Supporting Participation in Communities of Practice by Scientists from Developing Countries --- the Case of High Energy Physics

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Over the last decade, researchers have hypothesized that a new form of scientific organization, the “collaboratory” holds promise to greatly benefit scientists from developing countries by allowing them to reach remotely located experts, instruments, and databases. However, there have been no empirical studies to prove or disprove this hypothesis. Adopting a qualitative approach, this study examines how collaboratories affect one of the factors that purportedly lead to scientific productivity—communities of practice. Results of data analysis indicate that collaboratories bring about new opportunities for scientists from developing countries to access scientists from developed countries and their practices, but barriers also exist. The full value of collaboratories can be achieved only after the technologies themselves and the social practices surrounding the use of technologies are improved.

Introduction

In 2003, Kofi Annan, the Secretary-General of the United Nations, called attention to the clear inequalities in science between developing and developed countries. Mr. Annan asserted that “This unbalanced distribution of scientific activity generates serious problems not only for the scientific community in the developing countries, but for development itself” (Annan, 2003).

Many researchers and policy makers seek to reduce this inequality. Over the last decade, researchers have hypothesized that a new form of scientific organization, the “collaboratory” holds promise to greatly benefit scientists from developing countries by allowing them to reach remotely located experts, instruments, and databases (Finholt, 2002). A collaboratory is “a network based organizational entity that spans distance, supports rich and recurring human interaction oriented to a common research area, and provides access to data”(Olson, Bos, & Zimmerman, 2008). However, there have been no empirical data to prove or disprove this hypothesis.

It is also notable that prior studies of the impact of information technology on scientific work tend to focus on the correlation between technology use and scientific productivity as measured by publications and citations. This approach ignores the mediating factors affecting the relationship between information technology use and scientific productivity. As a result, we are not clear about the dynamics through which information technology exerts its influence. Neither do we understand how information technology enhances productivity, if it indeed does so.(Cohen, 1996; Hesse, Sproull, Kiesler, & Walsh, 1993; Walsh & Bayma, 1996; Walsh, Kucker, Maloney, & Gabbay, 2000). In addition, collaboratories are a relatively new phenomenon, and it takes time for publications and citations to emerge. Thus, this study focuses on one of the mediating factors that purportedly leads to productivity and appears at an early stage in scientific projects—communities of practice (CoP).

Wenger (1999) defines communities of practice along three dimensions:
(1) It is a joint enterprise, the value of which is understood and continually renegotiated by its members.
(2) It involves mutual engagement in which members are bound into a social entity.
(3) It produces shared repertoire of communal resources (e.g., routines, sensibilities, artifacts, vocabulary, styles, etc.)

In a CoP, knowledge resides in the daily routine practices of the community members. The informal learning process in a community is labeled as “legitimate peripheral participation” (Lave & Wenger, 1991). People participate in communal learning at different levels depending on their experiences or level of authority, i.e., whether they are a newcomer or a long-term member to the community. When newcomers enter a community, they embark on a trajectory toward gaining full membership. Newcomers’ successful learning is premised on “legitimacy” to participate in CoPs, usually granted by the masters. They gain legitimate membership through beginning with peripheral practices, and their gradual mastery of these practices enables them to progressively increase their legitimacy within the community. The newcomers learn "how masters talk, walk, work, and generally conduct their lives," and "how old-timers collaborate, collude, and collide, and what they enjoy, dislike, respect, and admire." The newcomers, however, are not mere observers; they contribute to producing and reproducing the community. Social structure and the old timers' view of the newcomers influence whether the newcomers can be granted "legitimacy." Because Lave and Wenger (1991) focus on self-contained single communities, they were criticized for neglecting the relationship among communities or between communities and other social entities (e.g. organization) as a source of change for a community or a community member (Cox, 2005; S. Fox, 2000).

Wenger (1999) elaborates the concept of CoP by adding a discussion of identity. He argues that community members' identity extends along an axis of time and space. Along the time axis, the community members' move from peripheral to center through "legitimate peripheral participation." Along the space axis, people belong to different communities, and their multimembership affects their participation and identity formation in every community in which they are involved. Thus, people's learning in a community not only depends upon interactions between old timers and newcomers, among old timers and newcomers themselves in that specific community, but also the meaning other communities that they belong to attribute to them. However, because Wenger's (1999) empirical study still focuses on a single community (insurance claim processors), he fails to provide any evidence for his theoretical discussion of the impact of multimembership, and leaves his argument abstract. We cannot obtain a clear picture of the types of tensions and dependencies in cross-communal relations and their impact.

Moreover. Lave and Wenger (1991) and Wenger (1999)'s discussions imply that the primary processes of CoPs involve members' frequent interactions, through which they recount stories and share experiences. Thus, to facilitate communities of practice, we should create opportunities for interactions among members, and increase the quality of their interactions. However, this literature does not systematically discuss how to support these interactions and the barriers that community members face when attempting to participate in collaboratively and socially constructed practices. In the literature of computer supported cooperative work (CSCW), Nardi (2005) and Nardi and Whittaker (2002) suggest a framework to understand the processes of interpersonal communication. They argue that interpersonal communication consists of two processes: (1) building fields of connection, and (2) information exchange. A field of connection refers to the social conditions that ready people to be involved in information exchange. Information exchange is the major goal of communication. Inspired by this framework, we can consider community members' interactions in a CoP are constituted by two processes: (1) building fields of connection, which enables community members to access and gain attention of each other (2) transferring knowledge and practice, which enables community members to learn through practices. In this study, this framework is used to understand participation in communities of practice by scientists from developing countries.

A collaboratory is seen as having a community component consisting of various communities of practice. Collaboratory members participate simultaneously in communities of practice within their local academic communities and with collaboratory members from other organizations. In different communities of practice, different levels of peripherality exist. In their local organization, senior scientists tend to be the old-timers of the community of practice while junior scientists participate at the periphery. In a collaboratory as a whole, some organizations become the newcomers, and members from these newcomer organizations are regarded as peripheral participants. For example, in some collaboratory projects, scientists from developing countries are participating for the first time and are therefore the newcomers. The newcomer organizations tend to have poorer infrastructure and less experience. Member peripherality in collaboratories also results from geography. This can occur when most of the collaboratory members are located in the US and Europe and only some participant labs are in developing countries far from the US and Europe.

Given the existing knowledge of communities of practice, and given the geographical dispersion and different levels of peripherality in collaboratories, the study intends to understand:

- How do collaboratories facilitate scientists in developing countries to participate in communities of practice?

    - How do collaboratories facilitate scientists in developing countries to build fields of connection with their collaborators?
    - How do collaboratories enable knowledge and practice transfer between scientists from developed and developing countries?
- What are the social, technical, cultural, and political obstacles that hinder scientists in developing countries from participating in communities of practice in collaboratories?
    - What are the barriers for scientists in developing countries to build fields of connection with their collaborators?
    - What are the barriers for knowledge and practice transfer between scientists from developed and developing countries?

Research Context

Data analyzed for this paper were collected in the high energy physics community (HEP). The goal of high energy physics is to search for the fundamental particles and forces which build the world around us. Since these particles cannot be seen directly, physicists build complicated detectors in which the particles register their activities. The detector is hit by particles and converts their impact into electrical currents and pulses that may be interpreted as physical processes. (Knorr-Cetina & Karin, 2003; Traweek, 1992).

The scale and cost of the detector determine that research projects in HEP must be collaborative ones. These projects need to draw funds and manpower from various institutions in different countries. At the stage of detector-building, different components of the detector were built in participant countries before being shipped to the institute where the detector was assembled. At the subsequent stage of analysis, the physicists begin their task of deciding what part of their data can be considered valid and what must be “cut,” and discarded as “noise.” However, interpretation of data taken from the detector is far from straightforward. It depends on scientists’ understanding of the detector’s components and processes. Because of the large scale of the detector, it is difficult for a physicist to have full knowledge of every component of the detector. They tend to only have deep knowledge of a single, or a few components of the detector, on which they have been working. Consequently, physicists must seek each other’s help for the knowledge of other parts of the detector and the particular particles they register. In the final stage, physicists obtain the results of analysis. These results must be shared and scrutinized by the community of collaborators, and also confirmed by data from other experiments—a process that depends upon persuading the community the significance of these results (Traweek, 1992).

This study examines two collaboratories of high energy physics. Each collaboratory consists of participants from almost 200 institutions in about 40 countries. They have a physical center, Institute X, which houses the detectors. Physicists from all over the world try to visit the center as often as they can. Many institutions locate their representatives in Institute X. Although the two collaboratories studied aimed to build different types of detectors, they share the same nature of management and collaboration. Thus, in this paper they are referred as the collaboratories.

Research Method

Semi-structured interviews complemented by field observation comprise the primary data collection methods of the study. The interview protocol includes open-ended questions, which were built upon literature review and research questions. The interviews aim to collect data on collaboratory members’ perceptions of whether collaboratories enable them to participate in communities of practice and the factors that contribute to those effects. In total 34 scientists were interviewed. 24 scientists from developing countries are mainly from China, Korea, and Morocco. Ten of their collaborators in the US and European countries were also interviewed. The interviews lasted from 40 minutes to two hours. Most interviews were conducted in the labs where scientists work. When this was not possible, interviews were conducted on the phone. The interviews were all conducted by the researcher herself, who speaks fluent Chinese, Korean and English. The researcher translated the interviews into English, conveying the meaning of the conversation, but not necessarily word-by-word literal translation.

Field observation was conducted to observe scientists in their everyday work, as well as during meetings and videoconferences. The researcher stayed in the Institute X for three weeks in July 2006. She also visited the participant labs in China and Korea each for one week in 2005 and 2006. Field observation helped ground interviews in individual contexts and allowed a deeper understanding of scientists' working process and communication behavior, as well as the communication and research infrastructure of the labs.

Public documents available on the websites of collaboratory projects, such as annual reports, databases and news articles about the collaboratories, were also analyzed. Public documents enable the researcher to understand the historical background of the projects. Web forums were also observed.

Inductive qualitative data analysis method were adopted (Miles & Huberman, 1994). The data were first coded for content. Then the emergent concepts and themes were analyzed and organized into conceptual and thematic categories. Finally, the data were rechecked to verify that conceptualizations and emergent theoretical perspectives represented valid readings of the data (i.e. there were no counter examples).

Findings

As discussed in the introduction section, a CoP consists of two processes, that is, building fields of connection and transferring knowledge and practice. The findings were grouped into two parts accordingly.

Building Fields of Connection

The HEP collaboratories include about 2000 participants from all over the world, and thus many people are competing for the attention of specialists. Those who have personal relationships with the specialists will gain more attention. In addition, no common funds exist to support collaboration between different participant institutions, nor do more experienced scientists from developed countries rely heavily on scientists from developing countries for resources or work support. Scientists from developed countries do not feel the automatic need to help scientists from developing countries. Thus, it is especially important for scientists from developing countries to build good relationships with scientists from developed countries.

Prior experiences of working together which enable scientists to become mutually acquainted prove to be particularly helpful for scientists from developing countries. Dr. Ching[1], a Chinese high energy physicist, responsible for a Chinese lab participating in the Collaboratory, worked for a year at a lab of University M in the US, which also participated in the Collaboratory. This experience enabled him not only to know the scientists, engineers and technicians of the lab at University M, but also those scientists and engineers from other US universities. Dr. Ching commented that establishing a relationship with the US lab and US scientists were critical for him. Since it was his first time being responsible for such a project, he encountered many difficulties at the beginning. However, he never hesitated to seek help from those experts. They answered his questions regarding technical design, helped him order parts that he could not find in China, etc. Some scientists and engineers from University M subsequently traveled to China on their own funding to help Dr. Ching solve problems that could not be solved through remote communication.

When collaboratory members did not know their collaborators before their collaboration began, scientists endeavored to build fields of connection through site visits. For example, because the Israeli team knew it needed more hands to work on a component of the particle detector, they welcomed Chinese teams to the collaboration when three Chinese institutions showed interest. However, at the same time the Israeli team was concerned about the capacity of the Chinese teams. A team of experienced scientists led by the leader of the sub-project visited China a few times. They were impressed by the Chinese scientists' strong will to become part of the collaboratory. During the visits, they also discussed with the Chinese scientists how the collaboratory as a whole as well as the experienced scientists on the subproject could aid Chinese science. Thus, these site visits enabled the Israeli scientists to appreciate the strong will of Chinese scientists and understand what efforts they

[1] [1] All the names appearing in this paper are pseudonyms.

should make to help them. The Chinese scientists also became better informed about how they should plan for the participation in the collaboration.

Scientists also found their relations through informal communication at coffee breaks, lunch and dinner time during conferences and workshops. These kinds of personal contacts ensure more efficient communication in their future contacts through information technology. Mr. Huang, a Chinese doctoral student who was performing physics analysis offered an example. He explained that in the Collaboratory, all the data scientists used should be officially produced and recognized as correct, and thus it would be helpful to know the person who was in charge of the work of producing the data. He got to know a Japanese scientist who produced the data he needed at a workshop. From the Japanese scientist's presentation, Mr. Huang could know his responsibilities. Through informal conversation during the coffee break, Mr. Huang further clarified his own research interests to the Japanese scientist. Later he could email the Japanese scientist to ask for help. Since the Japanese scientist already knew Mr. Huang and his research interest, Mr. Huang could obtain the Japanese scientists' quick response as needed. Mr. Huang emphasized this type of communication could not be replaced by email. He said, "In email that person is only a name. But through interpersonal interaction, he is a human being."

At Institute X, the physical center of the collaboratories, scientists have more opportunities for personal contacts. They could have chance encounters with others during coffee breaks, lunch and dinner time, get to know each other in a sport club, and they could also go to find and talk to the specialists in their offices.

Barriers to Building Fields of Connection for Scientists from Developing Countries

Scientists build relationships through prior encounters; previous experiences of working together; informal communication during coffee breaks, lunch or dinner time at conferences; and physical proximity to other scientists at the physical center of the collaboratories. However, limited travel funding prohibits scientists from developing countries from going to conferences and workshops as frequently as their counterparts in the developed world. Scientists from developing countries cannot stay or visit the physical center of the collaboratories as frequently as their collaborators in the developed world. For example, the French scientists mentioned that a few scientists from their institutions stay at Institute X almost all year round, and their students stay at Institute X for one week every month. The US scientists interviewed also said that they had representatives from their institutions stay at Institute X all year round, and the senior scientists try to visit Institute X as frequently as they could. By contrast, due to limited funding or heavy teaching load, scientists from developing countries could only afford a short stay in Institute X.   Dr. Milton, a senior US scientist, expressed his concern for Dr. Ching, his collaborator in China:

> Dr. Ching doesn't even know the people to talk to here. He knows me and some people from University M. But if he wants to get into data analysis or into any of those, he has to talk to the specialists here…It's easy to send email to me because he knows me. If he sends email to someone he never met, so that guy is like "what's the interest?" If he comes here and works here for half a year or one year, he knows the people and then he can go back and do the data analysis and come back every half a year and talk to the specialists. I think it's important for him to be here.

In addition, fields of connection tend to degrade over time when no efforts are paid to refresh them (Nardi and Whittaker, 2002; Nardi, 2005). Having fewer opportunities for personal contacts makes it more difficult for scientists from developing countries to refresh these fields of connection. Thus, the scientists become easier to be neglected. For example, scientists in one US lab complained that they could not know what occurred with their Chinese collaborators because they could not see and communicate with them often enough.

Fields of connection can be even broken when the collaborators cannot meet mutual expectations. For example, a French institute closely collaborated with Chinese scientists to work on physics analysis of one particle. When asked about why they collaborated with less experienced Chinese scientists instead of more experienced scientists from other countries, a French scientist answered that it was because it was easier to convince less experienced people to work on the subjects in which the French were interested. He also believed that because there was some time (about two years) before the experiment really started, there would be enough time to train Chinese scientists. The French physicist, Dr. Frank, was interviewed twice. During the first interview, he talked about how the Chinese scientist learned from the experiences of working with French scientists. When Dr. Frank was interviewed for the second time about five months later, he began to express his concern with this collaboration. He said,

> If it's really a collaboration, you should be independent…If it's more like I said "do this,", and when you finish this, I said again, "do this and this," it's not collaboration. It's "teaching." … It's not my job. I can do it when you start something, you need some teaching. Then you make your life. Collaboration means that it always comes from one side and the other side.

Obviously, Dr. Frank, was expecting intellectual contributions from Chinese scientists after a certain period of training, and he was disappointed because he could see no evidence of what he had anticipated. Dr. Frank also pointed out that distance exacerbated the problem. When the Chinese scientists worked at Institute X, they could come to speak with him face-to-face every week. He could see the results of their data analysis and receive timely feedback from the Chinese scientists. He explained that distance made it more costly to communicate. He would not spend more time on this kind of "teaching."

Transferring Knowledge and Practice

Collaboratories enable scientists in developing countries to access the practices of scientists from developed world in several ways:

On-site Participation and Observation

Scientists from developing countries find that site visits, which enable them to work side by side with their counterparts in developed countries, provide opportunities for different kind of learning than what they can gain from books and conferences.

Working in their collaborators' labs in developed countries enables scientists from developing countries to learn the process of managing lab work, as described by Dr. Lin, a Chinese high energy physicist who worked in her US collaobrators' lab for six months commented,

> We were very impressed by the way our American collaborators conduct their mass production quality control. For every chamber, they have a book [of guidelines for mass production quality control], which describes the detailed regulation for each process, from how to prepare the parts to testing and cleaning the parts. For each step, people who are in charge should sign the documents so that it will be easy to assign responsibility if problems occur… I learned the management process and brought it back to our lab in China…

This example illustrated that it is important for scientists from developing countries to be exposed to the whole procedures of certain practices such as management processes.

Site visits are especially helpful for scientists in the transmission of tacit knowledge. Building detectors involves many technologies, which can be acquired only through observation and participation. A Chinese technician, Mr. Liang, offered an example. He described how he learned the technology of gluing tubes. When building chambers, tubes should be glued to the board. At first, Liang's understanding of chambers came exclusively from the drawings and pictures brought back by the scientists who visited other labs. Mr. Liang described it was a very difficult process because it was difficult for him to "imagine" from the drawings and pictures how the tubes were glued on the chamber. Later, he was able to visit a Greek site and see the whole process of how the work was done. He said,

> The visit made a big difference. I noticed that when they applied the glue to the tubes, they first put a thinner tube between two tubes, which functioned as a "trail." The "gluing gun" (which is

> used to apply the glue) then followed the "trail." The width of the diameter and of the "trail" tube is related to the angle between the "gluing gun" and the tube when the glue was applied.

Mr. Liang added that the technology he described was not a complicated one. However, he would have never learned it if he had not seen how the Greek scientists and technicians performed the task.

Acquiring the technology itself is important. Learning the process of how the technology is designed can also be helpful. Mr. Song, a Chinese engineer, reported that he was very impressed by a technology called the wending machine when he worked in their US collaborators' lab. When he was asked about why he did not just purchase the machine and use it in his own lab, but needed to watch the process of how it was designed, he explained,

> The wending machine went through several versions. There have been many changes since the first version. The final version is only the essence. … When the final product is presented to you, many problems have been solved. The information about [how to use it to solve various problems] is not described or told. It is different from when you participated in the whole process. You have used your mind, your brain to think about [the design and how to solve problems with your design].

What Mr. Song emphasized is that technology transfer should not only involve the technology itself. It is important to know the context of technology design; that is, what types of problems the technology is designed to solve. Only after understanding this context, can those who seek to learn it apply the technology in different contexts. To do this, the learner needs to participate and observe in the whole process of technology design.

Informal Communication

Informal communication provides another channel for knowledge and practice transfer.

Scientists exchange their thoughts and experiences at informal discussions at meetings, workshops and conferences. A Chinese high energy physicist, Dr. Ching, explained that when they built detectors, much knowledge came from experienced people. It was significant for newcomers to access the experiences of old timers through informal discussions. Dr. Ching commented,

> When people make presentations, they can't include many details. Then participants at the meeting would ask questions like, "How did it happen? What was the reason? What was the solution? Was it a good solution?" Then people would start discussions. Then the presenter would talk about more details, such as, "It is for this reason, the result looks like this." He or she would also point out where they failed, and their experiences of solving the problems.

Dr. Ching is suggesting that formal presentation at meetings, workshops and conferences often play the role of a trigger, which arouses more informal conversations among participants. Scientists learn from the details included in informal conversations.

Another opportunity for informal communication in the collaboratories is web forums, where scientists post their questions and wait for the answers. The following is an example of a conversation thread, where scientists discussed the updates of the software,

> A. When I look into "Truth0" tree in TopView1213 and 1214, no light quark can be found and only 0ne b quark in each event. How to explain it? Thanks, Fang
> B. …t and s channel single top samples have leptonic decay modes only. Topview only keeps the light quarks from W decay. If you need other particular objects (say spectator light quark in **t-channel**) then you will need to write your own tool…Anna
> C. I think including the spectator light quark in **t-channel** is quite important, as its direction is used as a basis for top spin analyses. I would like to include it by default in TopView v13 Marcus

In this example, the initial inquirer, Fang, asked why he could not find light quark. In the answer to the original question, Anna mentioned t-channel. Then the discussion focus shifted to whether to include the spectator light quark in t-channel. This example illustrates that scientists, who are distributed all over the world, can stimulate each other through online discussion.

Scientists also mention that online discussions can benefit those inexperienced participants, who sometimes hesitate to ask questions. These inexperienced participants can be “lurkers” of online discussion. They “watch” other people’s questions and answers and learn from them.

Online Document

Many labs document and post their work online. Scientists from developing countries reported that these online documents inform them of the latest development in the field and enable them to learn from scientists from developed countries. Ms. Qian, a technician in a Chinese lab mentioned that she could not contact her collaborators in foreign countries because of both a language barrier and the organizational protocol; she could, however, learn from the website of their collaborators. For example, when they tested leakage of the tubes in 2006, she found that similar tasks were accomplished by University M in the US in 2004. They documented their work in their web site for the project. The documents indicated that lighting was important. Then the Chinese participants tried to find the appropriate lights as described in the documents. Ms. Qian emphasized that she could benefit from University M’s website because their documents were detailed and well-organized. These features made it easier for her to identify the information she needed.

Other online documentation that scientists find helpful includes minutes and presentation slides and wiki pages, which include information ranging from the news of the collaboratories, the division of research groups, archives of reports of technical design, tutorials of various tools that scientists might use in their physics analysis.

Barriers to Transferring Knowledge and Practices in Collaboratories

Although participants in collaboratories reported that they benefited from working side by side with scientists from developed countries, they could not visit their collaborators’ labs as frequently as they desired due to limited travel funding.

Scientists in developing countries have fewer opportunities to participate in informal communication. They participated in fewer video or teleconferences than their collaborators in developed countries because of poorer communication infrastructure. Moroccan and South African scientists reported that they could never participate in any videoconference because of the low speed of their countries’ telecommunications network. Neither could they attend any teleconference, because of their high costs. Chinese scientists also complained about the high costs of teleconference and low quality of videoconferences.

Another barrier to scientists’ participating in informal communication at meetings and workshops is the time difference. Many of the meetings and workshops in the collaboratory are held from 9 AM to 5 PM local time for Institute X, which was 3 PM to 11 PM in China and 4 PM to 12 PM in Korea. If Chinese and Korean scientists finish working at 5 PM every day, there will be only two hours of overlap for the Chinese scientists and one hour for the Korean scientists with the 9 AM to 5 PM schedule at Institute X. Thus, the Asian scientists would miss most of the meetings. Some of the Chinese and Korean scientists reported trying to attend some of these meetings at home. However, even though they had attended these meetings, they missed opportunities to engage in informal discussion with other colleagues in their own institutions. When I observed video conferences at University M and Institute X, I found that scientists often discussed with others present whatever they found interesting or problematic. If there were interesting issues raised by the meeting, the scientists would continue their discussion even after the meeting ended. However, when a scientist can only attend meetings alone at home, he or she tends to miss that stimulation from colleagues who were also present at the same meeting.

Participants from developing countries learn much from online documents posted by institutions from developed countries. However, these online documents do not share the same quality across various institutions because most institutions do not have specialists in charge of the management of documents. Documents from some institutions include more details and are better organized. In addition, since participants in the collaboratories are from all over the world, many detailed documents are not written in English. In addition, in such large HEP laboratories, many scientists contribute information, resulting in information overload. Scientists reported that they had difficulties locating useful information. For example, they obtained helpful information from wiki pages, but sometimes they could not locate the helpful page in need. They mentioned that informal communication with others is still one of the most efficient ways to help scientists locate information. In project meetings, it is often heard, “By the way, … do you know that Y used that software? You can find the information on their wiki pages.” Because scientists from developing countries have fewer opportunities to access informal communication, they were less capable to access information in online documents.

Cultural differences constitute another barrier to knowledge and practice transfer. The hierarchical culture in Asian countries results in that the leaders of participant labs tend to think they should be the ones who shoulder the tasks they think are important, such as video or teleconferencing with their remotely located collaborators, attending international conferences and visiting their collaborators’ labs. As discussed in the previous section, scientists agree that participating in video or teleconferences and attending workshops and conferences provides them opportunities to learn from others through informal communication. However, junior scientists, engineers and technicians from developing countries had fewer opportunities to participate in various meetings and conferences. The Chinese doctoral students participating in the collaboratories reported that they seldom attended video or teleconferences in their institutes, and they thought the video conferencing system was for their advisers to use. The Korean students mentioned that they did not participate in video conferences because the advisers did not think it helpful. By contrast, it is observed that at video conferences at University M in the US, the professors, engineers, and students who were involved in the project were all present and voiced their opinions.

Conclusions and Implications

Collaboratories concentrate scientists sharing similar interests or working for the same project, and thus offer opportunities for scientists to engage in communities of practice with scientists outside their own institutions. CoPs in collaboratories are different from the self-contained CoPs described by Lave and Wenger (1991). In CoPs described by Wenger (1991), the masters and apprentices agree on their relationships and are clear about their responsibilities corresponding to their roles in the community. However, in collaboratories, even though scientists from developing countries benefit from learning from scientists in developed countries, scientists from developed world do not feel the automatic need to offer help to scientists from developing countries. In addition, the large size of collaboratories results in that many scientists compete for attention from specialists. Without personal relationship with other scientists, a scientist may only be a name among the hundreds of names on the group mail list. His or her need cannot be attended. Thus, in order to ensure they can access scientists from developed countries, it is important for scientists from developing countries to build relationships with scientists from developed countries. Conferences, workshops and frequent visits to the physical center of the collaboratories provide scientists opportunities to meet each other face-to-face and become acquainted with one another. When face-to-face contact is not available, teleconferences and video conferences can at least offer the chance for scientists to communicate well enough to share their work and make plans for future research. However, due to their limited travel funding, poor communication infrastructure, and time difference, scientists from developing countries have much fewer opportunities to participate in conferences or workshops, video or teleconferences, leaving them much fewer opportunities to build personal relationship with scientists from the developed world.

In collaboratories, information technologies enable scientists from developing countries to overcome somewhat geographical barriers and access practices of scientists from developed countries. They have the opportunities to discuss research questions with scientists from developed countries through email, online discussion forums, and video or teleconferences. They also learn from the documents posted online by their collaborators in developed countries. However, these information technologies are limited in different ways. Email and online forums are only good at discussing questions that can be clearly described, but cannot be used for ambiguous ones. Due to the technology infrastructure and time difference, it is difficult for scientists from developing countries to participate in video or teleconferences. It is also difficult to follow up video or teleconferences with subsequent discussions. Online documents are helpful, but scientists do not always remember to document their research experiences, and not all the documents can be as well-organized and detailed as expected. The large number of documents make it difficult to locate information. Learning new procedures and tacit knowledge still occur more often with scientists from developing countries traveling to scientists to the labs in developed countries. For scientists in the developing world, who are typically isolated and do not have access to substantial travel funds, this can be a huge obstacle for learning.

This study has several important policy and design implications. Results of this work suggest that communication among scientists from different labs critically aid scientists in their exchange of information and experience. Thus, funding agencies should invest funds to both help scientists build communication infrastructure and facilitate travel.

Scientists in collaboratories benefit from various information technologies. However, the full value of collaboratories can be achieved only after the technologies themselves and the social practices surrounding the use of technologies are improved: First, in order to maximize the benefits of online documents, scientists should be reminded to post their work from time to time, and the participant sites need to be encouraged to conduct document management to ensure the quality of online documents. Second, Collaboratories need to pay attention to scientists' need for information seeking, and employ better information architecture or alternative practices to annotate and characterize information (e.g. social tagging). Finally, since in some developing countries, scientists cannot afford high-end technologies, collaboratories should look for solutions that do not require highly advanced communication infrastructure. For example, instead of video conferencing technologies, they can apply low bandwidth technologies that also allow data sharing with voice over IP (e.g., Centra).

References

Annan, K. (2003). A challenge to the world scientists. *Science, 299*, 1485.

Cohen, J. (1996). Computer mediated communication and publication productivity among faculty. *Internet Research: Electronic Networking Applications and Policy, 6*(23), 41-63.

Cox, A. (2005). What are communities of practice? A comparative review of four seminal works. *Journal of Information Science, 31*(6), 527-540.

Finholt, T. A. (2002). Collaboratories. *Annual Review of Information Science and Technology, 36*, 73-107.

Fox, M. F. (1991). Research productivity and the environmental context. In T. G. Whiston & R. L. Geiger (Eds.), *Research and Higher education: The United Kingdom and the United States* (pp. 103-111). Buckingham, England: Social Research into Higher Education/Open University Press.

Fox, S. (2000). Communities of practice, Foucault and actor-network theory. *Journal of Management Studies, 37*(6), 853-867.

Hesse, B. W., Sproull, L. S., Kiesler, S. B., & Walsh, J. P. (1993). Returns to science: Computer networks in oceanography. *Communications of the ACM, 36*(8), 90-101.

Knorr-Cetina, K. (2003). *Epistemic Culture*. Cambridge, Massachusetts: Harvard University Press.

Lave, J., & Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation*. Cambridge: Cambridge University Press.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative Data Analysis*. Thousand Oaks, California: Sage Publication.

Nardi, B., & Whittaker, S. (2002). The place of face-to-face communication in distributed work. In P. J. Hinds & S. Kiesler (Eds.), *Distributed Work* (pp. 83-110). Cambridge, Massachusetts: MIT Press.

Olson, G. M., Bos, N., & Zimmerman, A. (2008). Introduction. In *Science on the Internet*. Cambridge, Massachusetts: MIT Press.

Traweek, S. (1992). *Beamtimes and Life times: The World of High Energy Physicists*. Cambridge: Harvard University Press.

Walsh, J. P., & Bayma, T. (1996). The virtual college: Computer-mediated communication and scientific work. *The Information Society, 12*, 343-363.

Walsh, J. P., Kucker, S., Maloney, N. G., & Gabbay, S. (2000). Connecting minds: Computer-mediated communication and scientific work. *Journal of the American Society for Information Science, 51*(14), 1295-1305.

Walsh, J. P., & Maloney, N. G. (2007). Collaboration structure, communication media, and problems in scientific work teams. *Journal of Computer-Mediated Communication 12*(2), 712-732.

Wenger, E. (1999). *Communities of Practice: Learning, Meaning and Identity*: Cambridge University Press.