers, and between them and their facilities (offices, resources, libraries, etc.)—diminishing in significance. Other dimensions are increasingly essential in shaping the circumstances in which research takes place. Among these dimensions are the reliability of the infrastructure, the conditions of access to specific resources, new organizational structures that slowly seize the new opportunities, and the possibilities presented by new cybertools. This is not to say that the traditional material basis will no longer play a role. By contrast, proximity to specific locales in the real world as well as the ''core'' researchers in a field will still be a key feature in many respects. When it comes to informal research activities in particular, the new media can only partially fulfill academics' needs. The café as a meeting place cannot be opened in cyberspace without losing much of its character. Furthermore, meetings in person will retain an important function when it comes to initial contact, ''contracting''—that is, agreeing on the terms of a collaborative project—and conflict resolution. I nonetheless expect that CMC tools will soon become a regular part of all scholars' daily routine. Quick cybermeetings to discuss a research issue that arose in a collaborative project are likely to replace phone calls or lengthy e-mail exchanges. Asynchronous e-conferencing will be used to complement face-to-face meetings with a view to overcoming time restrictions and avoiding the loss of a crucial thread of argument. Distance cooperation based on e-mail will increasingly be enhanced by shared workspaces, such as file repositories and common databases. Access to written resources will largely shift to cyberspace, as specialized and near-comprehensive digital or virtual libraries will be available and accessible worldwide.

The Promises and Limits of Virtual Conferencing

Asynchronous e-mail lists are but one way of meeting virtually; there are various other ways to hold virtual seminars, workshops, or conferences, such as videoconferencing and/or audio conferencing, with or without desktop sharing, along with e-lists, multiuser object-oriented dialogues, and so forth. With a view to assessing the promises and limits of virtual conferencing, I propose to look at the functions of seminars and conferences, and ask whether these functions can be fulfilled in a virtual environment. The following functions of academic seminars, workshops, and conferences may be distinguished.

Quality Control Here, the function involves quasi-experiments in the humanities and social sciences; a paper is tested against the arguments of an audience. This is probably the function most easily transferred to the electronic environment. In the context of e-journals, there is promising experience with this type of quality control. Philippe Hert reported that participants of the e-mail discussion he studied said their main goal was ''to get their opinions across, to test the reactions elicited, and to get people used to these opinions'' (1997, 352). He concluded that the ''forum was used mostly by people to express, or at least to experiment with, their disagreement concerning some part of the heterogeneous [particular scientific] community'' (355).

There is even potential for improvement in real seminars. The usual disadvantage of time constraints is less important in an electronic environment as there may be both a synchronous and an asynchronous part of the conference. Hence, lively debates do not have to be stopped because a coffee break is needed or the time is over—as they can continue in asynchronous mode in cyberspace. In addition, in an asynchronous virtual seminar, the advantages of a written ''discourse memory'' fully apply. A written record enables much more thorough analysis of the meat of arguments. If organized properly and supported by sophisticated software, another advantage applies: threading. The various related contributions (threads) may be separated more easily both during the debate and afterward. Whereas in the real world no particular argument can be pursued up to the point ''where nothing is left to say,'' virtual seminars, as a matter of principle, are not restricted in this way.

Transmission This function serves as an instrument to transmit knowledge and ideas to participants, a market for ideas, and an instruction for students. It is hotly debated whether knowledge can be transmitted as effectively in a virtual setting as in a physical one. The written format requires special skills, both on the part of the presenter and the receiver of the information. The virtual environment may offer the opportunity to follow a lecture in an asynchronous mode, thereby providing the choice to replay particular sections to enhance comprehension (Kling and Covi 1995).

Networking This function is a node in the scientific network facilitating the renewal or establishment of relations, especially before and after seminars or during a conference. In principle, academics can ''meet'' in cyberspace and networking is possible. Renewing contacts in a virtual setting is certainly easier than establishing new contacts. There is the strong argument that first-time contacts are more promising if they occur face-to-face. Also, in the literature and among the interviewees for my study, there is a general sense that seminars and congresses are critical for sustaining academic networks (Fröhlich 1996, 22; Riggs 1998).

Yet virtual conferencing may play an important role in network building. Linton Freeman (1984) discusses in-depth how a (relatively primitive) e-mail-based conference system impacted the formation of a subdiscipline. He notes that the ''whole of the scientific enterprise depends on effective communication among people working in an area'' (203). As Freeman further states, ''Particularly in the early stages of the emergence of a new specialty, progress requires communication in order to establish the sorts of norms and consenses that define both problem and approach'' (203).

Social Management The function here comprises instruments of institutional or associational social management: participants get socialized in the group; paper givers are being ''initiated''; and seminars may even serve as a way for students to learn how to behave in the academic environment (e.g., when to talk and when to listen). Virtual seminars would certainly need some time to be able to become ritualized and fulfill the same function as face-to-face seminars. As long as they are something new and not a tradition, they cannot serve the same purpose. I hold, however, that there is no convincing reason why they should not do so in the long run. Many of the same social management functions can be enforced in the electronic environment.

Engendering Ideas and Discourse Here, seminars and conferences help to generate new ideas and assertions by way of collective brainstorming and reflexive arguing. In the context of his look at a vivid e-mail discussion list debate, Hert observes that the properties and opportunities of the medium—that is, the possibility to compose one's message by ''cutting and pasting'' previous messages as well as marking and indenting original text—enabled the participants to use the discursive context. The ''medium,'' explains Hert (1997, 345), ''is then a resource for negotiating different interpretations of some messages.'' Hert speaks of the ''collective appropriation'' of the messages sent during an e-mail debate: ''Unlike traditional written texts, these forms of writing show the process of constructing arguments in interaction with some of the recipients of those arguments. The debate is rewritten as it moves along, and one's texts are mixed with others' to become somehow the position emerging from the electronic discussion'' (350). This is not to say that e-mail discussions will lead to consensus. Rather, they may contribute to dissension ''more explicit to the general audience than is possible in a scholarly paper'' (354), simply because an author cannot know all the points of dissent in advance. In addition, the asynchronous nature of e-lists allows participants to contribute ideas quickly without waiting for one's turn—as is necessary in a face-to-face situation. This might help to generate and record ideas.

To summarize, most of the functions of conferences and seminars may be met in a virtual setting. In some cases, it will take time until the results become satisfactory. It is, however, not yet clear whether the more socially oriented, informal functions can be fulfilled.

The Increase of Collaboration and the Emergence of New Collaboration Patterns

A number of studies show that collaboration has been increasing over the last decades. For instance, scientometric data document the increase in multiauthored papers, particularly in the natural sciences (see, e.g., Price 1986; Thagard 1997). One study found that the number of international collaboration papers approximately doubled, whereas at the same time there was a ninefold increase in the number of publications by large international collaborations (Walsh and Maloney 2002, 3). Furthermore, the percentage of papers published with authors from more than one country significantly increased (Walsh and Roselle 1999, 54). For instance, in theoretical physics, translocal cooperation is increasing (Merz 1997, 248–249; 1998). Physics projects that require the resources and expertise of multiple teams of researchers have proliferated (Chompalov and Shrum 1999). Similar observations could certainly be made in other fields, too. Thus, scientific work is increasingly geographically distributed.

Cyberscience provides for a number of services essential for collaboration at a distance. In particular, fast communication, resource sharing, version control, and other groupware functions sustain cooperation without face-to-face meetings. In essence, CMC reduces the need for coworkers to be colocated. Arguably, multiauthorship and the increase of distant collaboration are not unilaterally caused by CMC, but the latter contributes to and favors the former to a large extent. Present-day research more often requires collaboration. There are a number of other reasons that favor the recent increase in transnational cooperation, among them funding policies, growing mobility, the increase of the overall number of researchers and their specialization, and last but not least, content-related reasons. There is, however, no doubt that many recent collaborative projects were started because the ICT infrastructure was at hand, and promised to secure their smooth and efficient operation. Had this new infrastructure not been available and had there not been another overwhelming reason to start the collaboration (e.g., tied funding), perhaps many would not have happened at all.

Collaboration is not only increasing; collaborative patterns themselves are changing. John Walsh and Ann Roselle (1999, 71) claim that the prior empirical work on the effects of the Internet on science suggest scientific work is changing in profound ways (see also Finholt and Olson 1997, 33; OECD 1998, 197). Whether the changes are profound is certainly open to debate. Nevertheless, at least the following significant novelties can be distinguished:

- *Increasing personal networks*: The number of individuals with whom a researcher can interact has expanded. This provides ''greater access to potential collaborators and pathways for diffusing ideas'' (Lewenstein 1995, 125).
- *Enabling larger groups of researchers to collaborate*: The new tools provide for an environment that potentially can be used to organize collaboration among a much larger group of researchers than ever before. A U.S. report on collaboratories Distributed Sequence Annotation System rightly notes that ''when too many human minds try to collaborate meaningfully, the requirements for communication become overwhelming'' (Computer Science Technologies Board 1993, 7). Cyberscience attempts to facilitate the necessary robust communication among scientists. To be sure, it involves more than technical considerations such as access to useful computer facilities, networks, and data sets; social considerations also play an important role. For instance, the collaborative environment has to account for ''differing academic traditions, approaches to and priorities in research, and budget constraints'' (ibid.).
- *Increasing collaborative continuity*: Thanks to e-mail and other cybertools, two authors originally working together at one spot may more easily continue their collaboration

after one of them has moved to another job (Starbuck 1999, 189). This may also be true on a larger scale. E-lists are a perfect device to sustain the sense of community among a group of researchers between their rare face-to-face meetings.

- *Better match of competencies*: Collaboration patterns may become ''more mediated by substantive fit, rather than geographic or personal linkages'' (Walsh and Bayma 1996, 349). In other words, the composition of teams in terms of members' competencies may be optimized because of new opportunities to find researchers with highly specific matching or complementary skills. Also, due to increased communication, we may expect more attachment to the research group and the discipline (Walsh and Roselle 1999, 59). This might lead to overall better group performance in the research—as was supported by my interviewees. Although agreeing in principle, many respondents stated that personal acquaintance will remain as important as ever and that the Internet is only one factor pushing in this direction.
- *Specialization*: The possibility of becoming involved in worldwide collaborations may favor the trend to more specialization as specific skills and expertise can be used fruitfully despite the lack of local projects in need of them. When asked about this possible trend, the experts in my study indicated a potential specialization effect is only expected in political science and philosophy, and to some extent in law, language studies, and sociology, while in all other disciplines the answers were negative or split. Many pointed at a general ''meandering'' between specialization and generalization in their fields, and they were rather doubtful whether the former could be attributed to CMC. A number of my interviewees argued that specialization would increase due to the greater complexity and internationality of their fields as well as because of personal career path decisions. Further, they remarked that teaching obligations tend to discourage too much specialization.
- *New forms of collaboration*: Collaboration in the age of cyberscience may take the form of cooperative activities to build shared data or knowledge bases. In some fields, academics already contribute and have access to common databases, often managed by international networks (e.g., the Human Genome Project). Increasingly, filling and structuring e-archives and databases has become the content of whole research projects as well. Even more advanced would be what I call a ''hyperbase'' or ''knowledge base'' (Nentwich 2003, 270ff.), which as opposed to the multitude of articles in a field, is a dynamic database of manifold interlinked text modules that encompasses the knowledge of a given subject area. As already noted, researchers—like many others—tend to behave strategically and hence cooperatively when it comes to sharing information. The question is whether the Internet is about to create environments in which there are more incentives to cooperate than before.
- *Standardization of working habits*: Groupware may lead to the standardization of working habits (Scheidl 1999, 101). The idea is that the technology (groupware or database interfaces) would force different users to accept the same workflow—that is, to follow

similar patterns, perform the same steps in the same order, search for the identical elements, and so forth. This may simply mean coordination of workflows or standardization. In some circumstances the latter could certainly have a positive impact on research; in others it may hamper creativity.

- *Intensification of communication*: While the traditional means of communication have been comparatively cumbersome (slow or needing simultaneity), the cybermeans are easy to use and may increase the frequency of communication among distant collaborators.
- *Different division of labor*: Further studies are needed to assess how researchers engaged in disembedded collaborations share, exchange, and divide problems and objects, and whether collaborators split up or parallel the work among them. "Are the rhythm and sequencing of these actions different when performed in an embedded or instead a disembedded locale?" (Merz 1998, 327). Taken together, these nine changes lead me to the conclusion that the new tools indeed have the potential to create qualitatively different patterns of distant collaboration in cyberspace. They will accommodate the involvement of more researchers while allowing researchers to have larger networks of potential collaborators. Moreover, the competencies of coworkers may match better, and their workflows may be coordinated in a different way and perhaps become standardized.

New Information Infrastructure Requirements

The various elements of the new spatial layout also affect the academic infrastructure as a whole. Looking at the totality of the cyberscience developments taking place at the moment, we may assume that the scientific infrastructure will become less characterized by well-equipped libraries with large archives, seminar rooms, and close proximity to an international airport. Rather, broadband and reliable access to the virtual information space via state-of-the-art multimedia desktop (or mobile) computers will be common. Here I will focus on only one aspect—the future information infrastructure—and leave aside such key issues as the infrastructure demands for universities as teaching enterprises. For the emerging publishing infrastructure, see Nentwich (2006).

The future information infrastructure will have various forms. Based on databases, archives, link collections, and full-text servers, digital and virtual libraries will probably spread. Traditional libraries aim at providing researchers with whatever is needed. Researchers have to go to the library to get what they want. Most research units have their own specialized library, which often parallels the holdings of similar collections elsewhere. In the case of university and other large libraries, these redundancies are particularly obvious. This multicenter spatial institutional model of the library may no longer persist in the networked world. Large domain-based libraries that serve all users within an entire nation (or even at the supranational level) or a specific discipline or subject domain (Owen 1997) are likely to emerge. A single center may succeed the multicenter model. While the parallel holding of identical items was useful and necessary in the predigital world, a single copy of a digital resource may serve a whole academic subdiscipline as long as the access rights are distributed widely.

As the World Wide Web with its typical hyperlink structure lends itself to distribution, the new ''central'' libraries and academic databases are, however, most likely to be of a decentralized nature; what is central is the access point (the ''portal''), but the holdings may be distributed. Virtual libraries in general are of a distributed nature. Given the financial difficulties of many academic libraries, specialization and cooperation may be the key to overcoming the current crisis. MathNet, PhysNet, SocioNet, and the like are typical examples of this trend toward decentralized resource sharing and access. Similarly, projects like the Distributed Annotation System in biology are decentralized systems. In this case, there is a reference server with basic structural genome information, various other annotation servers around the world, and a Napsterlike browsing and exchange system (Rötzer 2001).

When it comes to digital resources provided by commercial publishers, however, the new global (virtual) library consortia will have to negotiate with the publishers to license the particular digital items for worldwide use. Different models are conceivable. For instance, it is possible that academic publishing will not be outsourced to the private sector any longer but taken care of by academia itself. In this case, a worldwide exchange system based on mutuality may be established (Nentwich 2001).

In sum, we observe a tendency toward central access to distributed resources, managed in a cooperative way. Traditional physical libraries will lose ground as more and more publications will be available in digital form. For some time, this will be parallel to print, but sooner or later central printing will cease for the majority of academic publications. The division of labor between libraries may be crucial as no single library can fulfill all the needs of local academics, but large consortia with each participating library having a unique specialization may be able to do so. Libraries may become virtual libraries for most of what they offer their users, yet stay a traditional and/or digital library for only a small fraction of the knowledge available. By becoming virtual or digital libraries, they transform themselves, but do not lose their traditional functions. Most important, their role as knowledge managers for researchers will be as important as ever. Librarians will become ''cybrarians'': information brokers and consultants (Nentwich 2003, 241).

The Dematerialization of Research?

While the above considerations support the conclusion that at least in the medium run, a completely virtual academia is not likely to emerge, the impact of this gradual shift to cyberspace activities on academia should not be underrated. We have to expect a further increase of distant collaborations. Furthermore, cybertools have the potential to create qualitatively different patterns of distant collaboration. For instance, more researchers will be involved, researchers' networks will be larger, collaborations may last longer, and workflows may change. While communication among remote collaborators will increase and perhaps be of a more instrumental character, the vision of isolated researchers in front of their computer screens seems unjustified. Cyberscience will be characterized, at least for a while, by an increase of written discourse. At the same time, academic writing is in part changing its character (e.g., through hypertext modularization or multimedia enhancements). Further important effects are to be observed with regard to the infrastructure of academia. In particular, there are many demands for a profound change as regards the traditional university. Equally, traditional physical libraries will lose ground, as discussed above. For researchers in the field, by contrast, mobile equipment with a good connection to the virtual infrastructure of their institutions becomes more attractive and essential. Peripheral institutes will profit from the diminishing significance of space. It is, however, uncertain if this will narrow down the gap between them and the top institutions (chapter 20, this volume). Especially in relation to the informal channels of research, it is rather unlikely that CMC will change much in favor of peripheral institutes, and hence there will be no "digital unity effect." The new media also both transform and reinforce the existing structure of communication within a community. The traditional invisible colleges will persist, but will increasingly communicate in cyberspace, and the emergence of such new colleges will be favored. Scientific communities will become increasingly worldwide with a highly improved communication infrastructure. In addition, the establishment of specialized—and thus tiny and yet worldwide—dynamic, and constantly shifting minicolleges whose members communicate much more among themselves than with outsiders is likely.

So where does all of this lead us? If we define as "material" the dedicated offices, books, libraries, and conference facilities, and as "immaterial" everything that flows among researchers in the form of bits and bytes, the notion of dematerialization surely depicts an overall trend. Yet the importance of physical locales will not disappear soon. Moreover, much of what researchers do is only marginally touched by these changes in the spatial layout, especially laboratory work and thinking itself. The future of academia is therefore by no means complete dematerialization, but will be characterized by a new balance of both material and immaterial elements.

Note

1. The results of the Internet search are in Cyberlinks, an online database, available at ⟨http://www.oeaw.ac.at/ita/cyberlinks.htm⟩.

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