Communication and Collaboration in e-Science Projects

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Executive Summary

This report forms part of the 'Embedding E-Science Applications: Design and Managing for Usability project. Through five case studies, it focuses on communication practices within e-Science projects, and how they support the collaborative work of these projects.

Section 1 introduces the report. It explains how the large-scale distributed nature of e-Science projects can complicate communication practices as information and knowledge is transferred across institutional, disciplinary, and even international boundaries. Existing literature suggests this is the case for three main reasons. The first is that people working in different contexts may find it difficult to achieving mutual understandings. Secondly, geographic dispersal of project members frequently necessitates the use of Information Communication Technologies (ICTs), which often do not afford the same richness of communication as face-to-face communication. Finally, when participants are not collocated, there are usually fewer valuable opportunistic and informal encounters that occur than when colleagues are collocated. The aim of this report is to examine how e-Science projects negotiate these challenges using the existing communication methods available to them, and to identify issues impeding effective communication practices which nevertheless still arise.

Section 2 introduces the five e-Science consortia which formed the case studies for this report (myGrid, preDiCT, CancerGrid, NeruoGrid and NeuroHub), and describes the qualitative methodology employed. For each case study, a series of semi-structured interviews was conducted with various members of the consortium, and an analysis of documents produced by the consortium was undertaken.

Section 3 describes some of the communication practices found in the case studies, as well as providing a brief overview of one particularly significant ICT used in e-Science projects, AccessGrid. This section relates different aspects of the collaborative work of these case studies to the communication practices and methods that were selected to support this work. For example, face-to-face communication has been employed when the work is very tightly-coupled, complex and non-routine (for instance, in writing a project's initial proposal). On the other hand, less-sophisticated ICTs have generally been selected to support more routine, less-intensive work (such as day-to-day monitoring of work groups). Additionally, this section also describes instances of work carried out using a combination of methods that complement each other, some of which may be adopted in response to the emergence of new aspects of the task as the project progresses (for instance, requirements elicitation).

Sections 3 and 4 report the findings from these case studies. Two findings (the effect of unshared work contexts and the effect of incentives on communication) are discussed in greater depth in another report for this project, *Shared Understandings in e-Science Projects*. The rest fall into two broad categories (although it should be noted that there is some overlap between the two). The first are largely related to the technologies used in ICT-mediated communication and are presented in Section 3. These are:

- **Controlling meetings conducted via ICTs.** In particular, because ICTs often do not allow for the transmission of audio or visual cues, or transmit such cues poorly, interviewees reported difficulties with keeping meetings focussed on the issue-at-hand, preserving sequentiality, and resolving decision-making processes;
- **Shared material objects in ICT-mediated communication.** Some interviewees found it difficult to establish a shared frame of reference with others because they

could not share material objects with them via ICTs, or found it difficult to highlight particular features of such objects to enrich communication;

- **Access to ICTs.** In particular, it was found that it was not possible to conduct meetings with some communication technologies because one (or more) of the sites involved did not have the appropriate expertise to set up and run the technology, or did not even possess the technology. This was particularly reported to be the case with AccessGrid;
- **Coordinating ICT-mediated meetings.** Although it was often hoped that meetings would occur spontaneously between non-collocated personnel, interviewees reported that this did not happen, and thus there was often a greater need to schedule formal meetings. However, this proved difficult due to the busy schedules of many of the project members (especially senior personnel) and the challenges of coordinating meetings to fit the diverse timetables of the various partner institutions; and
- **Lack of response to emails.** Interviewees reported particular difficulties in securing responses to emails from senior project staff, which sometimes resulted in delays in the sender receiving important information and some industrial partners questioning the commitment of academic partners.

The second category comprises issues that arise from the very fact that e-Science projects are distributed. These issues are:

- **Non-collocated project members not knowing each other.** It was found in our case studies that the level of rapport between project members can impact upon the choice of communication technology used, with a higher level of rapport often leading to the use of a technology affording richer, more rapid, and thus more effective, communication. However, because e-Science projects are distributed, many of the project participants did not know their collocated colleagues;
- **Organizational structures.** Partner institutions in an e-Science project often have a diversity of hierarchies. This has been found to lead to differences in communication practices between groups at different institutions, and also slower communication flows as some project members did not feel able to bypass their home institution's hierarchical structure to communicate directly with colleagues at partner institutions;
- **Uneven distribution of knowledge** amongst project members**.** Although a feature of most collaborative projects, this issue has proven particularly acute in the case of e-Science projects because project members at one site may know very little about colleagues at partner institutions and the contexts in which they work, and some features of ICTs may exacerbate the issue (for instance, an email is only between two people, so other parties may not have access to the information it contains);
- **Communication across time zones.** Because projects often involve partners in different countries, colleagues may be working in different time zones. This can often reduce the amount of time that project members are able to communicate with each other, as their working hours may not fully overlap. Furthermore, this issue can also slow down the flow of information because, if a project member sends a request for information to a colleague outside of the colleague's working hours, they may have to wait until the next day to receive a response; and
- **Language barriers.** e-Science projects frequently involve members whose first language is not English. Such individuals may feel inhibited from contributing at meetings, or may not fully understand what is being discusses. Furthermore, some interviewees reported that the use of ICTs exacerbated this issue, because they made it more difficult to realise that an individual was experiencing language issues.

Section 5 concludes the report by summarizing the findings, and presenting a number of recommendations for practice. These are:

1) **Creating opportunities for non-collocated project members to meet each other, to work together, and to visit other sites.** Such opportunities might include visits to other sites, placements and personnel exchanges, hackathons, workshops, and peer-programming, involving the pairing of colleagues from different sites;
2) **Providing ways of sharing information (both personal information and information about the various sites in which project members work)**, including: providing each project member with a personal web page, and having web pages giving an overview of each site; and circulating a document, for instance at the start of the project, for which each project member is encouraged to submit a personal profile and that contains details of the facilities at each site;
3) **Using online methods to schedule meetings.** For instance, the tool meet-o-matic (www.meetomatic.com) enables project members to indicate times that they are available for a particular meeting, and then suggests the times that are convenient for the greatest number of potential attendees;
4) **Setting a detailed agenda in advance of meetings.** Clearly defining in advance which topics will be covered in the meeting should help to prevent discussions from veering off-topic. Such an agenda should be fairly detailed, but a balance needs to be struck between the level of detail specified and allowing some flexibility in the meeting. The agenda should also be circulated in advance of the meeting;
5) **Providing text sidebars alongside the main meeting.** A participant may feel that they wish to continue discussing an issue or to press another individual on the issue (for instance to gain more information about the issue), but due to time constraints, the meeting might have to move on to the next item on the agenda. Text sidebars can allow the participant to continue discussing the issue;
6) **Ensuring the meeting has one person acting as a chair with clear authority over the meeting**, including the authority to, for instance, say when the meeting has veered off-track or to specify whose turn it is to speak. Such a person should also be more direct and forceful than they might be in a face-to-face conversation;
7) **Assigning an individual to look out for participants who might be struggling with language,** who might then prompt them to encourage them to share additional information they may have or to check they understand what has been said.
8) **Providing training for project members at each location regarding how to set up and use communication technologies.** This should help to enhance the access at some sites to particular ICTs;
9) **Assigning particular individuals as experts for particular domains of knowledge.** It has been found that by so doing, other project members usually share information and knowledge about this domain with the assigned expert. Furthermore, project members tend to consult this expert when they require information about the domain, and the expert is also able to identify new information and bring it to the attention of others;
10) **Providing online knowledge repositories** (for instance, where documents can be placed) and, in particular, set up specific repositories for specific domains, so that information about a particular domain is available in one place and is accessible to all;
11) **Providing project members with two email addresses,** one for day-to-day communication, and the other for messages of high importance; and
12) **Adopting a collaborative wiki approach to developing plans and other decision-making,** in order to allow project members to contribute more to decision-making processes.

1 Introduction

e-Science projects are large-scale, multi-disciplinary, multi-institutional research projects, with the goals of developing technological systems and middleware to support highly-distributed computationally-intensive scientific research. They have been set up to support in a variety of academic disciplines, spanning the life and physical sciences, the social sciences, and the humanities. Typically, e-Science projects involve software engineers and developers working in close conjunction with researchers in particular fields in order to develop software and computational tools that closely match the needs of these researchers.

These projects involve the management and coordination of work of a wide range of project members, and also involve them working together on joint activities on a day-to-day basis. Successful communication practices about a wide range of aspects of such projects play a critical role in ensuring this (Darch *et al.* 2010; Warr *et al.* 2007a). These aspects include the project's overall goals and visions, the tools and software under development (including the features and user requirements that will be incorporated into them), and how to proceed with the work of developing these tools (such as timescales and deadlines, the project members' roles and responsibilities, and how these roles fit together, and the methods and work practices being used to develop the tools).

Communication about these aspects may take a number of forms. For instance, there will be many one-way transfers of information, such as project management informing new personnel of the project's vision and goals, the communication of work plans (including individuals' roles, the model of software development employed by the project, timescales and deadlines) from those who have created them to those expected to execute them, documents specifying user requirements being given to those designing the tools and software, and the presentation of work by an individual or team to their colleagues. Such transfers of information may in turn give rise to further communication, for instance when feedback is given (for instance regarding whether a developer feels the tasks they have been assigned are realistically achievable) and requests for clarification when there is only partial understanding of the message. Communication may also take the form of negotiations or discussions. These could be regarding either day-to-day issues, for instance a team prioritising the tasks they need to complete and dividing work amongst team members, or higher-level issues such as seeking to define the project's overall vision, or constructing an overall plan of work.

The task of communicating effectively at every level is made significantly more complex given the nature of e-Science projects. This is a result of such projects being large-scale and involving multiple institutions (often both academic and commercial), multiple scientific disciplines and (in many cases) partners from different countries. These factors may make the task of effective communication more difficult for a number of reasons. One is that information needs to be transferred across boundaries (institutional, disciplinary etc.), and this can impede communication between those on either side of such boundaries. For instance, it has been found that individuals tend to conceptualize a task in terms of their own immediate work context, including the language used to describe the task and whether it is thought about in abstract or practical terms (Bechkey 2003), and hence there may be difficulties in achieving mutual understandings between individuals working in different contexts (e.g. different institutions).

Geographic dispersal of project members also impedes effective communication in two other ways. Firstly, because face-to-face communication is frequently not possible, it often necessitates the use of Information Communication Technologies (ICTs, such as e-mail, telephone, and Instant Messaging): it has been widely-reported in the literature that ICTs often restrict the amount of information that can be transmitted compared to face-to-face communication (de Rooij *et al.* 2007; Veinott 1999), or can be beset by technological difficulties (Olson & Olson 2000).

Thirdly, when participants are not collocated, there are usually fewer opportunistic and informal encounters that occur than when colleagues are collocated (such encounters might, for instance, result from two colleagues meeting at the water cooler, or looking up and glancing at a colleague across an open-plan office, or looking through a window into a colleague's office to see if they are free for a conversation) between non-collocated project members (for example, Li & Mantei 1991). Such encounters have often been found to constitute a large portion of an individual's work time (for instance, Whittaker *et al.* 1994 estimated that such encounters constituted 31% of the work time of people they studied), and it has been argued that such encounters play a fundamentally important role in coordinating the success of collocated projects (Galegher *et al.* 1990; Whittaker *et al.* 1994).

Much of the research into how communication practices and technologies might better support distributed collaborative projects has focussed on how to reproduce opportunistic and informal encounters. In the case of non-collocated personnel, these might take place using telephone calls, text messaging, Instant Messaging or via email. However, such media do not afford the same richness of communication as face-to-face communication (Olson & Olson 2000). For instance, none allow for the transmission of audio (such as tone of voice) or visual (such as facial expressions or body language) that can convey a great deal of information. Furthermore, objects (such as documents, diagrams or physical prototypes of products under development), which can provide a point of reference in face-to-face communication in order to establish common ground and convey information, cannot be shared via telephone calls or text messaging.

Thus, and in particular, in order to increase the extent to which informal encounters might occur in non-collocated collaboration, and the efficacy of such encounters, much of the focus of this research has been on the development of *media spaces*, which are particularly sophisticated forms of ICTs. Media spaces are virtual shared spaces set up using audio and video communication equipment in order to create awareness of whether colleagues in other locations are available for informal encounters (for instance, being able to tell whether another colleague is present by glancing at a screen displaying a video image of their desk) and enabling communication between them (Bly *et al.* 1993). Media spaces can consist simply of a single camera and microphone at each location (Fish *et al.* 1992), or a multiplicity of cameras offering a variety of views of an individual's workspace (Gaver *et al.* 1993), or configurations of cameras and desk layouts that enable one person to display a document to which all parties in a communication are able to gesture and have their gestures seen by others (Luff *et al.* 2006).

A number of issues have been raised in the literature on media spaces, and attempts to address these have been made. In terms of encouraging informal encounters, it is vitally important to create the presence of non-collocated colleagues in the workspace of an individual's workspace, so that the individual is aware of whether a colleague is available for a conversation without disturbing this colleague. In a collocated work environment, it can be easy to establish such awareness without disturbing the other colleague: in the case of open-plan offices, a glance may be enough, and even when workspaces are not open-plan, it may be possible to look through an office window or peer round and office door to gain this awareness (Fish *et al.* 1992). In the case of non-collocated colleagues, media spaces include a camera trained on people's desks, so that others may see whether they are available for conversations without causing a disturbance.

However, such an approach gives rise to issues regarding privacy. It has been found that people tend to like to have control over what information about themselves is disclosed to others, and the extent to which and the context in which such information (Davis & Gutwin 2005). In this respect, many people have found video to be highly invasive (Neustaedter *et al.* 2005), for instance, they may not know who exactly is watching them at a particular time, which may make them feel uncomfortable or inhibited (Boyle & Greenberg (2005)). Furthermore, an individual may also wish, at times, to restrict the amount of information she receives about other people, for instance if she does not wish to be disturbed or distracted: she may turn off the video images of others at their desks, but these others may not be aware that she cannot see them so may erroneously believe that she is being rude and ignoring them when they attempt to attract her attention (Kim *et al.* 2007).

A final important issue is how to enable seamless collaboration. Olson & Olson (2000) found that in collocated work, there is usually a seamless integration of referents (for instance, gesturing or pointing to shared material objects, such as documents, maps, diagrams etc.) into the flow of communication (see also Whittaker & Schwarz 1995). Heath & Luff (1991), however, found that remote collaboration fractures relationships between the body making the gesture, the environment in which the object being gestured to is situated, and the action of gesturing, thereby interrupting this seamless integration. Some media spaces have attempted to address this by having multiple cameras filming a single workspace, enabling the viewer to switch between a variety of perspectives of the person making the gesture, the object to which he is gesturing, and the environment in which this object and the gesturer are located, however it has been found that this can, in fact, further complicate the establishment of a shared frame of reference between those communicating (Gaver *et al.* 1993).

Much of this research has fed into the design of communication technologies, such as AccessGrid[1], which will be described in more detail in Section 3.1. Such technologies can support the collaboration of non-collocated personnel in e-Science projects, but, nonetheless, there are still a number of issues that have been experienced by members of these projects which impact upon effective communication practices. Through case studies of five e-Science projects, this report aims to:

1) Provide an account of communication practices (both using face-to-face methods of communication and ICTs) within e-Science projects. This constitutes Section 3; and
2) Identify issues arising in these e-Science projects that may impede seamless communication flows amongst project partners. These will constitute Sections 4 (which will focus on issues relating to communication technologies) and 5 (which will focus on other issues that are not so directly related to the technologies employed); and
3) Suggest techniques and strategies for addressing these issues. These recommendations will be presented along with concluding remarks in Section 6.

First, however, the case studies will be presented. This will consist of brief descriptions of the five projects selected as case studies, why they were selected, and the methodology employed for conducting the studies.

[1] www.accessgrid.org

2 The case studies

Case studies have been conducted of five projects. These consortia have been selected as case studies for this report because they are multidisciplinary, multi-institutional, and geographically-distributed (sometimes involving international collaborations) and therefore investigating them will give the opportunity to focus both on the issues that might impede effective communication and collaboration practice in e-Science projects, and on the methods undertaken to address these issues. Our analysis will inform the recommendations made in this report.

In this respect, the consortia studied were felt to complement each other well. Some are relatively new projects, and strategies and techniques for addressing these issues that were being developed or attempted at the time of the case study. By contrast, some have run to completion or have been operating over a much longer period of time, allowing for greater reflection about issues, and the success (or otherwise) of steps taken to address them.

These consortia are briefly introduced below.

2.1 myGrid

The myGrid consortium was originally formed in 2001, and since its formation, has been coordinated at Manchester University[2]. The consortium has been through a number of phases, each involving Manchester University with a variety of partners, both academic and commercial, and drawing on funding from a range of sources, most notably the Engineering and Physical Sciences Research Council (EPSRC) and the Open Middleware Infrastructure Institute (OMII-UK).

The principal aim of myGrid is to support knowledge- and data-intensive *in silico* scientific work, for instance such as that carried out by bioinformaticians. To this end, it aims to build applications that will allow scientists to plan and execute *in silico* experiments, and to analyse and publish the results of these experiments. In addition to this core work, myGrid project members are also involved in associated projects where they may be working with partners, in some cases based in other countries, from a particular scientific field to help incorporate myGrid applications into their work.

2.2 preDiCT

preDiCT is a three-year project, commencing in June 2008 and funded by the European Commission as part of the Virtual Physiological Human (VPH) Initiative[3]. It is coordinated at the University of Oxford, and also involves four other academic institutions from a variety of European Union countries, three pharmaceutical companies and one data management company.

preDiCT's aim is to produce software that will enable the simulation of drug interactions to predict the performance of pharmacological compounds on the heart's rhythm, which could be used by pharmaceutical companies and academic scientists in drug development, to offer improvements upon current methods for determining whether candidates for drug development will have harmful side effects on the heart.

[2] www.mygrid.org.
[3] www.vph-predict.eu

2.3 NeuroGrid

NeuroGrid was a three-year project, running from March 2005-March 2008, and funded by the Medical Research Council (MRC)[4]. The University of Oxford was the lead partner, in collaboration with six other academic partners.

The aim of NeuroGrid was to support collaboration between neuroscientists, clinical practitioners and computer scientists to develop Grid-based services to enable the sharing, curation and analysis of neuroimaging data from multiple sites and to promote large-scale clinical studies.

2.4 NeuroHub

The NeuroHub project commenced in April 2009 and is due to run until March 2012, funded by the Joint Information Systems Committee (JISC)[5]. It involves three partner institutions (the Universities of Oxford, Reading and Southampton) and is part of e-Research South, a consortium spread across the south of England and comprising a number of projects involving a range of scientific disciplines.

NeuroHub aims to develop a framework that will support neuroscientists' work from the conception and design of experiments through to the publication and dissemination of results. As part of this, it seeks to develop new tools, as well as adapt existing tools so that they can be integrated into the framework.[6]

2.5 CancerGrid

CancerGrid began in May 2005. It initially ran for three years, but its operation has been extended until March 2010. It was an MRC-funded project involving scientists at the Universities of Oxford and Cambridge[7].

It sought to develop a grid-based network to support clinical trials for cancer treatments, including patient entry, randomisation, and follow up, as well as to provide methods to store, share and mine complex datasets.

2.6 Methodology

All cases studies consisted of:

- Semi-structured interviews conducted with members of the consortia; and
- Analysis of documents produced by these consortia, including:
  - Funding proposals;
  - Project progress reports (such as annual reports); and
  - Papers and presentations produced by members of project consortia.

Drawing on data from a range of sources allowed for triangulation to take place (O'Donoghue & Punch 2003). It has been observed that the content of texts (including interview transcripts, reports etc.) is contingent on the context in which they are produced (e.g. the interaction

[4] www.neurogrid.ac.uk
[5] www.neurohub.ac.uk
[6] www.eresearchsouth.ac.uk
[7] www.cancergrid.org

between interviewer and interviewee) rather than simply reflecting an underlying reality. Triangulation involves the cross-checking of data from different sources (and thus which have been produced in different contexts) which helps to ensure that conclusions drawn from the data are not biased by the context in which the data are produced.

A series of interviews were conducted with various members of the consortia described above. During the course of the interviews, the interviewees were questioned on (see Appendix A for a schedule of questions related to communication practices asked in the interviews):

- Communication practices within their consortia, including frequency of instances of communication, which project members were involved, and the communication technologies that were employed;
- Challenges and shortcomings of the various instances of communication; and
- How these challenges were addressed and the extent to which these efforts were successful.

Interviewees were selected in order to provide a cross-section of consortia members. These included:

- Principal investigators;
- Project Managers;
- Application developers;
- Postdoctoral researchers;
- Doctoral students; and
- End-users of applications.

The data was analysed using a *grounded theory* approach (Strauss 1987). Interview transcripts and other documents were read closely, and a number of issues relating to shared understandings emerged from this. These documents were then coded according to these issues, allowing for both the frequency with which each issue arose to be seen, along with the context in which they arose. This mean that it was possible to see the ways in, and the extent to, which each issue impacted upon shared understandings in the consortia studied. Adopting a grounded theory approach meant that the findings in this report are data-driven, in the sense that they emerged from the empirical research rather than being imposed upon the data in a top-down fashion.
The findings from these case studies are presented in the following three sections.

3 Communication practices in e-Science projects

This section presents an overview of the communication methods used in our case studies, and the circumstances under which they are used. It was found that members of the e-Science projects studied here employ a wide range of methods, including both face-to-face communication (such as meetings, workshops, presentations of work, and focus groups of end-users of a project's tools) and communication mediated via ICTs (such as email, Instant Messaging, telephones and teleconferencing, videoconferencing, wikis, project websites, and AccessGrid). This section will describe some of the communication patterns found in the case studies, and will explain why these patterns may have emerged. First, however, a brief overview will be given of one particularly significant ICT, AccessGrid: one feature of the e-Science vision was the use of AccessGrid as central in both supporting formalized meetings as well as fostering informal encounters between distributed project members through the creation of media spaces.

3.1 AccessGrid

AccessGrid was originally developed in response to the emergence of large-scale, distributed scientific projects (Stevens *et al.* 2003). It has been designed to enable audio and visual synchronous communication, as well as the sharing of objects (including texts, diagrams, animations, and PowerPoint presentations) (Childers *et al.* 2000). Furthermore, it is intended to be flexible in terms of the site configurations it allows, so that it can be used to link rooms containing many dozens of people or to link individual PCs (or to link such rooms with individual PCs), and is highly-scalable so it can allow up to 30-40 nodes to connect (Stevens *et al.* 2003). It can thus be seen that meetings might take place AccessGrid, but that it also might allow for the creation of shared media spaces allowing non-collocated individuals and teams to work together.

In addition to the basic AccessGrid tools, there are ways in its functionality can be extended. One way is that it allows for the creation of shared applications. Hasan *et al.* (2005) give an example of such an application that enables the creation, viewing and sharing of molecular images. The functionality of AccessGrid can also be extended is through the deployment of a system that allows for the recording of AccessGrid sessions so that they might be replayed at a later date. One such system that has been developed is Memetic (Buckingham Shum *et al.* 2006; see also Chernich *et al.* (2007) for details of another such system).

3.2 Communication patterns in e-Science projects

People wishing to communicate must balance a number of factors when choosing their method of communication. In particular, these include the outcomes that they intend to achieve as a result of the instance of communication, the nature of the work that might be involved in achieving this, and the costs or difficulties of employing particular methods of communication. Conversely, the particular method of communication chosen can constrain the work that is carried out during the communication due to the particular affordances and practical limitations of the chosen method. (Olson & Olson 2000). Thus, it can be seen that the method of communication chosen and the work conducted during a communication co-emerge, in the sense that one influences but does not completely determine the other, and vice versa.

3.2.1 Tightly-coupled and loosely-coupled work

Those working in an e-Science project need to perform a variety of collaborative tasks, and different methods of communication may be better or less-well suited to different tasks. Olson & Olson (2000) referred to the notion of *coupling* to distinguish between different types of tasks in collaborative work. *Tightly-coupled* work is work that requires colleagues to become deeply involved in collaboration with each other, and is usually non-routine. *Loosely-coupled* refers to work where an individual is less dependent on others, and is generally less ambiguous than tightly-coupled work (i.e. those conducting the work have a firm idea of what they are doing without needing to refer to others) and more routine[8]. Tightly-coupled work by its nature usually requires communication that is complex, frequent, permits information to be transmitted across multiple streams, and allows for rapid feedback; by contrast, loosely-coupled work generally requires less complex or less frequent communication.

[8] In reality, this is not a binary classification of tasks: work can vary in terms of the coupling involved along a continuum from very-loosely to very-tightly coupled.

3.2.2 Factors in determining the choice of communication method

Clark & Brennan (1991) identified a number of aspects of face-to-face communication that make it particularly useful for tightly-coupled work because they allow for rich and rapid flows of communication. These include[9]:

- **Co-presence.** All parties involved in the communication are in the same location and can see what the other parties are doing, which allows for easy integration of physical referents into the flow of communication;
- **Visibility.** All parties can see each other, which allows for the transmission of visual cues. Such cues might include body language and facial expressions, which can convey a great deal of information, for instance if the listener does not feel they understand or if they do not approve of what is being said, or if the speaker is being humorous;
- **Audibility.** All parties can hear each other, which allows for the transmission of audio cues. As with visible cues, these cues can convey a great deal of expression and meaning; and
- **Co-temporality.** Each party receives the utterance of another party as soon as it is produced. This enables rapid feedback, and allows for conversations to progress rapidly to greater levels of detail.

Many of the above aspects are often not afforded by ICTs, which might compromise the extent to which they can mediate tightly-coupled work. Common to all such ICTs is that they do not afford co-presence, and as discussed in the Introduction, even the more sophisticated ICTs (such as videoconferencing or media spaces) do not fully permit the seamless integration of physical referents into communication flows. A number of ICTs do not support both audibility and visibility (Instant Messaging, email, wikis, and project websites), whilst telephones and teleconferencing do not afford visibility.

ICTs can be further broken down into two groups: those which are *synchronous*, i.e. all parties involved in the communication are present at the same time (these include Instant Messaging, telephones and teleconferencing, videoconferencing); and those which are *asynchronous*, i.e. parties involved in the communication do not need to be present at the same time (these include email, wikis, and project websites). It should be noted that synchronous methods afford co-temporality, whilst asynchronous methods do not.

However, although ICTs might not afford communication as rich as face-to-face communication in the sense discussed above, it should also be noted that Clark and Brennan (1991) identified two features that are afforded by some ICTs that can help to make communication richer, and may therefore allow the work to be conducted by them to be more tightly-coupled:

- **Reviewability.** All parties are able to access previous utterances in the communication; and
- **Revisability.** All parties are able to revise and edit an utterance before they send it to other parties. For instance, this helps an individual to ensure that their message is framed in such a way that it is comprehensible to other parties.

[9] It should be noted here that many of these aspects are not binary, but instead are continua: for instance, as was discussed in Section 1, there may be ways to improve the extent of co-presence, even when colleagues are non-collocated. For instance, it might be possible to increase an individual's awareness of colleagues in other locations, and some success has also been reported in improving the extent to which physical referents can be integrated into communication flows in media spaces (Kirk *et al.* 2007).

These features are generally restricted to text-based or asynchronous methods of communication, such as Instant Messaging, email, wikis and project websites. As discussed in Section 3.1, it may also be possible to review and refer communication on AccessGrid due to some applications that have been developed.

Thus, it can be seen that different methods of communication vary in the extent to which they can support tightly-coupled work. It would seem that face-to-face communication is generally better-able to do so than ICT-mediated communication. However, ICTs vary in terms of how sophisticated they are in this respect. For instance, some allow for information to be communicated over more channels than others, some are better able to create some elements of co-presence even when colleagues are non-collocated, and some allow for rapid feedback and two-way communication. However, the extent to which a particular method of communication is able to support a particular type of work is not the only important factor in its selection.

Different methods of communication vary in expense, and the effort required in using them. For instance, whilst face-to-face communication may be highly-desirable, its frequent use for meetings of distributed members of e-Science projects is prohibitively costly in terms of travel expenses and is also very time-consuming, and thus might in many instances be replaced by ICT-mediated communication. Furthermore, whilst some ICTs may be more sophisticated in terms of their affordances for supporting more tightly-coupled work than others, it is often the case that less sophisticated technologies are more lightweight in terms of the effort and technical expertise required to set them up and run them and in terms of the facilities they required. For instance, AccessGrid requires a great deal of expertise to run (and, indeed, at many sites, there is a person whose job it is to provide this), and also requires video screens, microphones, and video cameras. By contrast, telephones need very little specialist expertise to use (especially as people will be very experienced with using them), and does not require access to a great deal of technology.

Thus, it can be seen that a trade-off might occur between the extent to which a communication method can support tightly-coupled work, and the cost and effort required to use that particular method. It could therefore be supposed that in e-Science projects, the use methods such as face-to-face communication and more sophisticated ICTs tends to be restricted to tightly-coupled work, whilst those seeking to perform loosely-coupled work choose less sophisticated ICTs. This has indeed been observed in our case studies, as the next section will discuss.

3.2.3 Supporting collaborative e-Science tasks

This section describes some of the communication practices and patterns that have occurred within our case studies. In particular, it presents three instances of project work, and discusses how communication patterns developed to support each of these instances. This section is not designed to be comprehensive with regard to all the collaborative work undertaken in these projects, nor to give a complete account of all communication practices, but rather to highlight how some of the work of e-Science projects and the communication methods used to support this work have co-emerged. For an overview of all the communication methods reported by our interviewees, please see Appendix B.

3.2.3.1 Tightly-coupled work: Writing the initial project proposal

The writing of the initial project proposal is a critical piece of work, both because it needs to be sufficiently detailed and robust to secure funding for the project, and because it provides a blueprint for the future operation of the project (Warr *et al.* 2007b). Amongst other things, it involves determining the project's overall visions and goals (for instance, in terms of the particular scientists for whom the project will build tools) and how they will be achieved, delineating the roles of the various partner institutions and how these roles will fit together, deciding staffing requirements, drawing up timetables, and budgeting.

This is very tightly-coupled work, typically involving senior representatives of all the partner institutions. Those involved are very dependent on each other, for instance, because each has expertise and knowledge regarding their own institutions (such as its particular goals, hierarchical structures, and the characteristics of its members) that is critical for writing a proposal and which the others involved could not be expected to have. Furthermore, specifying a project proposal is certainly a non-routine task, and indeed can be very ambiguous, especially as it can involve designing a large project from rather vague initial ideas. Finally, because the task of specifying a project proposal is so vast, but must be completed by deadlines specified by funding bodies, rapid feedback is essential.

This would suggest that the bulk of such work might be conducted using intensive face-to-face communication, and this is what occurred in practice in our case studies. For example, in the case described in the following quotation from one of our interviews, those involved in writing the proposal conducted went away on a retreat together to conduct most of this work:

> *"So we all went to some big house somewhere, in the middle of nowhere, and we spent the week just talking a lot, and writing a lot, and that's how we came up with the proposal"* Interview 01/i-a

In addition to allowing for much face-to-face communication, going on a retreat suggests that the work was very intensive indeed, allowing for long meetings and discussions, and few interruptions.

A similar level of intensity was found in other case studies. For instance, the interviewee who gave the following quotation reports how representatives from partner institutions came and stayed at their house, where the writing of the proposal was conducted:

> *"There were the three of us, so two of them came here and moved into my house for three weeks, and we discussed every aspect of the project intensively. We worked long into the night, every night…and we came up with lash-ups – this is what we're going to build in the project, this is who we're designing for"* Interview 01/i-a

This quotation also highlights the important role of co-presence in this collaborative work, because the lash-ups provided a shared referent for those involved to communicate and discuss complex ideas about what exactly it was that the project should aim to achieve.

Thus, we have seen one example here of how some very-tightly coupled work was conducted by intensive face-to-face communication. Other instances of tightly-coupled work supported by face-to-face communication from our case studies include: ensuring that all project members have a fine-grained understanding of the project's overall visions and how their work fits into these (supported by an initial kick-off meeting and annual meetings attended in person by all project members); disciplinary meetings, whereby the actions of individual project memberd need to be clearly established; and ensuring that project members are able to integrate their work effectively with the work of non-collocated colleagues, which requires detailed discussions and a great deal of feedback (supported by visits to colleagues at other sites, workshops etc.).

3.2.3.2 Loosely-coupled work: Keeping track the day-to-day work of the project

An important task in e-Science projects is the monitoring of the day-to-day work of project members by Project Managers or work group leaders to ensure that members are progressing well and to identify any potential difficulties as they arise. It is also an important task for project members to stay informed about the progress of their immediate colleagues (i.e. the project members with whom they work most closely or upon whom they are most dependent).

If project members are clear about the work and roles that have been assigned to them, how their work fits in with the work of other project members, then these tasks are likely to be straightforward and fairly routine and are unlikely to involve detailed discussions. Thus, these tasks seem to be fairly loosely-coupled work[10].

Given the costs and effort involved in face-to-face communication and more sophisticated ICTs, it is therefore to be expected that such work is usually conducted using more lightweight ICTs. It was consistently reported in our interviews across the range of case studies that such work was accomplished in regular (usually daily or weekly) meetings, thus underlying the extent to which it is routine, employing easy-to-use ICTs such as Instant Messaging, and Skype teleconferencing. For example:

> *"We have daily Skype messaging chats every day with [project members at the other site] at 5pm"* Interview 01/iv-a

3.2.3.3 A mixture of communication methods: Gathering user requirements

The overriding goals of e-Science projects are to produce tools and software to support the work of particular domains of scientists. It is thus vitally important that the developers working in e-Science projects gain a fine-grained understanding of the requirements of these scientists. This is tightly-coupled work, because it is non-routine, developers may begin with a very ambiguous notion of what the users' requirements might be and how to proceed with eliciting these, and intensive interactions with (and rapid feedback from) users on the part of developers is essential if these developers are to gain a rich comprehension of domain scientists' requirements.

It might therefore be supposed that requirements elicitation takes place using face-to-face communication, and certainly such methods form a fundamental part of this[11]. However, because such communication can be difficult and expensive to set up, much of it was often conducted at the start of a project. Even in the cases where the elicitation of requirements is regarded as an on-going process, an end-user may only seldomly be able to meet with developers on a face-to-face basis.

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[10] However, it should be noted that once a problem has been detected, this can turn into tightly-coupled work as resolving it is likely to be a non-routine task, involving getting more details about the problem and attempting to resolve it.

[11] Such methods include interviews with domain scientists, in situ observations of their work, workshops presenting prototypes for scientists to try, sessions teaching users how to operate the tools, or having some users collocated with developers.

However, many user requirements may emerge over time, rather than being apparent at the beginning of a project, as users develop a more complex understanding of how the tools under development might be integrated into their existing work practices and become more aware of these tools' shortcomings. Thus, it is useful to provide channels of communication other than formalized requirements gathering activities for end-users to give feedback or express their requirements to developers. In a number of our case studies, this has occurred, for example:

> "*We also have our mailing lists, and these are lists where the users of our software, they post problems they might be having with the software, they write what they would like to see in future releases, they tell us about their experiences"* Interview 01/v-a

Here, end-users can alert developers to new requirements they may have. Although email may not be seen as supporting tightly-coupled work, it does allow for detailed textual descriptions of the requirement to be given, along with picture files (such as screen shots or diagrams) to show the requirement visually. Furthermore, it also alerts developers to new requirements who may then use this as a basis for more tightly-coupled work in incorporating this requirement into the tool, using more sophisticated ICT communication methods or even face-to-face communication to discuss this requirement with users, as the following quotation illustrates:

> *"So I might get to know one of the users via the mailing lists, say they write something interesting on the mailing list, I might try and add them to my Skype list to talk to them more, and then sometimes after that we even get them to come and visit us"* Interview 01/vii-a

Thus, it can be seen that some collaborative tasks in e-Science projects are performed using a variety of complementary communication methods. For instance, here, although requirements elicitation is tightly-coupled work, time and cost can constrain the use of communication methods to adequately perform this work at all times. Nevertheless, an alternative method was provided which, although not itself fully-supportive of the nature of the work, helped in conducting the work.

3.3 Conclusions

This section has discussed patterns of communication within our case studies. In particular, it has related different aspects of the collaborative work of these case studies to the communication practices and methods that were selected to support this work. For example, face-to-face communication has been chosen when the work is very tightly-coupled, complex and non-routine (for instance, in writing a project's initial proposal). On the other hand, less-sophisticated ICTs have generally been selected to support more routine, less-intensive work (such as day-to-day monitoring of work groups). Additionally, we have also seen that some instances of work are carried out using a combination of methods that complement each other, some of which may be adopted in response to the emergence of new aspects of the task: for instance, here we discussed the generally tightly-coupled task of eliciting requirements, much of which was carried out using face-to-face methods, but was also complemented by mailing lists as new, previously-unanticipated user requirements emerged.

Nonetheless, despite the plethora of methods available to support collaborative work amongst non-collocated members of e-Science projects and the ways in which these methods may complement each other, there were still a number of important issues encountered by our interviewees that have impacted upon effective communication flows, and it is to these that this report now turns.

4 Findings from the case studies: Issues relating to communication technologies

The following two sections present challenges to seamless communication that have been found in our case studies. This section describes those that stem from the ICTs that have been used in communication between non-collocated personnel. This is a list of these challenges:

1) Controlling meetings conducted via ICTs;
2) Shared material objects in ICT-mediated communication
3) Access to ICTs
4) Coordinating ICT-mediated meetings
5) Lack of response to emails

The next section focuses instead on challenges which are not directly related to ICTs.

4.1 Controlling meetings conducted via ICTs

It was widely-reported in our interviews that many difficulties were experienced with the control of meetings that were conducted using ICT methods, and the loss of cues (audio and/or visual) that can result from using ICT methods may have contributed to this. In particular, interviewees reported difficulties in keeping participants focussed on the issue-at-hand rather than disengaging from the meeting or veering off onto other topics, ensuring participants continued to afford the due level of seriousness to the meeting, preventing discussions from descending into chaos, and bringing discussions and decision-making processes to a resolution. Each of these difficulties will be discussed in turn below.

4.1.1 Keeping participants in a meeting focussed on the issue-at-hand

Some interviewees reported problems with keeping participants in a meeting focussed on the particular issue being discussed, and this occurred in a number of ways. One issue relating to this is that participants were sometimes easily distracted, with their attention being drawn away from the meeting, as the following quotation suggests:

> *"People disengage from chat sessions because they've picked up the phone or just read an email"* Interview 03/i-a

This quotation suggests two ways in which an absence of visual cues in some ICT-mediated communication can result in participants' attention being drawn away from a meeting. The first is that participants in the meeting may be more easily distracted, because they are receiving information from the meeting over fewer channels. Their visual attention is not necessarily fully on the meeting, and, for instance, a new email can catch their eye, drawing them away from the meeting. The second is that there is no way for others to check that somebody is still engaged with a meeting. For instance, if a meeting is being carried out via Instant Messaging, there may be no way of seeing whether a participant is taking a phone call, or even whether they are still present at their computer. This can impact negatively upon effective communication in a number of ways. In particular, the person who gets distracted is unlikely to receive all of the information that others involved in the communication intend to transmit to them.

However, even in cases where people's attention to the meeting is maintained, there have still been difficulties regarding keeping meetings focussed, with participants sometimes ending up discussing topics other than the intended topic:

> *"Some people are very ill-disciplined in Instant Messaging…some people will meander off…Some members of the team will make good technical comments but when you read it, you feel that they're just drifting off into another discussion"* Interview 03/i-a

Here, it seems that there was a snowball effect: somebody would make an utterance that was about a topic other than the one under discussion, and others would respond to this utterance, so that the conversation drifted off away from the issue-at-hand.

A final difficulty encountered in keeping participants focused has been maintaining a tone of seriousness in discussions, as sometimes there is a tendency for participants in a discussion to make humorous remarks:

> *"You can't stop people from putting in jokes…sometimes this gets mixed up with what I am trying to achieve…people are trying to make others laugh rather than make decisions"* Interview 03/i-a

Here, humorous comments appear to have hampered discussions in a number of ways. One is that they delayed the resolution of a discussion because people were too busy making humorous comments rather than making substantive contributions to the discussion. They may also have created a lighter atmosphere, so that participants found it harder to grasp the seriousness of the issue they were discussing, and hence the need to resolve it. Finally, some people may have been confused because they were not fully aware of which comments were humorous, and which were meant to be taken seriously.

An absence of visual and audio cues (as the communication took place via Instant Messaging) may have contributed to the occurrence of these last two problems: in the case of face-to-face communication, the tone of voice or a facial expression might signal disapproval on the part of the person in charge of the meeting to the initial off-topic utterance or to the humorous comment, thereby discouraging others from responding to this utterance or deterring others from making such utterances in the future. Furthermore, facial expressions, gestures, and tone of voice can be used to convey when a comment is humorous and not meant to be taken seriously: thus, an absence of visual and audio cues may have made it harder for others to detect when a comment was intended to be humorous.

4.1.2 Loss of sequentiality

A second challenge encountered by those chairing meetings conducted using Instant Messaging has been to prevent them from becoming chaotic, as the following quotation illustrates:

> *"IM chat can be difficult, one person might be typing and posting loads of messages and people then respond to an earlier message, so it can get out of sequence…you're falling over each other"* Interview 04/i-a

Here, a loss of sequentiality is reported in IM conversations. Sequentiality plays an important role in effective communication, because it enables participants to follow the thread of the conversation, for instance because it is clear that somebody's utterance is usually a response to the directly preceding utterance, and also helps to keep a conversation on a single subject, rather than splintering into a number of simultaneous conversations about different subjects.

Such a loss of sequentiality might be promoted by an absence of visual cues in IM conversations, as the following quotation suggests:

"In face-to-face communication, you could see when someone was about to talk, for instance they would move their body forwards or open their mouths" Interview 04/i-a

Such visual cues might help preserve sequentiality in face-to-face communication for a number of reasons. One is that it allows others to see when an individual wishes to speak, and may therefore remain silent, whereas in the case of IM, they may not be able to see that somebody else wishes to contribute until that person has actually posted their message. Another reason is that the presence of visual cues can help the person chairing the meeting to tell if somebody is seeking to speak out of turn, and they might be able to prevent this from happening, for instance by a hand gesture or by audibly stating the name of the person whose turn it is in order to make it clear that it is their turn to speak.

4.1.3 Resolving meetings and decision-making processes

A common complaint amongst interviewees was that, whilst face-to-face decision-making often achieved resolution after a limited period of time, virtual decision-making would sometimes prove interminable:

"People were only meeting virtually so things would drag on. People would treat the outcomes of virtual meetings differently to those of face-to-face meetings" Interview 03/i-a

In particular, such meetings often seemed to drag on in instances where decisions needed to be made:

"Sometimes I think it's easy to get paralysed by analysis paralysis…I felt as though sometimes we would have Skype chats that would go on for two hours and then at the end of that, we'd say we need another Skype chat the next day and so on, and so we'd discuss one particular thing for about five or six hours in different Skype chats cumulatively" Interview 01/iv-a

Visual and audio cues might help with the resolution of discussions in a number of ways. One is that visual cues can help to indicate whether agreements have been reached by glancing at people (for instance, this can be gauged from somebody's body language, such as whether they are nodding or shaking their head when somebody else is speaking) (de Rooij *et al.* 2007; Olson & Olson 2000), and somebody chairing a discussion is better able to see whether a majority of discussants – even those who do not speak in the discussion - are in broad agreement about an issue. By contrast, when such cues are missing, it can be difficult to assess to what extent discussants agree.

Even in cases where broad agreement has not yet been reached, visual cues can also be useful to resolve discussions, because they can be used to promote agreement. In face-to-face communication, an individual can look another directly in the eye and this has been found to promote agreement between the two (Olson & Teasley 1996). This is because, even if two individuals are in general disagreement, there may be aspects of the issue where there is agreement and eye contact can help to establish which these are, providing a basis for building further agreement.

Finally, visual cues can also help to resolve discussions by discouraging those who might speak after broad agreement has been reached (thereby contributing further to "analysis paralysis"). For instance, others might use body language or facial expressions to express disapproval of further, fruitless, discussion, or they may perform other visual acts, such as gathering papers together to leave, to indicate that they feel the discussion is drawing to a close.

This issue can impact upon communication flows in a number of ways. One is that by spending a long time discussing one topic, the amount of time available for discussing others is reduced, meaning that these other decisions may remain unresolved. This can be particularly frustrating for project members if, for example, they need a particular decision to be made before they can proceed with their work (for instance, a developer may have a list of features that they have been requested to incorporate into the software they are developing, and they may be awaiting instruction regarding which features they should prioritise).

Additionally, a failure to draw discussions to a close can impact upon communication flows is that it may act as a disincentive for individuals to raise issues at a meeting, because they may feel it is futile to do so as they are unlikely to be resolved or because they may find lengthy discussions quite tiresome and therefore wish to avoid them.

A final impact is that, as the second quotation in this section mentions, a failure to resolve a decision-making process in a meeting may mean having to schedule subsequent meetings in order to resolve the issue, but such scheduling may involve the coordination of a number of geographically-dispersed people, which may be very difficult and therefore lead to delays in resolving the issues under discussion (see Section 4.4).

4.2 Shared material objects in ICT-mediated communication

As was discussed in the Introduction, a beneficial feature of face-to-face communication is that it allows for the sharing and physical reference of objects. In the case of e-Science projects, such objects might include prototypes of the software being developed, lines of computer code, mock-ups (for instance of a user interface for the tools that are being developed), and video (for instance scientists may be filmed at work in order that developers might understand the work practices of the users for whom they are designing).

The sharing of such objects is particularly important to an e-Science project's goal of producing tools that scientists find highly usable, because it should help to keep the design of these tools very firmly grounded in the real practices, needs and experiences of users[12]. For instance, sharing prototypes or mock-ups with end-users can enable these users to gain a better understanding of what is actually under development and thus to evaluate how well they feel it will support their work. Furthermore, they can help these end-users to communicate their needs in a more fine-grained manner, because they can point to particular features of these mock-ups or prototypes to explain how such features might support their work.

Difficulties were reported by our interviewees in using shared objects in communication, even when all parties involved have access to the object, as the following interview quotation illustrates:

[12] The important role played in the production of usable e-Science applications by keeping design work grounded in user requirements is argued in Warr *et al.* (2007a). It is also illustrated by the following extract from our interviews:

> *"You need to stress to developers that they are designing for end-users. They need to understand that they are developing in the concrete and not in the abstract. If you design in the abstract then you might build something fancy, but it does not mean it will be suitable for the end-users.*

> *"It was difficult at times to see what somebody was talking about…for instance, if someone was sharing a piece of code, if someone is describing it or working through it, it would often be that during the conference call someone would say "Could you tell me where that is? Where are we looking?" The person sometimes used the mouse pointer to highlight this, but sometimes more support was needed…it sometimes interrupted workflow"* Interview 04/i-a

These difficulties arise because they are not collocated, and may therefore not be able to indicate to other parties the particular aspect of the shared object to which they are referring. This can mean the loss of some of the advantages mentioned above that result from the object being a shared referent, as the following quotation from our interviews illustrates:

4.3 Access to ICTs

There are a number of issues regarding access to particular ICTs that might impact upon communication flow and that have been brought up in the interviews from our case studies. Two in particular are highlighted in this section. The first is that technical expertise is required to set up and run particular ICTs, but such expertise may be lacking in some or all of the sites that are seeking to use this ICT. In the case of some ICTs, the level of technical knowhow required to set them up may not be possessed by many of those wishing to use them. This is illustrated by the following quotation:

> *"Many sites had AccessGrid, but had poor technical support so did not use it"* Interview 04/i-a

The second is that there may be unequal degrees of access to ICTs across the sites wishing to communicate (for instance, a particular site may lack facilities for communication present at other sites),as the following quotation suggests:

> *"We wanted to have [medical practitioners from a partner institution] to be part of [the teleconferences], but it was very hard to enable the software to do this due to various security issues, e.g. with the software"* Interview 04/i-a

There are at least two major ways in which these issues can impact upon effective communication flows in a project. The first is that it can lead to the use of ICTs that do not afford such rich communication amongst project participants. For instance, other ICTs, such as Skype, were used instead. The second impact is that a lack of technical support can lead to certain groups or individuals being excluded from meetings if, at their particular site, there is not the expertise to support the ICT being used for the meeting. This can lead to them missing out on learning important knowledge or information, or on participating in decision-making.

4.4 Coordinating ICT-mediated meetings

In the Introduction, the important role that opportunistic and informal encounters play in collaborative work was described. Some of our interviewees reported that, despite using ICTs designed to encourage such meetings, they happened infrequently between non-collocated personnel. As a result, it was felt that there was a greater need to schedule meetings between geographically-remote project members (either meetings between two or a few individuals or larger meetings). However, our interviewees also reported difficulties in scheduling meetings.

As was discussed in the Introduction, it seems that spontaneous meetings of distributed project members might be encouraged by using a technology that enables people to check with a glance whether others are free and does not entail setting up when a meeting is to take place. In one of the case studies, such a piece of videoconferencing software was used, which enabled people to sit in a "virtual room" where others could see that they were available for spontaneous communication and could contact them easily. However, as the following quotation suggests, spontaneous communication still did not occur:

> *"The vision was that [the software] could be used at any time, people could sit in a 'virtual room' and then interactions could happen whenever, but in reality that never happened…There was one instance where someone was sitting in a room…but they were there on their own"* Interview 03/i-a

It therefore seems that meetings between distributed project members should be scheduled in advance, or indeed at regular times (for instance, daily, weekly, monthly etc.) if they are to occur at all. There are, however, a number of challenges in doing so. One is that it is difficult to find a time that is convenient for all those who need to be involved. This is difficult because it requires communication from project members from different locations. Further complications arise because these meetings may need to fit in with each of the different routines or schedules of the institutions where the members work.

Secondly, the scheduling of regular meetings involving different groups of project members may result in an overload, as the following quotation illustrates:

> *"I have too many meetings to attend, so I can't make them all"* Interview 01/i-a

As a result, it can mean that project members might not attend all the meetings they are expected to attend which can mean they miss out on hearing important pieces of information for their work, or communicating information they hold to colleagues who might need it. It can also result in communication difficulties in future, because Person A may not realise that Person B does not have a particular piece of information because Person A assumes that Person B was at a particular meeting where the information was shared or discussed whereas Person B was, in fact, absent. Finally, a project member may unfairly gain a reputation as an unreliable attendee at meetings if they are expected to attend so many meetings that they cannot attend them all.

4.5 Lack of response to emails

Some of our interviewees reported encountering difficulties in securing responses from other project members (particularly senior project staff such as Principal Investigators (PIs) and Project Managers) to emails. The senior members are often extremely busy, and are in contact with a vast number of people, because they need to coordinate activities both at their own institution and with partner institutions, pursue funding applications, and promote their project and the tools it is producing to, for instance, potential groups of end users. One result of this is that they frequently receive a vast number of emails:

> *"I receive over 200 non-spam emails per day"* Interview 01/i-a

This can often mean they are not able to reply to all emails, even in the cases where it is highly important to the sender that they receive a response. In such cases, the recipient may not realise the importance to the sender of the email. The following quotation illustrates the problem:

> *"The communication at the Principal Investigator level was the main problem, I am really struggling… [the PI] is no longer replying to my emails."* Interview 05/i-a

In particular, this issue has been found to impede communication flows in two ways in our case studies. Firstly, it can create tensions between project partners. For instance, industrial partners are often used to finding that emails they send are responded to fairly rapidly, but it has been reported in our case studies that academics may take some time to reply to an email, if at all, which can cause industrial partners to question the commitment of academic partners, as the following quotation from our interviews illustrates:

> *"Academics don't reply to emails straightaway, and this comes across as very unprofessional to those working in industry"* Interview 02/iii-a

The second is that it can cause delays in the flow of information, meaning that important information may not be communicated to those who need it in a timely manner:

> *"At the moment, I need [the PI] to give me data and to do this, I have to visit them as I am getting no reply to my emails. This is slowing me down"* Interview 05/i-a

5 Findings from the case studies: Other issues impacting upon communication flows

As well as necessitating the frequent use of ICTs, the distributed nature of e-Science projects can give rise to a number of other issues relating to effective communication flows within such projects. This section presents some of these issues that have arisen in our case studies. This is a list of these issues:

1) Effect of unshared work context;
2) Incentives for communication;
3) Non-collocated project members not knowing each other very well;
4) Organizational structures;
5) Uneven distribution of knowledge; and
6) Communication across timezones.

It should be noticed that some of these issues are exacerbated by the limitations of ICTs discussed in Section 4: how this occurs will be explained below, where appropriate.

5.1 Effect of unshared work context

One impact that the multi-institutional nature of e-Science projects can have upon effective communication flows is that it means that project members may have to communicate with those who work in very different contexts. There are many ways in which such contexts can differ. One is that there are differences in the work practices and methods employed at different sites. These include the model of software development that is used (for instance, a Waterfall method as opposed to more agile methods (Goguen *et al.* 1992), and the way in which decision-making processes (such as who is involved and the nature of the contribution they are allowed to make, and how such processes are involved). There are also significant differences between the work carried out in different scientific disciplines, regarding the phenomena under investigation, and the experimental methods and modes of reasoning employed to arrive at scientific knowledge, as well as there being differences in the extent to which scientists in different disciplines collaborate and the typical size of such collaborations (Knorr-Cetina 1999).

There may also be substantial differences in the technologies and technical support available at different sites, which might constrain the work that can be carried out at these different sites (Hinds & Weisband 2003). There are also likely to be substantial differences in the goals that the various institutions possess and are seeking to pursue through their involvement in the project, for instance a commercial company's overriding goal is likely to be the production of saleable goods, whereas an academic institution is driven by the need to secure funding for future research. The hierarchies and communication systems within these institutions are then likely to be organized in a way that it is thought best allows an institution to pursue its own particular goals.

Furthermore, because project members in different work contexts are not collocated, it is very difficult for them to learn about their colleagues' contexts: indeed, it has been observed in the literature that people may not be aware of the extent to which these contexts may vary, instead assuming that they are fairly similar, and this means they tend not to communicate important information about their own contexts to others (Cramton 2001).

The major impact of unshared work contexts on communication is the extent to which can individuals make themselves and their ideas (for instance, regarding work plans, goals and visions of the project, and the features of the tools and software under development) understood to others: as a result, this issue is treated in more detail (along with recommendations for addressing it) in another report for this project, *Shared Understanding in e-Science Projects* (Darch *et al.* 2010).

5.2 Incentives to communicate

It has also been found that the incentive and career structures in which stakeholders are embedded can impact upon communication flows. For instance, different stakeholders may be competitors, for instance different industrial partners may be commercial rivals and research groups in the same field may be in competition for funding, and may therefore withhold information from their partners. Additionally, project members will be pursuing individual career goals, in addition to working towards project goals. This can impede information flows amongst project members as they orient their work towards pursuing their own particular career goals (Spencer *et al.* 2008). For instance, doctoral students may be more concerned with presenting their work in such a way that helps to establish them as researchers in their field (e.g. the production of their thesis or journal articles) rather than in a way that is useful for their colleagues on the project.

This issue is also dealt with more thoroughly in Darch *et al.* (2010).

5.3 Non-collocated project members not knowing each other

When participants are not co-located, there are fewer opportunities to build personal rapport with other project members (Hinds & Weisband 2003). As well as sharing knowledge regarding the project, people who are co-located are more likely to develop rapport through learning personal details about each other (e.g. family life, interests outside of work, holiday plans), and socializing together.

The level of personal rapport between people can impact upon their communication practices, as this quotation from one of our interviews suggests:

> *"I know [the team at another institution] well, so we often speak on the phone instead of emails"* Interview 02/i-a

Here, a greater personal rapport with a particular group of individuals meant that the interviewee felt comfortable contacting them via telephone, rather than relying on emailing, which might have been the method of communication otherwise. In other words, the choice of communication medium can be strongly influenced by the relationship between the communicators, with a medium that affords richer communication being more likely to be selected when they know each other better.

5.4 Organizational structures

Different institutions involved in an e-Science project may have very different organizational structures and hierarchies. There may therefore be differences between project members in terms of what they are used to in terms of hierarchies and how authority is exercised. Furthermore, project members may feel the need to respect and conform to the existing hierarchies within their home institutions in addition to the project's structures and lines of authority. These factors can give rise to a number of issues that can impede the effective flow of communication within a project.

The first factor mentioned, namely the hierarchies that project members are used to in the context of their home institution, can lead to differences in communication practices between different groups of project stakeholders, as the following quotation illustrates (see also Gibson & Manuel (2003)):

> *"[the other institution] are not used to the same level of communication than we are. They're much more structured, they have a much more organizational/managerial style where a boss tells someone to do something, he goes and does it and then reports back to the boss, whereas we are more about…group chats…they weren't used to the same level of Skype chats every day, tel-cons regularly, and reporting and reprioritising"* Interview 01/iv-a

What is happening here is that there were disparities between the communication practices of two groups of stakeholders. One group came from an institution with a very structured hierarchy and clear lines of authority, and this impacted upon their communication practices in the sense that communication tended to flow in a more vertical fashion from someone higher up in the hierarchy to those underneath (e.g. instructions regarding action to be taken) and vice versa (e.g. reporting back when this action had been taken). Furthermore, those lower down in the hierarchy were often not really in a position to question or criticise what was being communicated to them. In contrast, the other group were used to a flatter hierarchy, which had given rise to more two-way flows of communication with greater levels of questioning and feedback.

A diversity of hierarchies can also impact on communication flow in the sense that they can impede the flows of communication between groups. This is because both groups may feel obliged to respect the lines of authority in their own institutions, as the following two quotations illustrate:

> *"If the project leader wasn't there, the people underneath would be waiting for an answer from them"* Interview 01/iii-a

And:

> *"In [a previous project], people on the ground in one part of the project didn't have a direct line with people on the ground in another part of the project. In order to communicate, they had to go through their managers, although the people higher up don't really understand what's going on"* Interview 06/i-a

In these instances, people on the ground in one institution wishing to communicate with people on the ground in a partner institution tended not to communicate directly, but rather to communicate with their manager, who would then communicate with the manager in the partner institution, who would then communicate with the people below them in that institution's hierarchy. These quotations suggest two ways in particular how this impedes communication. The first is that it can slow down communication. Secondly, it can lead to greater misunderstandings because, as suggested by the quotation, the managers may be remote from the context in which the utterances are originally produced and the context in which the intended end recipient will interpret these, which can promote misunderstandings (see Section 5.1).

5.5 Uneven distribution of knowledge

Information and knowledge regarding all aspects of an e-Science project can be very unevenly-distributed across project members and sites. This is an issue common to all collaborative projects (Stewart & Stasser 1995), but there are two reasons in particular that mean e-Science projects may be more susceptible to this issue arising than in projects where all participants are collocated. The first reason is that information about the project may be more unevenly-distributed to begin with as a result of project members not being collocated and working in very different contexts. Participants may know very little about their colleagues at partner institutions (see Section 5.3) or about the work contexts in which they work (see Section 5.1); on the other hand, they may be very familiar indeed with the work context and project members at their home institution.

Secondly, the use of ICT-mediated communication may result in information being more unevenly-distributed, and less likely to be transmitted to those who may find it useful, as the following quotation illustrates:

> *"There would be times when misunderstandings developed between people during a conference call...if they were not able to resolve this misunderstanding, and if they are not able to do this, they may use, say, email to follow up. Because email is just between two people, then the other people in the conference call are missing out on that information"* Interview 04/i-a

Certainly, the issue of unevenly-distributed information can arise when all project members are collocated: those who are not part of face-to-face meetings or conversations may also miss out on the information and knowledge discussed therein. However, whilst somebody may overhear two people having a face-to-face conversation and might join in if they feel the conversation may be useful when they are collocated, they would not notice an email correspondence between two people.

5.6 Communication across time zones

A number of the projects studied for this report involve collaborations between institutions that are situated in different countries. In some of these cases, a project's main consortium involves international partners, whereas some other projects involve specific sub-projects where a group of project members work with partners based in other countries. One result of this is that different partners may be based in different time zones. It was found in the case studies that this can impact on communication in two particular ways.

The first is that a colleague may not be available when somebody wishes to speak with them because the working hours in one location may overlap only partially with the working hours in another location, as the following interview extract illustrates (see also Olson & Olson (2000) and Gluesing *et al.* (2003)):

> *"There is only a two to three hour slot in the afternoon to be able to talk to those in the US"* Interview 01/v-a

The impact of this is that communication flows can be slowed down considerably, leading in turn to the holding up of work because, for instance, an individual requires information or consent from somebody at another location in order to perform a task. This is discussed in the following interview extract:

> *"There was a time delay…that sometimes slowed us down….when we're working here, they're sleeping there, and if there's something and you want them to respond, you have to wait for the next day…It happened quite a lot, where we worked on something and we wanted to know, 'Is this OK?', and then you just have to wait at least a day for them"* Interview 01/iii-a

It could be supposed that this issue might be (partially) mitigated by employing communication technologies that enable project members to be reached outside of their office hours, for instance mobile phone technologies or the use of Instant Messaging when somebody is online at home. This can lead to some communication taking place, but not necessarily to the same extent as when all the parties involved are at work, as the following quotation describes:

> *"I can communicate with them on Skype or MSN if they need to talk at, say 9pm…if I'm at home in the evening and I'm not busy, then I can spare 10 minutes. If I'm very busy, then I'll say to put it in an email and I'll look at it tomorrow…my wife can complain"* Interview 01/vii-a

Here, there are clear constraints that are placed on the level of communication that can take place outside of the working hours of one of the parties involved, such as family commitments. It is also clear that, in the evenings, work is not the main priority of this interviewee because they state that they will only communicate with their colleagues if they are doing nothing else.

The second way in which time zone differences can impact upon communication is that the need to conduct meetings or other instances of communication may need to take place outside of normal working hours, and this in turn may influence the choice of communication technology used, as the following quotation illustrates:

> *"Using a telephone is good when the hours of meetings are outside of normal working hours, for instance at 7am or midnight, because a telephone doesn't require specialist support"* Interview 01/vii-a

As mentioned in Section 4.3, some communication technologies may require specialist expertise to ensure they work effectively, but they might not be available outside of normal working hours, leading to a choice of technology that does not require such support. A possible impact of such a choice is that it may lead to a flow of information that is less rich: in the example here, instead of the use of videoconferencing, communication takes place using telephones, which do not allow for visual cues to be used.

5.7 Language barriers

As mentioned in the previous section, a number of e-Science consortia involve partners in different countries. Furthermore, even in the case of projects whose institutional partners are all based in Britain, a project's team has a strongly international flavour, with members drawn from a number of different countries. Thus, there are often instances where communication is taking place between project members who do not share the same first language. In the cases studied here, the primary language in which the project work and communication are conducted is English. However, this is not the first language of many project members, and it has been found that this can impede communication in the projects studied here in two particular ways.

The first is that it can deter individuals from making contributions because they do not feel comfortable or confident in expressing themselves in a second language. This may be because they feel self-conscious when doing so, or because they are inhibited by the prospect of making errors (de Rooij *et al.* 2007). This is illustrated by an example from one of our interviews:

> *"There is a big language barrier there. I often think that when they participate in conference calls, they don't understand 50% of what's being said…one of the partners just kept quiet, he didn't say, 'can you repeat that?'…it wasn't for some time that we realised he was silent due to language barriers"* Interview 02/iv-a

Here, this individual's reticence impacted upon the flow of communication in a number of ways. One important way is that the individual did not share information that they held that other partners may not have known, for instance about the progress of their own work, their skills and competencies, and contextual circumstances that may have been impacting upon their work (for instance, whether they had other duties or work outside of the project that may have delayed their work or their access to the facilities necessary to conduct their work). Additionally, they may not have asked for clarifications or further information in order to advance their understandings of what was being communicated to them by others.

In the example given here, the problem was compounded further because it was not realised immediately that the individual's silence was due to the language barrier. As Cramton & Orvis (2003) have noted, an individual's silence can be interpreted by others in a number of ways. For instance, silence can be taken as indicating agreement with what has been said, or as signifying indifference or apathy.

The second way in which language issues can impact upon communication is, even where individuals are not deterred from communication, the flow of information is impeded by difficulties in translating and understanding meaning and sense, as the following quotation illustrates:

> *"There were a number of instances where people's first language weren't English…Sometimes there were breakdowns in communication because a mutual understanding wasn't being built between people"* Interview 02/iv-a

There are a number of ways in which such misunderstandings may arise (de Rooij *et al.* 2007). One is that inaccurate translations, whereby the understanding of the listener is different to the meaning that was intended to be conveyed by the speaker. For instance, in the case of information-sharing between two groups who have different first languages, this could arise where a message is formulated by one group in their own language, and then translated into the language of the other group. Secondly, simplifications, for instance a speaker may be unable to express themselves fully in the language of the listener and therefore may simplify the concept they are communicating or lose some of the nuance of their message. These simplifications can lead to a compromise in the richness of the information conveyed. Finally, communicating in a second language requires more effort, and this burden can deter people from communicating for longer periods of time, impact on the amount of information shared, and result in less willingness to express dissent or ask for clarification (Hinds & Weisband 2003).

6 Conclusions and Recommendations

In this report, we have seen that there are a raft of existing technologies that are used to support communication amongst non-collocated members of e-Science projects, and that they are often selected according to how well it is felt that they will support the intended purpose of a particular instance of communication. For instance, face-to-face communication is often used for tightly-coupled work, whilst lightweight and less-sophisticated ICT methods (such as Instant Messaging) tend to be employed to support loosely-coupled work. Furthermore, a variety of complementary methods are often used for a particular type of work.

Nevertheless, this report has found that a number of challenges still remain for establishing seamless distributed collaboration. Two (the effect of unshared work contexts and the effect of incentives on communication) are discussed in greater depth in another report for this project, *Shared Understandings in e-Science Projects* (Darch *et al.* 2010). The rest fall into two broad categories (although it should be noted that there is some overlap between the two). The first are largely related to the technologies used in ICT-mediated communication. These are:

- **Controlling meetings conducted via ICTs.** In particular, because ICTs often do not allow for the transmission of audio or visual cues, or transmit such cues poorly, interviewees reported difficulties with keeping meetings focussed on the issue-at-hand, preserving sequentiality, and resolving decision-making processes;
- **Shared material objects in ICT-mediated communication.** Some interviewees found it difficult to establish a shared frame of reference with others because they could not share material objects with them via ICTs, or found it difficult to highlight particular features of such objects to enrich communication;
- **Access to ICTs.** In particular, it was found that it was not possible to conduct meetings with some communication technologies because one (or more) of the sites involved did not have the appropriate expertise to set up and run the technology, or did not even possess the technology. This was particularly reported to be the case with AccessGrid;
- **Coordinating ICT-mediated meetings.** Although it was often hoped that meetings would occur spontaneously between non-collocated personnel, and that technology was provided with the intention of encouraging these, interviewees reported that this did not happen, and thus there was often a greater need to schedule formal meetings. However, this proved difficult due to the busy schedules

of many of the project members (especially senior personnel) and the challenges of coordinating meetings to fit the diverse timetables of the various partner institutions;

- **Lack of response to emails.** Interviewees reported particular difficulties in securing responses to emails from senior project staff, which sometimes resulted in delays in the sender receiving important information and some industrial partners, who are often used to receiving rapid responses, questioning the commitment of academic partners.

The second category comprises issues that arise from the very fact that e-Science projects are distributed. These issues are:

- **Non-collocated project members not knowing each other.** It was found in our case studies that the level of rapport between project members can impact upon the choice of communication technology used, with a higher level of rapport often leading to the use of a technology affording richer, more rapid, and thus more effective, communication. However, because e-Science projects are distributed, many of the project participants did not know their collocated colleagues.
- **Organizational structures.** Partner institutions in an e-Science project often have a diversity of. This has been found to lead to differences in communication practices between groups at different institutions, and also slower communication flows as some project members did not feel able to bypass their home institution's hierarchical structure to communicate directly with colleagues at partner institutions;
- **An uneven distribution of knowledge** amongst project members. Although a feature of most collaborative projects, this issue has proven particularly acute in the case of e-Science projects because project members at one site may know very little about colleagues at partner institutions and the contexts in which they work, and particular features of ICTs may further exacerbate the issue (for instance, because an email is only between two people, other parties may not have access to the information contained therein).
- **Communication across time zones.** Because projects often involve partners in different countries, colleagues may be working in different time zones. This can reduce the amount of time that project members may be able to communicate with each other, as their working hours may not fully overlap. Finally, this issue can also slow down the flow of information because, if a project member sends a request for information to a colleague outside of the colleague's working hours, they may have to wait until the next day to receive a response.
- **Language barriers.** E-Science projects frequently involve members whose first language is not English. Such individuals may feel inhibited from contributing at meetings, or may not fully understand what is being discusses. Furthermore, some interviewees reported that the use of ICTs exacerbated this issue, because they made it more difficult to realise that an individual was experiencing language issues.

There is a great deal of on-going research that is now looking into addressing some of these issues (those which are more technological-based), for instance in the cases of AccessGrid, although some of the results of this research is still waiting to be incorporated into products that can be used to support remote communication[13]. Other challenges may never be fully addressed

[13] Some examples of research into communication technologies include improving video services for AccessGrid to enable higher-quality images of participants in a meeting and better resolution of graphics for document-sharing (Han & Kim 2004). This should enhance participants' abilities to share and refer to objects (such as diagrams or documents) (see Section 6.2). Furthermore, this should help to improve the transmission of audio and visual cues, and thereby help to keep order in meetings because participants may be better able to see who is talking, who wishes

by technological developments, or at least not for the foreseeable future (Olson & Olson 2000). Some of these relate to the cosmopolitan nature of e-Science projects, for instance when international project partners are in different time zones. Unshared work contexts amongst non-collocated project members and such individuals not knowing each other very well at the start of the project are also challenges that will always require a particular effort to overcome, whatever technology becomes available.

In the cases of both the technological and non-technological challenges raised in this report, therefore, there are recommendations which can be made for the use of existing communication technologies. The first two recommendations are designed to foster a greater awareness amongst project members of their colleagues at other sites, and the contexts in which they work. This is particularly important for making project members aware of the communication facilities and technical support available at each site (see Section 4.3), developing rapport between non-collocated project members (see Section 5.3), and for encouraging members in different institutions to see themselves as members of the same team, thus overcoming some of the organizational issues discussed in Section 5.4.

The next recommendations regard the organization and conduct of ICT-mediated meetings. Section 4.4 discussed the need to, and challenges of, scheduling regular meetings amongst non-collocated personnel, whilst Section 4.1 highlighted the need to improve the quality of ICT-mediated meetings for all participants. It is important to ensure that participants in a meeting who have information or knowledge that is useful for others are able to share it, that they do not miss useful information when it is shared by others, and that the meeting results in decisions and plans of action being made and understood by all participants. Furthermore, language issues can provide barriers to understanding or inhibit contributions to meetings (see Section 5.7). Recommendations 3-7 are intended to help mitigate these issues.

The distributed nature of e-Science gives rise to two further issues. One is that it can lead to more unevenly-distributed information amongst project members and, can yet result in less awareness of the extent to which this information is unevenly-distributed (see Section 5.5). The distributed nature of projects can also mean that expertise for particular technologies does not exist at all sites. In order to help address these two issues, recommendations 8 and 9 suggest roles that might be assigned to particular e-Science project members.

The final three recommendations suggest the establishment of alternative channels of communication between project members, in addition to providing the usual methods of communication using ICTs (such as email, mailing lists, telephone, Instant Messaging, and meetings via video- or audio-conferencing). These may help communication for a number of reasons: to prevent meetings from veering off-topic if participants believe they can raise other issues using other communication methods (see Section 4.1); some project members may not be responsive to emails so alternative methods need to be used (see Section 4.5); direct lines of

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to talk, and to pick up on the visual and audio cues of the meeting's chair when the discussion might be in danger of veering off-topic (see Section 6.1). The control and keeping of order in AccessGrid-baased meetings might also be enhanced by identifying and displaying to participants who is currently speaking in a meeting, because this should help to encourage turn-taking and maintain sequentiality (see Section 6.1.2), and research into this has been conducted (for instance, see Juby & DeRoure 2003). Other research has been conducted into making communication technologies easier to use, thereby reducing participants' reliance on technological expertise to set up and run meetings (see Section 6.3.1). For instance, Chernich *et al.* (2007) describe an application for AccessGrid which is designed to help with the recording of meetings, whilst Hasan *et al.* (2005) focus on making it easier for a participant in an AccessGrid meeting to share applications with others.

communication may be set to overcome the organizational issues that can inhibit them from communicating directly with their non-collocated colleagues (see Section 5.4); and it can help to reduce an uneven distribution of information amongst project members (see Section 5.5).

The recommendations are:

1) **Creating opportunities for non-collocated project members to meet each other, to work together, and to visit other sites** (Hinds & Weisband 2003). Such opportunities might include visits to other sites, placements and personnel exchanges, hackathons (Sommerville 2001), workshops, and peer-programming (Sommerville 2001) involving the pairing of colleagues from different sites;
2) **Providing ways of sharing information (both personal information and information about the various sites in which project members work)** (Hinds & Weisband 2003), including: providing each project member with a personal web page, and having web pages giving an overview of each site; and circulating a document, for instance at the start of the project, for which each project member is encouraged to submit a personal profile and that contains details of the facilities at each site;
3) **Using online methods to schedule meetings.** For instance, the tool meet-o-matic (www.meetomatic.com) enables project members to indicate times that they are available for a particular meeting, and then suggests the times that are convenient for the greatest number of potential attendees;
4) **Setting a detailed agenda in advance of meetings.** Having clear agendas for meetings have been found to play a very important role in retaining control over a meeting, as the following quotation from our interviews suggests:

    "It is much better when meetings are more structured, and have set agendas. Structure is the key"
    Interview 03/i-a

    Clearly defining in advance which topics will be covered in the meeting should help to prevent discussions from veering off-topic. Such an agenda should be fairly detailed, but a balance needs to be struck between the level of detail specified and allowing some flexibility in the meeting. The agenda should also be circulated in advance of the meeting;
5) **Providing text sidebars alongside the main meeting.** A participants may feel that they wish to continue discussing an issue or to press another individual on the issue (for instance to gain more information about the issue), but due to time constraints, the meeting might have to move on to the next item on the agenda. Allowing participants in a meeting to continue discussing the issue even once the meeting has moved on (for instance, through a text sidebar) might help to address this, as the following quotation from one of our interviews suggests:

    "If you mix mediums, for instance have an ongoing text sidebar alongside the main meeting, participants may continue discussion on a particular point while the rest of the meeting has moved on. This is very useful if you are trying to get something out of one particular participant"
    Interview 04/i-a

    However, it should be cautioned that if two participants use such a text sidebar to communicate whilst the rest of the meeting has moved on, they may miss important information that is being shared or issues being discussed in the meeting, thus exacerbating the uneven distribution of knowledge (see Section 5.5);

6) **Ensuring the meeting has one person acting as a chair with clear authority over the meeting**, including the authority to, for instance, say when the meeting has veered off-track or to specify whose turn it is to speak. Such a person also needs to be more direct and forceful than they might be in a face-to-face conversation;
7) **Assigning an individual to look out for participants who might be struggling with language,** who might then prompt them to encourage them to share additional information they may have or to check they understand what has been said.
8) **Providing training for project members at each location regarding how to set up and use communication technologies.** This should help to enhance the access at some sites to particular ICTs;
9) **Assigning particular individuals as experts for particular domains of knowledge** (Stewart & Stasser 1995). It has been found that by so doing, other project members usually share information and knowledge about this domain with the assigned expert. Furthermore, project members tend to consult this expert when they require information about the domain, and the expert is also able to identify new information and bring it to the attention of others;
10) **Providing online knowledge repositories** (for instance, where documents can be placed) and, in particular, set up specific repositories for specific domains, so that information about a particular domain is available in one place and is accessible to all (Stewart & Stasser 1995);
11) **Providing project members with two email addresses,** one for day-to-day communication, and the other for messages of high importance to try and secure an immediate response; and
12) **Adopting a collaborative wiki approach to developing plans and other decision-making,** in order to allow project members to contribute more to decision-making processes.

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Appendix A

Schedule of interview questions:

1) Describe the project:
    a. Participating organizations;
    b. People involved; and
    c. What was the product under development, and how is it being developed?

2) Describe your involvement in the project:
    a. How did you become involved in the project?
    b. What is your role in the project?
        i. Has this role changed over time, and how?

3) Who are your main collaborators within the project?
    a. For each one mentioned:
        i. Why are they a main collaborator?
        ii. Describe how you work with them;
        iii. How do you communicate with them?
            1. What is communicated?
            2. Frequency of communication & meetings
            3. Media used;#
            4. How did you decide what type of communication strategy to adopt when communicating with them?
            5. Have there ever been any misunderstandings/conflicts/other failures resulting from a communication made?
                a. What happened?
                b. How was the situation managed?
                c. Was it resolved?

Appendix B

This section briefly presents the main methods of communication that have been employed in the case studies, in two tables. The first presents methods of face-to-face communication, specifically formalized methods rather than non-formalized methods (such as conversations over lunch or during a coffee break, ad hoc meetings in the corridor, or learning about others' work practices by seeing them at work). The second presents the methods used when face-to-face communication is not possible and personnel must therefore use Information Communication Technologies (ICTS) to support their work.

Method of communication	**What it is used for**	**Personnel involved**	**Regularity**
Hackathons	Bringing together developers from different parts of consortium to work together on concrete problems	Developers from different parts of consortium	Monthly /quarterly etc.
In-situ observation	Observing users at work as part of requirements gathering	Developers or requirements engineers, with users	During requirements gathering phase /as and when needed
Interviews	Gathering requirements	Developers or requirements engineers, with users	During requirements gathering phase /as and when needed
	Kick-off meeting	All project personnel, plus some from other consortia	One-off
Meetings	Project meetings	All personnel	Quarterly /annually
	Project management meetings	Senior project personnel	Monthly /quarterly etc
	Focus groups of users	Users, plus a representative of the developers	Monthly /quarterly etc.
	Presenting prototypes or software to users, teaching them how to use it and seeing how they respond to it	Developers and users	Quarterly /annually etc., or *ad hoc.*
Workshops	Bringing together stakeholders from different parts of consortium to present and discuss their work, and to see how it fits in to the consortium's work as a whole	Developers from remote locations	Six-monthly /annually etc.

Table 1: Formalized face-to-face methods of communication employed in the case studies.

Method of communication	What it is used for	Personnel involved	Regularity
Instant messaging (e.g. Skype text chat)	Project meetings	All project personnel	Daily /Weekly etc.
Instant messaging	General communication	Developers	*Ad hoc.*
Teleconferencing (e.g. Skype)	Meetings of senior project personnel, work package leaders	Senior project personnel	Weekly /Monthly etc.
Teleconferencing	Project meetings	All project personnel	Weeky /Fortnightly etc.
Telephone	General communication	Developers	*Ad hoc.*
Telephone	Workpackage groups	Workpackage groups	Daily
Videoconferencing (e.g. PolyConPBX, AccessGrid)	Project management meetings	Project management	Weekly
Videoconferencing	Discussing requirements with end-users, feedback about software developed	End-users and developers	Monthly /Quarterly etc., or as needed
Wiki	Meetings of minutes, development and dissemination of workplans	All personnel	*Ad hoc.*
Project management website (e.g. BaseCamp)	Workplans and deadlines to be communicated to project personnel	Project management communicating to personnel	*Ad hoc.*
Project management website (e.g. BaseCamp)	Message boards	All project personnel	*Ad hoc.*
Email	Mailing lists for users to share requirements, discuss software under development with developers, give feedback	Developers and end-users	*Ad hoc.*
Email	Mailing lists amongst developers	Developers	*Ad hoc.*
Email	General communication	Developers	*Ad hoc.*

Table 2: ICT methods employed in the case studies.

Author Bibliographies

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Matteo Turilli is a Grid Systems Support Officer responsible for the NGS clusters at the Oxford e-Research Centre (OeRC). He recently completed his DPhil in Software Engineering under the supervision of Dr Marina Jirotka and Prof Lucas Introna. Also, he collaborates with the Centre for Ethics, Business and Economics (CEBE) at the Catholic University of Lisbon. Matteo's main interests are in parallel and distributed computing, software design, specifically as it relates to ethical requirements, formal methods and applied ethics.

Sharon Lloyd is a project manager and research facilitator at Oxford University. Sharon was project manager for the 2-year £4 million eDiaMoND project led out of Oxford in collaboration with IBM and 10 partner sites. She is now project manager for both Integrative Biology and NeuroGrid projects, which are led from Oxford, working with over 120 people over 25 sites. Before joining the University in February 2003, she worked in industry for 17 years where she gained extensive experience in project management in a commercial environment as well as people management through her management of IT teams. She has experience of both scientific and commercial IT development projects both in the UK and overseas.

Marina Jirotka is Director of the Oxford Centre for Requirements and Foundations, Lecturer in Requirements Engineering at Oxford University Computing Laboratory and Fellow of St Cross, Associate Director of the Oxford e-Research Centre (OeRC), and James Martin Research Fellow at the e-Horizons Institute. She has degrees in Social Anthropology and Psychology and Computer Science and Artificial Intelligence. She received her DPhil in Context Driven Requirements Capture from the University of Oxford Computing Laboratory in 2000. Her main areas of research have been developing novel methods and techniques for requirements capture drawn from the social sciences, focussing on workplace studies, practice driven requirements and design elicitation. Her research interests have long been concerned with developing systems that support everyday work and interaction, primarily to bring a richer comprehension of socially-organised work practice into the process of engineering technological systems. She developed the Requirements Engineering module that forms part of the MSc in Software Engineering and the MSc in Computer Science at Oxford University. In recent years her research has focussed on requirements for e-Science applications, particularly e-Health and she has worked on various industrially funded research projects, DTI, ESRC and EPSRC projects. She has been the requirements analyst on flagship e-Science projects such as eDiaMoND and is advisor on requirements methods and techniques for e-Science projects such as Integrative Biology and Virtual Research Environments for Humanities. She is a member of the UK e-Science Usability Task Force, Co-Director of the Oxford e-Social Science node that is investigating the Ethical, Legal and Institutional Dynamics of Grid Enabled e-Sciences and is Principal Investigator of the EPSRC project Embedding e-Science Applications: Designing and Managing for Usability.

Grace de la Flor is currently a DPhil student at the Oxford University Computing Laboratory studying the ways in which e-Science can change and improve the working practices of researchers and scientists. Her current research will assess how best to design and evaluate e-Science systems in support of the complex ways in which science happens; from 'in silico' experimentation, data sharing and visualization to new knowledge generation.

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