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Emilie-Pauline Gallié & Renelle Guichard

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DO COLLABORATORIES MEAN THE END OF FACE-TO-FACE INTERACTIONS? AN EVIDENCE FROM THE ISEE PROJECT

EMILIE-PAULINE GALLIÉ[a] and RENELLE GUICHARD[b,*]

[a]*Matisse, University of Paris I Sorbonne, 106-112 Boulevard de l'Hôpital, 75647 Paris Cedex 13, France;* [b]*Institut pour le Management de la Recherche et de l'Innovation, University of Paris Dauphine, Place du Maréchal de Lattre de Tassigny, 75775 Paris Cedex 16, France*

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Scientific collaboration encompasses two main issues: knowledge sharing and trust. Geographical distance has an impact on both. Our purpose is to test the impact of information and communication technologies (ICT) sophistication on remote collaboration: do collaboratories mean the end of face-to-face interactions? We first analyse the importance of geographical proximity with regard to knowledge transfer and trust. For both, we address the main problems set by geographical distance and the answers provided by ICT. These technologies come in a rich variety in a 'collaboratory'. They can be classified according to two criteria: their degree of synchronisation and the 'quality' of the communication cues. It turns out that the diversity of technical solutions can lead to firm solutions or palliatives to overcoming the barriers of geographical proximity. A case study in the field of space physics allows us to test our hypotheses.

Keywords: Collaboratory; ICT classification; Knowledge transfer; Trust; Geographical proximity; Space physics

JEL Classification: 031; 032

1 INTRODUCTION

Historically, joint intellectual activity has depended on physical proximity. Katz (1994) showed that proximity has a direct effect on the quality and frequency of collaboration. As Finholt (2003) states, the conventional response to these limitations has been residency, either permanent or temporary, at an instrument site. Recent works by Olson and Olson (2003) also demonstrate that 'radically collocated' working teams can produce twice as much (double the function points per unit of staff time), compared with the previous average in a certain company.

Nonetheless, with today's modern communication technologies, people can now work together while being remote. The scientific community itself is more and more characterised by distant computer-mediated communications. As scientists recognised the potential represented by expanding national and international computer networks, the notion of 'collaboratory' emerged, a hybrid of collaborate and laboratory. First proposed by visionary scientists in the late 1980s, a collaboratory is defined as '. . . a centre without walls, in which researchers can

* Corresponding author. E-mail: epgallie@univ-paris1.fr

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perform their research regardless of physical location [. . .] interacting with colleagues, accessing instrumentation, sharing data and computational resources, and accessing information in digital libraries' (Wulf, 1989, p. 19, as quoted in Finholt, 2001, p. 7).

The elaboration of the collaboratory concept stresses the simultaneous need to solve problems of control and operation of instrumentation over the Internet, of access and distribution of datasets, and of convenient and flexible interactions with colleagues.

In the same vein as the works conducted in behaviourist sciences, we wonder how well can today's long-distance technologies support remote work? In a world that has so many options for distant communications, is face-to-face interaction still so highly valued that people will go to great trouble to get together (Olson and Olson, 2003)?

This paper deals with Information and Communication Technologies (ICT)-mediated international scientific collaboration, from the perspective of two French public research teams. The objective of this paper is to study whether and how ICT can take up the challenge of reducing the spatial constraint induced by knowledge sharing and building and maintaining trust.

In Section 2, we begin by examining the dynamics at work in local networks. This first analysis provides insight into what works so well when collaborations occur face-to-face. We then proceed to an overview of the opportunities offered by ICT with regard to knowledge sharing and trust development. It turns out that the diversity of technical solutions can lead to firm solutions or palliatives to overcoming the barriers of geographical proximity. After proposing a classification of technologies according to their potential for distant collaboration, we formulate two hypotheses relative to the capacities of technologies to achieve efficient knowledge transfer at a distance and to develop trust at a distance.

Section 3 is a confrontation of these elements with the real-life context of a case study. We had six interviews with the protagonists of the ISEE project, an international collaboratory in space physics. Space physics is one of the 'usual' domains studied with regard to collaboratories, because of its heterogeneity in size, style of research, technical sophistication and traditional sources of support (Finholt, 2003).

Section 4 concludes the article by commenting our results and giving some recommendations.

2 ICT AS A MEANS TO MITIGATE THE EFFECTS OF GEOGRAPHICAL DISTANCE ON SCIENTIFIC COLLABORATION

Scientific collaboration encompasses two main issues: knowledge sharing and trust (building and maintaining). Geographical distance has an impact on both. This section is dedicated to the study of the dynamics of local networks and the importance of geographical proximity with regard to these two issues (Sec. 2.1). We will then proceed to an overview of the opportunities provided by communication technologies (Sec. 2.2), which will lead us to formulate two hypotheses to test the capacities of ICT to overcome the barriers of time and space.

2.1 Virtues of Local Networks

Local networks are a very effective organisational configuration for scientific collaboration: they allow knowledge sharing in real time and offer many opportunities for social interaction needed to build and maintain trust. Indeed, collaboration entails trust to allow to reduce uncertainty and to develop efficient interactions. Does this all turn geographical proximity into a severe constraint?

2.1.1 Knowledge Creation Entails Knowledge Sharing

Steinmueller (1999, p. 9) underlines that knowledge offers the capacity to generate, extrapolate and infer new knowledge and information. As a consequence of this cumulative nature, knowledge creation is a collective process: interactions allow for exchange and debate. Thus, a crucial question is that of sharing knowledge, which requires an adapted means of communication for each of the different types of knowledge.

The economic literature traditionally distinguishes codified knowledge from tacit knowledge. This frequent distinction rests on the degree of knowledge accessibility and on its nature (Malerba and Orsenigo, 2000). Codified knowledge[1] is perfectly expressed (Foray, 2000). On the contrary, tacit knowledge is not, by definition, explicitly described; it is personal to the agent. This distinction is the most common but Cowan, David and Foray (2000) have refined it. They establish that two forms of knowledge, both qualified as 'unarticulated', can be further distinguished according to their degree of visible manifestation: when a manual of reference (or 'codebook') exists but it is out of sight, it can be either displaced or not yet stable. The first case refers to a situation where the codebook is not explicitly manifest because it has been internalised by the group which uses it. In the other case, we are dealing with knowledge that starts to be expressed.

With regard to the conditions of knowledge sharing, codified knowledge can be acquired through reading, lecture, etc. Transfer and learning require neither the presence (or the intervention) of another agent nor human interaction. Thus, it does not depend on the location of the agent. This sort of knowledge can be transmitted through a 'lean'[2] form of communication.

Unarticulated knowledge (including tacit knowledge) is more difficult to formalise and to communicate: learning this knowledge entails experience through social relations and apprenticeship-relationships (Foray and Lundvall, 1996, p. 20). Thus, the usual way of transmission is face-to-face interactions. In that respect, unarticulated knowledge requires geographical proximity.

2.1.2 'Trust Needs Touch'

Following Akerlof (1970), Arrow (1974) and Dasgupta (2000), we consider that trust is a social lubricant that makes possible production – including learning (Lundvall, 1992; Lazaric and Lorenz, 1998) – and exchange: people need to trust each other to get their work done (Olson and Olson, 2003, p. 36).

Lazaric and Lorenz (1998, p. 217) define trust as 'the belief that our collaborators will act in a way designed to improve our situation rather than worsen it, in situations of uncertainty'. Trust is thus necessary as soon as we are dealing with uncertainty.

Uncertainty can be about the competences of the partner or on his/her intentions, and trust refers to both of these aspects. This distinction is close to the one done by Rocco *et al.* (2001), who name these two categories 'cognitive trust' and 'emotional trust'. The former can be easily developed *ex ante* thanks to reputation. In fact, especially in scientific communities, articles, colloquies, etc. constitute good clues to estimate the competences of a researcher. With regard to intentions, trust is more developed along with the co-operation as the partner can more easily dissimulate his/her intentions.

As analysed by Dasgupta (2000), the dynamics of trust formation and maintenance is comparable to an inter-temporal game in which history clearly matters. 'For trust to be developed between individuals, they must have repeated encounters, and they must have some memory

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[1] Codified knowledge is a message which can be manipulated like information (Foray, 2000, p. 48).

[2] Cf. 2.2.2 for distinction between lean and rich media.

of previous encounters' (Dasgupta, 2000, p. 56). People trust each other when they have shared experiences or follow the same norms (Olson and Olson, 2003). Geographical proximity then acts as a factor of cohesion and contributes to create long-lasting co-operative behaviour thanks to the repetition of commitment (Dupuy and Torre, 2000).

Rocco *et al.* (2001) put a strong emphasis on the difficulty of building and maintaining emotional trust through distant collaboration. Personal interaction with others provides the opportunity to gauge their beliefs and attitudes, which is critical to accurate assessments of (emotional) trustworthiness. Distant workers have many fewer opportunities for the kinds of interactions that maintain and develop emotional trust. There can be even more misunderstandings at a distance, as the context in which the remote team works is not known from their distant colleagues.

Thus, the fact that team members are remote hinders their work: remote teams have been reported to be less effective and reliable than face-to-face teams, based on the observation simply stated as 'trust needs touch' (Handy, 1995).

2.2 ICT Versus the Proximity Constraint

Two among the many virtues of the local network seem incompatible with distant collaboration: sharing of unarticulated knowledge and building and maintaining of emotional trust. Here, we try and understand by what measure ICT can help solve these problems, and formulate some hypotheses with regard to their capacities to overcome the obstacles to distant collaboration.

2.2.1 Opportunities Offered by ICT

With regard to knowledge sharing, the transfer of tacit knowledge may be facilitated by the use of ICT as they considerably open the space of codifiable knowledge and at the same time increase the profitability of codification operations (Foray, 2000).

On the other hand, several behaviourists' studies (most of them from the Collaboratory for Research on Electronic Work, at the School of Information of the University of Michigan) give us some clues so as to formulate strategies to improve emotional trust formation and maintenance at a distance through ICT. It seems that technical solutions could potentially reduce the dependence on face-to-face interactions. Rocco *et al.* (2001) suggest that technologies that are rich in terms of immediacy of feedback (for instance, that incorporate features of the phone conversation) and available channels for interpreting communication cues (e.g. sound, video, text, etc.), may perform more effectively in terms of interacting and of fostering emotional trust (Daft and Lengel, 1984, 1986). According to Zhen *et al.* (2002), it can also be explained by the fact that when participants are interactive, they are able to assess the attention that the others pay. When participants are visible to each other, there is an implied accountability. Behaviour might be more co-operative because the other person will recognise you in a future situation and will behave towards you according to what they learned from you in that situation. Seeing a person also makes the humanity of the partner more salient: it makes one appear vulnerable in some cases, and it allows the opportunity of finding similarities that lead to trust.

From these examples, it appears that ICT can provide us with solutions that, up to today, are palliatives to face-to-face interactions.

2.2.2 Classification of ICT

As a structure allowing for distant scientific collaboration, the collaboratory clearly has to overcome the barriers that we previously mentioned. In this section, we propose a classification of ICT that is suited to our purpose of evaluating the impact of technologies on overcoming the obstacles to remote collaboration, in terms of knowledge transfer and building and maintaining trust.

Media richness theory states that communication technologies, or in a more general way communication media, differ in the extent to which they can (1) overcome various communication constraints of time, location, permanence, distribution and distance (what Trevino, Lengel and Daft (1987) named 'situational constraints'), and (2) transmit the social and non-verbal cues of human communication (Rice 1987). Daft and Lengel (1986) thus built a classification according to the medium's capacity for immediate feedback, the number of cues and senses involved, personalisation and language variety. They obtained a classification such as in a decreasing media richness, we find face-to-face, telephone, personal documents (letters or memos) and then impersonal written documents. To complete our classification, we still need to add ICT. Computer-mediated communication was studied by Walther (1996, 1997). According to his social information processing theory, it does not differ from face-to-face communication in terms of the capability of social information exchange, but rather in terms of a slower rate of transfer. In the same vein, other studies tend to show that if face-to-face remains the gold standard for trust building, rich media can also prove to be very efficient (Rocco *et al.*, 2001; Bos *et al.*, 2002). In fact, new electronic means of communication increase the available channels for remote communication. They influence the context of social interaction and the 'content' of knowledge exchanged (Caldas, 2003).

We therefore come to consider the degree of sophistication of a technology as positively correlated to the speed of feedback and to the quality index of the communication channel (does it include features for sound, gestures, facial expression?). Then, the degree of sophistication is given by a simple measure of distance (from the origin of the graph to the technology), as illustrated in Figure 1.

This classification will help us test our hypothesis with regard to the capacities of the technologies at stake in collaboratories to diminish barriers of time and space that hamper scientific progress. We will test these capacities with regard to knowledge sharing and the 'technology transposition' of trust. We have put forward proposals in favour of a positive answer (e.g. synchronised and high quality media could act as a vector of trust), but we still have to test if they are palliatives or real substitutes to face-to-face.

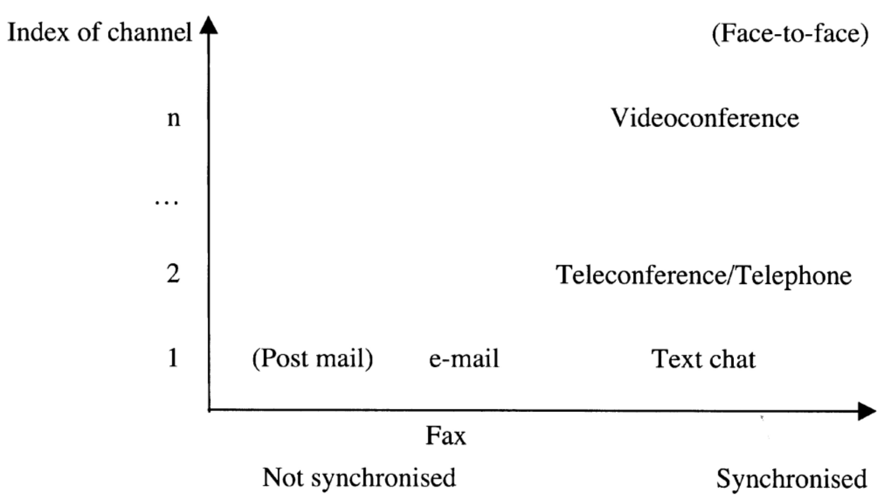

FIGURE 1 A classification of technologies that link people to people.

We can formulate our hypotheses as such:

- H1: The greater the degree of sophistication of the communication technology, the more the interactions tend to be equivalent to face-to-face in terms of knowledge sharing.
- H2: The constraint of proximity with regard to trust building and maintaining is decreasing with the degree of sophistication of the communication technology.

To gather elements for the answers to our hypotheses and assess whether technologies can allow scientists to take up the challenge of remote collaboration, we investigated the real-life context of plasma physics.

3 INTERNATIONAL SUN–EARTH EXPLORERS (ISEE) PROJECT

We carried on an empirical study in the field of space physics. It provided us with an in-depth understanding of virtual collaboration. We focused on two French teams who participated in the ISEE project (detailed in Sec. 3.1): one team at the Observatoire de Meudon (the 'DESPA' team), and the other at the Centre National des Etudes en Télécommunications (the 'CNET' team). Both teams were specialised in the study of electromagnetic waves, one of the essential aspects of space plasma physics.

We proceeded to interviews and e-mail contacts, so as to understand the organisation and management of remote collaboration.

In a first approach, we present the project and explain why we deem it a collaboratory (Sec. 3.1). We then present our methodology for collecting data (Sec. 3.2). In the next section, we develop the case study (Sec. 3.3). Eventually, we come to the testing of our hypothesis (Sec. 3.4)

3.1 Outline of the Project: A Transdisciplinary and International Collaboratory

The ISEE project is an international co-operative programme between the National American and Space Agency, NASA, and the European Space Agency, ESA, to study the interactions of the solar wind with the Earth's magnetosphere. The different participating laboratories were selected on the basis of the replies received to a competitive Announcement of Opportunity issued jointly by the NASA and the ESA. The programme used three spacecraft: a mother/daughter pair (ISEE 1 and 2, from 1977 to 1987) and a heliocentric spacecraft (ISEE 3, later renamed ICE, from 1978 on). These three spacecraft carried a number of complementary instruments for making measurements of plasma, energetic particles, waves and fields.

The setting and exploitation of the experiments were very complex in the sense that they required the skills of several scientists from different sub-disciplines of space physics at the same time. A transdisciplinary approach was then called for; no single laboratory could undertake such a programme on its own, because of human as well as of budget resources limitations. The ISEE project thus brought together scientists from all over Europe and the United States, every lab being specialised in a particular sub-discipline of space physics.

The setting and the following up of the experiments were undertaken in dialogue with all the partners of the project. The members then had to face 'the simultaneous need to solve problems of control and operation of instrumentation, of access and distribution of datasets, and of convenient and flexible interaction with colleagues' (Finholt, 2003). We will therefore regard this project as a collaboratory. As defined by Atkins (1993), the capabilities used in a collaboratory can be defined as technology to link people with information, technology to link people with people and technology to link people with facilities. We will use this typology in our exposé of the case study (Fig. 2).

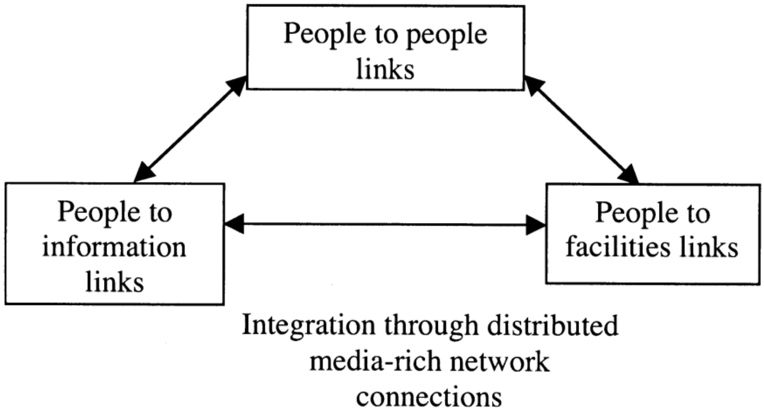

FIGURE 2 The three categories of technologies as by Atkins (1993), from Finholt (2001, p. 49).

Indeed, many technologies were made use of in the ISEE projects, at different levels of co-operation. First came the technologies to link people to the infrastructure: to transmit the data from the satellite (linking people to 'raw' information) to the operating space agency. After data had been processed, data sharing and recording technologies were at stake (linking people to information). And finally came the technologies to interact between members (linking people to people). They were used before launching the explorer and during the experiment (basically, the information and knowledge shared are about satellite operating issues). These technologies considerably evolved and improved with time, as we will see further on (Sec. 3.3).

3.2 Methodology

We chose to interview two French teams who participated in the ISEE projects, as it gave us the opportunity to have face-to-face interviews, occasionally followed by further e-mails or telephone conversations. We proceeded to semi-directive interviews (questionnaire in Appendix 1) of an average duration of 3 h.

The ISEE project started in the 1970s and lasted until May 1997 (end of the ISEE 3 experimentation). We chose to interview scientists who took part to the different stages of the project, to gather information on its whole duration. Nonetheless, three of the people we contacted had left the ISEE project behind for such a long time that they did not consider it useful to answer to us. We finally ended up with six consistent interviews (see Appendix 2).

3.3 Case Study

3.3.1 Genesis of the Project

The different participating laboratories were selected on the basis of the replies received to a competitive Announcement of Opportunity issued jointly by the NASA and the ESA, the different laboratories each being funded by their national sponsoring agency. The two French teams we interviewed, 'CNET' and 'DESPA', postulated together as they had complementary experiences. More precisely, the results of the experiment on ISEE 2 was measured by the instrument situated on ISEE 1; both teams also developed common tools for the systematic data exploitation. They also collaborated with American teams, especially for the building of the instruments and for data treatment.

This preparation phase lasted more than six months, as the communication means used were not very rapid.

3.3.2 Launching, Monitoring and Trajectory Control of the Satellites (People to Infrastructure Technologies)

Each satellite was launched after all members participating to the elaboration of the mission had installed their instruments on the spacecraft (launching phase). In a second step, and during its whole life, each explorer was operated according to the mission's science objectives and the received data, gathered and processed by the operating agencies (operating phase). The scientific objectives played a major role in determining the operations.

The control of the spacecraft was assured by the joint ISEE command facility, which was located at the NASA Goddard Space Flight Centre, in Greenbelt, MD (near Washington, DC). This agency was in charge of transmitting the commands to the satellite. Two kinds of commands were used to control these spacecraft. First, some commands allowed to modify the trajectory and to deal with logistic problems. These commands were instructed only by the space agencies. Secondly, some other commands were sent by the scientists who wished to modify the experiments. The scientists could not directly control their experiments because of the need for centralised control of the explorers (security and political reasons). Nonetheless, they could send coded command sequences by telex to the command facility once a week.

3.3.3 Reception and Dispatching of the Data (People to Information Technologies)

The data from the satellite were gathered by only one antenna in the NASA Goddard Space Flight Centre. Afterwards, they were dispatched between the collecting agencies (NASA or ESA) and the other members of the community.

In the late 1970s, the data were inscribed on magnetic tape by the agency. Then, researchers could ask, by post, for the data they needed. The magnetic tapes were sent by post. This global operation would take three months on average, but it could even take longer (up to 10 months, if the tapes were stopped at the customs).

Then, these raw data were processed at the CNES,[3] as the CNET and DESPA had few computer resources. As our interviewees pointed it out, space physics data require 'strong computing capacities', which were very rare in the 1970s and early 1980s.

In the late 1970s, the development of the VAX system (computer hardware) allowed more important data treatment. It was widely used in the US, but for national preference arguments it was little used in France. The DESPA team managed to obtain the first VAX in 1980 and could then increase the speed of data treatment.

In the 1980s, the development of the Space Physics Analysis Network (SPAN) – a VAX proprietary system – increased interest in the VAX system. The SPAN, a precursor of the Internet, was the first step towards a wide and rapid connection to information. The DESPA team managed to obtain a transatlantic SPAN connection in 1986.[4] French researchers could thus have access to data directly from the NASA computers: thanks to the SPAN, data were directly broadcasted to the laboratory without being transcribed on magnetic tape. The flow of information was then low (9.6 kbits/s) but at least, data could be collected and diffused within 24 or 48 h. It considerably improved the co-operation among the several research units.

[3] CNES (Centre National d'Etudes Spatiales) is the equivalent of ESA or NASA at the French national level.
[4] ESA was first connected in September 1985.

From 1991, the SPAN suffered from the competition with the Internet as it was used only within the space physics community. Little by little the TCP/IP protocol replaced this proprietary system even though the latter was more secure. The SPAN ceased being used in 1994.

A further step was recently achieved, as two new patterns of data diffusion were developed in the last decade for the projects following ISEE (ULYSSES and CLUSTER 2). According to the requirements of the speed of access to the data, the research units can now choose between having an Internet access to some of the data (about 5%) or receiving the whole datasets on CD-ROMs. This second option is nowadays the standard way of data diffusion. The Internet display is restricted to a small number of units, which have a monitored access. Both of these patterns allow a wide diffusion of information. They both have emerged because of the increase in the amount of data.

3.3.4 Interactions Between the Teams in the Course of the Project (People to People Technologies)

As we mentioned in our introduction of the case study, space physics is a complex domain, which strongly depends on collaboration and teamwork.

Many interactions were done through face-to-face contact at the time of the genesis of the ISEE project. For example, to set the ISEE 1 experiments, some of the French researchers had to stay for a long period in the US. All the persons involved in the experiments had to be in the Goddard Centre for the launching phase. Every technical problem required a meeting. This need for personal interactions explains the number of important trips to the US made by the members of the French teams and more particularly by the two main representatives.

Scientists also used to meet at conferences and congresses. Taking advantage of being in the same place, they would work together and elaborate new projects, at least in an informal way; the projects were generally finalised afterwards.

The researchers were also great users of phone calls. Teleconference allowed exchange of ideas and information. This synchronised means of communication enabled dialogue (rapid interactions and confrontations). To grasp an idea of the frequency of use of this technology in the ISEE project, the Principal Investigator estimated that he participated in a teleconference at least once a month to discuss the evolution of the project; the average number of people taking part was 12, geographically distributed in five sites (dispatched in France and the US). The other researchers we interviewed responded that they could occasionally use teleconference up to once a week, as it allowed interactions that were not possible by post. For instance, French teams could organise teleconference between themselves to set up experiments and data treatment or to discuss and clarify their results.

But, the use of teleconference seemed problematic. It was difficult to manage because of the difference in time zones between the laboratories and sometimes because of the involvement of too many laboratories. Moreover, teleconferences required a long preparation and were thus more constraining than e-mails. They were much easier between French teams as there were neither jet lag nor cultural/linguistic gap.

Our interviewees acknowledged the fact that the frequent use of teleconference allowed a reduction in the number of trips to the US, from four a year to one a year. Teleconference thus appears as a complementary technology to face-to-face (and to post).

The installation of the transatlantic connection in 1986 also had repercussions on people-to-people technologies. At the beginning of the ISEE project, interactions for writing an article at a distance was achieved through post. In the instance of an American–French co-publication, the interactions could take place as follows. The American teams would send their articles of the project by post to France. Then the French team would complete the first version and post it back. This process could take about three weeks, as the scientists could not always answer by return of post. But when American researchers received the answer, they had often already changed their ideas or interpretation. The transatlantic co-operation was then a failure. Things even worsened when the American researchers implemented the SPAN. Through this tool, American scientists could not only gain early access to data, but also achieve efficient co-operation with geographically remote scientists (equipped with the SPAN). Then, as underlined by the Principal Investigator, it became urgent for the French teams to develop tools to become part of the network. The SPAN proved useful for co-publishing, and it even became more and more convenient for other types of e-mail communication.

As they did not possess a VAX computer, the CNET team had to send their message through the machine of the DESPA team. Even with this constraint, both teams considered that this technology improved the quality and efficiency of collaborations. This was the time of the beginning of electronic distant co-operation.

Since then, the Internet has replaced the SPAN. Every researcher now acknowledges the usefulness of e-mail as a means of communication, as it increases the speed of the interactions. Moreover, the elaboration of projects is easier as the information is available immediately to all the partners. E-mail has partly replaced telephone calls or meetings.

As a first comment, our interviewees helped us to identify some patterns of complementarity between technologies. Indeed, some meetings disappeared with the use of ICT: technical or organisational matters (about the operating phase, for instance) were progressively done through teleconference. The researchers did not have to plan meetings anymore to solve technical problems: they were solved through e-mails or at the occasion of other meetings (conferences and congresses). Another example of the complementarity of communication means is that nowadays, only a few key persons must be at the launching place. The other team members can follow the launching and give their advice and comments from their home laboratory. With the use of ICT, frequent physical interactions are becoming less compulsory.

Nonetheless, face-to-face interactions remained necessary for three main reasons:

- First, face-to-face was needed to ‘discuss about Science’. For instance, as each scientist built their data from the raw data, meetings were necessary to explain to the others how they were built and what their limits were, or to give expertise;
- Secondly, meetings were required when the project faced important technical, organisational or scientific problems such as faults in an instrument;
- Thirdly, scientists would meet more often to speak about the projects as they became more complex. As each one became more and more specialised, every team needed the expertise of members of the project from more disciplines, and this was more easily achieved through face-to-face.

These meetings often took place in the Goddard Centre, where the scientists could meet the staff who had achieved the first ‘data treatment’.

3.4 Analysis: What Do We Learn in Relation to Our Hypothesis?

What did ICT change in the organisation of remote co-operation? In relation to our hypotheses, we wonder what ICT have changed in the ISEE project for the transfer of the different types of knowledge shared, and for building and maintaining trust.

3.4.1 Hypothesis 1: Knowledge Transfer Through ICT

The case study shows that the use of the SPAN has allowed reducing the time delay to obtain data. Moreover, scientists noticed that the SPAN facilitated the co-publications between remote colleagues. The knowledge exchanged in these two situations is mainly codified. We can thus conclude that the use of ICT (such as e-mail or web sites) for the transfer of codified knowledge allows saving time and increases the efficiency of personal work (for obtaining data) and of co-operation (easier communication and paper exchanges). In fact, the data can now be received within less than three days and the exchanges of text are almost instantaneous.

For this type of knowledge, the evolution is mainly in reducing the time delay but ICT do not change the organisation of this type of co-operation: the text that was exchanged by post is now sent by e-mail.

The case study shows that space physics co-operation requires different types of meeting. The use of ICT does not have the same impact on each of them.

Meetings about average technical problems are now done through teleconference and/or mail. These problems mainly deal with codified knowledge or routine knowledge not codified or displaced codebook. In this case, the facts or the procedures required are very well known and allow finding a solution (Rice, 1987). Then, thanks to ICT, the meeting can be done through a less-rich media than before. This change has a great advantage to allow co-operation on real time through teleconference. E-mails are used to organise the teleconference and to complete it with codified knowledge. For instance, as we noticed, only the key persons need to go to the Goddard Centre for the launching phase. The others can follow the operations from their home laboratory. In case of trouble, they can react and transmit their instructions immediately. Thus, for this type of technical codified knowledge, no matter where you are (or the distance), as every research concerned is connected and can react in real time.

Two other types of meeting still require face-to-face despite the development of ICT, as follows.

- Meetings for expertise are based on knowledge that can either be codified with a displaced codebook or not codified. In the first case, the expertise is very well known by few experts who share it. In the second case, the codification of expertise is in progress. Anyway, in both cases, knowledge is too specific to be understood without ‘face-to-face cues’.
- Meetings about scientific work or to resolve crucial problems require face-to-face because they are based on unanalysable tasks; in such meetings, people are obliged to think about, create or find satisfactory solutions to problems outside of the domain of facts, rules or procedures (Rice, 1987). Interpreting the knowledge which flows in these discussions depends on interpersonal interactions and social cues. Thus, as we first thought in the theoretical part of our article, for these types of tasks, people are more likely to use the richest media. This corresponds to two sorts of knowledge: tacit knowledge (with or without visible codebook) with regard to the creation of knowledge and codified knowledge with displaced codebook when it comes to data treatment.

Actually, we can conclude that as soon as the codebook is not perfectly visible, face-to-face is required. That means that even if the codebook exists but it is not explicit for at least one agent, the meeting is organised in the same place.

We have identified some of the reasons why researchers still continue to travel for professional matters. We have to add that surprisingly, the use of ICT does not even decrease the number of trips. This is because, as we noticed in the case study, the laboratories have become more specialised: more meetings are needed to share expertise and to co-ordinate the experiments.

Thus, the use of ICT does not change the need for geographical proximity for these types of meetings.

3.4.2 Hypothesis 2: Trust Through ICT

The case study illustrates the importance of trust for collaboration and especially for remote interactions: our interviewees consider that remote collaboration was possible only because they had known each other for a long time, both under the 'cognitive' and 'emotional' aspects of trust (for some of them for more than 20 years). The space-physicist community was a small one at the time of the ISEE project, and the researchers used to meet regularly at congresses.

The case study shows one pattern of trust building through the integration of new physicists in the community. We consider that this is the first step in the development of trust, which is a quite established process as the size of this community is limited and people remain in the community for a long time. Indeed, PhD students were integrated progressively. They started working on one experiment related to a bigger project for their PhDs; then they would present their results in front of the different teams of the project and in colloquiums. Thus, they had the opportunity to initiate contacts with other scientists and to develop trust[5] before they became full members of the community.

This case study did not allow us to test building of trust at a distance. At the time of the beginning of the ISEE project, ICT were not available and face-to-face encounters were the only means to get to know people.

Moreover, if trust is initially required to establish remote relationships, it must be 'maintained'. It is particularly tricky for emotional trust. This 'keep in touch' activity is necessarily done through face-to-face. It is one of the main reasons for the maintaining of trips. Nevertheless, as trips are considered as a constraint (they are 'tiring and costly'), the researchers have developed partial substitutes: telephones and e-mails have become other means to maintain trust, as people exchange informal messages – we were mentioned twice that because of both the cost and the barriers of language, telephone sometimes seemed less practical between foreign partners.

With regard to maintaining trust, our conclusion is twofold, as follows.

- Cognitive trust seems to be totally achievable through publications and scientific works.
- Contrary to our hypothesis, the development of emotional trust is still mainly a face-to-face process. ICT can only provide palliative means of communication, no matter how sophisticated they are.

4 CONCLUSION

The use of ICT allows an increasing number of remote collaborations and therefore contributes to the improvement of the knowledge base. As a medium for communication, ICT have transformed the possibilities of pursuing projects of discovery and invention through complex collaborations among scientists and engineers who may be assembled 'virtually', freed from the restraints imposed by physical co-location. This capacity permits a division of investigative and inventive labour, the co-ordination of complementary tasks within larger projects, and the capacity to readily re-structure and re-combine research results to form insights (David and Steinmueller, 2003).

[5] Sometimes, the development of trust can take longer; gender and age issues can indeed complicate the process.

Nevertheless, these technologies are not perfect substitutes to face-to-face interactions: tightly coupled work is best done face-to-face. As Olson and Olson (2003) analyse, 'today's technology richness and responsiveness are just not up to the task of allowing rapid back and forth, clarification, detection of confusion, etc.'. Indeed, when it comes to the sharing of unarticulated knowledge or the development of emotional trust, face-to-face still remains the gold standard. As it is, the dream of reducing travel budgets through conferencing technology has not yet been achieved. While distance technologies might on the surface reduce costs, the organisational costs of eliminating travel has been viewed as too high for too many (Olson and Olson, 2003).

Our findings confirm the lessons learned from previous collaboratory efforts (Finholt, 2003). Its originality lies in the fact that just a few observations had been capitalised in France so far.

4.1 Side Comments

Collaboratories are transforming the way in which people create, accumulate, store and transmit information and knowledge, and the way in which they perform and react in their working environments. The use of ICT is not neutral with regard to working patterns; it engenders changes in both the nature and the organisation of scientific research. On the one hand, a division of labour is affected in the sense of an over-specialisation, which increases the inter-dependence between research units. On the other hand, the life within each participating laboratory is negatively impacted: the researchers we interviewed deplored the fading of working and social interactions among local scientists in parallel to the blooming of distant collaborations.

4.2 Recommendations

The fragmentation of the European research effort has been identified as a compounding factor in Europe's under-performance in the scientific arena. The European Commission's Communication on the implementation of the European Research Area (ERA), adopted in January 2000 in Lisbon, clearly states that the decompartimentalisation and better integration of Europe's scientific and technological area is an indispensable condition for invigorating research in Europe. Within the broad issue of how best to equip scientific research for the 21st century, harnessing the effects of advances of information and telecommunication technologies is of particular significance.

It is evident that in the case of collaboratories as elsewhere 'technology alone is not enough' (David and Steinmueller, 2003). 'Non-technological' factors in research collaboration have a bearing upon the realisation of new modes of research collaboration.

From our study, we can identify several measures complementary to public funding, to limit the negative social impact of virtual networks:

- kick-off meetings should gather all members of the project in the same place;
- regular physical meetings should be organised.

If both of these conditions are not met, we consider that the remote collaboration will not be able to produce new knowledge in an efficient way. Furthermore, we can add two less crucial recommendations, which are:

- public funding should be conditioned with respect to some indicators of local and social dynamism such as 'local' co-publications, local events, etc. so as to avoid the deterioration of the life within local laboratories;

– computer scientists should work more closely with technology users (research scientists) in order to implement well-suited tools, adapted to the real requirements of users.

These recommendations are based on a single case study. In order to validate and enrich our findings, we plan to investigate more empirical material, in other scientific communities, and with other technologies (videoconference, virtual blackboard, etc.).

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APPENDIX A: QUESTIONNAIRE

Part 1. About the Interviewee

- age
- Status
- Discipline and field of competences
- Professional background

Part 2. About the ISEE project

How did the ISEE project start?
What were your motivations for participating in the ISEE project?
How did you get involved in the ISEE project?
What position did you occupy in the ISEE project?

Who were your main partners?
What were their disciplines?
Where were they located?
How did you get to know them?
Had you already worked with them before?
How did your relations evolve during the project? (for the best or for the worse? And can you explain why?)
How was the work divided between teams?
How were the responsibilities shared between teams?

What did you communicate with your partners? (What knowledge did you share?)
How did you communicate?

For each means of communication:

- What was the frequency of use?
- Did this means of communication correspond to a specific use?
- Did you use this means in complementarity with another means?
- Did this means evolve during the project?

APPENDIX B: OUR INTERVIEWEES

Name	*ISEE team*	*Role in the ISEE project*	*Dates of interviews*
C. Harvey	DESPA	He was the Principal Investigator of the project on energy particle instruments; as such he was the privileged interlocutor of both French teams with the space agencies. He was also president of the European SPAN Coordination Group (see Sec.4.3.). He began working on the project in 1972 and was then about 30 years old.	(1) Jan. 2002 (2) Feb. 2002 (3) Apr. 2002
J. Etcheto	CNET	Responsible for the ISEE 1 experiments of the CNET team, she was then finishing her thesis and was 21 years old. She later took charge of the ISEE 2 experiments.	(4) Aug. 2002
P. Canu	CNET	He was a young CNRS researcher when he got involved in the ISEE 2 experiments (although he had already been linked to the experiments during his thesis).	(5) Oct. 2002
N. Cornilleau	CNET	She joined the project in the early 1980s and was responsible for an experiment on ISEE 2.	(6) Oct. 2002