Intensely distributed nanoscience: co-ordinating scientific work in a large multi-sited cross-disciplinary nanomedical project

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Abstract

This thesis is concerned with the study of biomedical scientific research work that is *intensely distributed,* i.e. socially distributed across multiple institutions, sites, and disciplines. Specifically, this PhD probes the ways in which scientists co-operating on multi-sited cross-disciplinary projects, design, use and maintain information-based resources to conduct and co-ordinate their experimental activities. The research focuses on the roles of information artefacts, i.e. the tools, media and devices used to store, track, display, and retrieve information in paper or electronic format, in helping the scientists integrate their activities to achieve concerted action.

To examine how scientists in globally distributed settings organise and co-ordinate their scientific work using information artefacts, a multi-method multi-sited study informed by different ethnographic perspectives was conducted focused on a large European cross-disciplinary translational research project in *nanodiagnostics*. Situated interviews with project scientists, participant observations and participatory learning exercises were designed and deployed. From the data analysis, several abstractions were developed to represent how the joined utilisations of key information artefacts support the co-ordination of experimental activities. Subsequently, a framework was developed to highlight key interactional strategies that need to be managed by experimenters when using artefacts to organise their work co-operatively. This framework was then used as a guiding device to identify innovative ways to design future digital interactive systems to support the co-ordination of intensely distributed scientific work.

From this study, several key findings came to light. We identify the role of the experimental protocol acts as a co-ordinative map that is co-designed dynamically to disseminate various instantiations of experimental executions across sites. We have also shed light on the ways the protocol, the lab book and the material log are used jointly to support the articulation of scientific work. The protocol and the lab book are used both locally and across co-operating sites to support four repeatability and reproducibility levels that are key to experimental validation. The use of the local protocol / lab book dyads at each site is further integrated with that of a centralised material log artefact to enable a system of exchange of scientific content (e.g. experimental processes, intermediate results and observations) and experimental materials (both physical materials and key information). We have found that this integration into a co-ordinative cluster supports *awareness* and the articulation of experimental activities both locally and across remote labs. From this understanding, we have derived several *sensitising tensions* to frame the strategies that scientific practitioners need to manage when designing their multi-sited experimental work and technologists should consider when designing systems to support them: (1) *formalisation / flexibility*; (2) *articulability / local appropriateness;* (3) *scrutiny / tinkering;* (4) *accountability / applicability;* (5) *traceability / improvisation* and (6) *lastingness / immediacy.* Lastly, based on these tensions, we have suggested a number of implications for the design of interactive information artefacts that can help manage both local and multi-sited co-ordination in intensely distributed scientific projects.

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List of Acronyms and Abbreviations

ANT	**Actor Network Theory**
CofA	**Certificate of Analysis**
CSCW	**Computer Supported Cooperative Work**
EC	**European Commission**
EFSA	**European Food Safety Authority**
EP	**Experimental Protocol**
ERA	**European Research Area**
ERC	**European Research Council**
FDA	**Food and Drug Administration (USA)**
FP	**Framework Programme**
LB	**Lab Book (i.e. laboratory notebook)**
ML	**Material Log**
MNC	**Multinational Company**
MRI	**Magnetic Resonance Imaging**
PTA	**Project Technical Advisor**
PTTs	**Preliminary Toxicity Tests**
RoA	**Range of Acceptance**
RPO	**Research Programme Officer**
SCOT	**Social Construction of Technology**
SME	**Small and Medium-sized Enterprise**
SOP	**Standard Operating Procedure**
SPIONs	**SuperParamagnetic Iron Oxide Nanoparticles**
STS	**Science and Technologies Studies**
Voice-over-IP	**Voice-over-Internet Protocol**

Chapter 1 Introduction

Diamo avvio a una nuovissima scienza intorno a un soggetto antichissimo.
[Let us begin a very new science on a very old subject]
Galileo Galilei, Discourses and Mathematical Demonstrations Relating to Two New Sciences, 1638

Le progrès dans les sciences est l'ouvrage du temps et de la hardiesse de l'esprit.
[Progress in the sciences is the work of both time and boldness of the mind]
Voltaire, The Age of Louis XIV, 1751

Now here we go dropping science, dropping it all over, expanding the horizon and expanding the parameter.
Beastie Boys, Sounds of Science, 1989

[The above quotes about science personally resonate with me, the author of this thesis, but more importantly they are in the three European languages towards which I have very strong affinities. As such, they are a nod to the European nanoscientific project at the centre of this research study.]

1.1 Setting the scene

This thesis is concerned with the study of biomedical scientific research work that is *intensely distributed, i.e. socially distributed across multiple institutions, sites and disciplines.* Essentially, it seeks to investigate how researchers, specialised in diverse scientific domains, and operating from various institutions at different sites, work together on a large, cross-disciplinary project to investigate a common scientific problem. Specifically, this research probes the ways in which scientists co-operating on such multi-sited, cross-disciplinary projects co-ordinate experimental activities to achieve the common goal of the project, and how information-based resources are employed to assist with this co-ordination. A particular emphasis is placed on the roles of information artefacts, i.e. the tools, media and devices used to store, track, display and retrieve information in paper or electronic format (Star et al; 2003), in the conduct of experiment-based work. Its goal is to apply the findings learnt from the analysis to think of ways to design computerised systems to better support the co-ordination of experimental activities in distributed settings.

Scientific research tackles increasingly complex problems and questions requiring ever more innovative cross-disciplinary solutions (Hill, 2015). In particular, biomedical research (scientific research to support the development of knowledge in the field of medicine to enhance human health and well-being) is investigating ever more complex issues which rely on research models that are increasingly contextualised, problem-centred and translational (Jackson et al., 2013). Translational research is an inter-disciplinary branch of the biomedical field which aims to coalesce disciplines, resources, expertise and techniques to probe medical problems along the entire clinical research continuum (i.e., from the lab bench to clinical trials with patients), and to produce innovative solutions in medical prevention, diagnosis, and therapies (Shahzad, 2015). The complex problems investigated by this type of scientific research often require the establishment of global collaborative projects that assemble a number of diverse geographically-dispersed institutions from different disciplines (Cummings & Kiesler, 2005). For instance, a large co-operative project in translational research may be set up to bring together biochemists from a university laboratory, material scientists from an academic centre, radiologists from a hospital unit and micro-technology engineers from a R&D company to investigate the development of a particular diagnostic system or therapy. These types of project require researchers with complementary expertise to organise and co-ordinate complex experimental investigations distributed across teams, sites, institutions and disciplines.

The distributed nature of the experimental work in these settings creates considerable challenges for the co-ordination of the design and conduct of experiment-driven scientific work, the sharing of physical materials necessitated by the experimental activities and the dissemination of data and results of distributed experiments. These challenges are intensified by ever more prominent constraints of transparency and accountability on large multi-institutional projects imposed by political institutions and funding bodies (European Commission, 2010a). Increasingly thorough step-by-step monitoring of the progress made and a systematic reporting and dissemination of the scientific results and deliverables produced by these projects are required to justify their societal impact (European Commission, 2009; de Jong et al., 2016).

The research in this PhD investigates the scientific enquiry work conducted by the scientists involved in a large EC-funded cross-disciplinary translational research project in the field of *nanomedicine* bringing together a consortium of fifteen partner institutions across seven European countries. Nanomedical research is an area of biomedical research that probes the effects of nanomaterials (materials in the nanorange, smaller than 100 nm) used in medical applications to enable new diagnosis and therapies (Hofmann-Amtenbrink et al., 2014). This project aims to develop a nanomaterial-based diagnostics tool (the NanoArth nanodiagnostics tool) to detect the molecular causes of joint disorders, such as rheumatoid arthritis and osteoarthritis. The project requires nanomaterial scientists, MRI physicists, bone biologists, biomechanics engineers and rheumatology scientists located in various European research sites to join forces to use their complementary expertise towards a common objective: the development of the NanoArth nanodiagnostics platform.

The study in this thesis seeks to construct an understanding of how these scientists use information artefacts to co-ordinate their scientific research work activities towards achieving the project’s common goal, and how these findings can sensitise technologists to the design of co-ordinative digital tools.

1.2 Research motivation

The motivation behind the research is both theoretical and practical. The theoretical motivation is to develop an in-depth understanding of how distributed scientific work is conducted in a complex multi-sited and multidisciplinary real-world settings and how the scientists create, use and maintain various resources to manage and support their interactions. Practically, the research seeks to apply the understanding of distributed scientific work to the optimisation of information resources used in a project with a common goal. In particular, the intent is to use the deep insights from the study of distributed scientific work practices and assistive roles of information artefacts to explore and inform the design of digital interactive systems. It also seeks to provide additional support to help practitioners organise their scientific work and use information artefacts to optimise co-ordination.

As scientific problems are becoming ever more complex and require ever more innovative cross-disciplinary solutions and access to funding is becoming increasingly competitive, particularly in a European context that is radically changing, there is a real drive for efficiency in scientific research. Large project consortia are under great pressure to ensure that the complex heterogeneous, cross-disciplinary setups they organise are able to deliver results which can have a beneficial impact on society. As a result, large consortia need to ensure that their teams of experts and scientific practitioners have access to the right tools and practices to maximise their collaborative efforts in order to meet project objectives and produce tangible deliverables. Insights gained through analysis of data collected from this study aim to address this emerging need.

1.3 Disciplinary positioning

The research in this thesis can be framed mainly in the area of Computer Supported Cooperative Work (CSCW), an interdisciplinary design-oriented field that expands the investigative research domain of Human Computer Interaction (HCI). CSCW aims to develop an understanding of the nature and requirements of co-operative work arrangements with a view to design technological solutions to support them. It endeavours to understand how people coming together in different work settings, with diverse positions and perspectives, interact socially to organise and collectively manage their working practices, and how technology can be designed and deployed to support these social interactions. Typically, CSCW is concerned with a range of issues in relation to co-operative work, whether it is co-located or distributed, which can include (Schmidt, 2011):

- investigating how the concerted action of multiple individuals can be accomplished despite differences in roles, approaches and viewpoints;
- probing the co-ordinative practices that co-operating actors adopt to align and integrate their actions and how these are related to the actors' actual working practices;
- examining the roles of representational artefacts in supporting co-ordinative practices;
- exploring how modifying and digitalising these representational artefacts can affect the co-operating actors' actual work practices and the co-ordinative practices they employ to make them work together.

To address these concerns, a rich scholarly tradition has been established in CSCW of conducting in-depth workplace studies to investigate co-operative work, and the uses of information artefacts to support it in a range of socially distributed settings. Detailed studies have been conducted in a number of co-operative work arrangements such as urban transit control rooms (Heath & Luff, 1992; Heath & Luff, 1996), air-traffic control systems (Hughes et al., 1988; Harper et al., 1989; Harper et al., 1991; Harper & Hughes, 1993), ambulance despatch centres (Bowers & Martin, 1999; Normark & Randall, 2005), call centres (Ackerman & Halverson, 1998; Martin et al., 2007); clinical operating rooms (Bardram & Bossen, 2005; Scupelli et al., 2010) and hospital radiology units (Hartswood et al, 2003; Jirotka et al., 2005; Johnson et al., 2011).

The issues of organising and managing co-operative work at the centre of CSCW have been intensified by the increasing globalised nature of distributed work as enabled by the exponential growth of networked digital technologies over the past thirty years (the number of years for which scholars have been identifying CSCW as a distinct field of research (Schmidt & Bannon, 2013)). In this time, the traditional model of co-operative work in co-located settings has evolved into one of increasingly complex distribution across teams, departments or entire organisations, thus bringing together actors with diverse perspectives and modes of operating from further afield. Hence, the challenges of co-ordinating and integrating work practices in a meaningful manner on a global scale become ever more prominent. The CSCW community acknowledges the need for new workplace studies to be conducted in complex distributed settings to explore innovative ways of co-ordinating heterogeneous and dispersed work practices (Schmidt, 2012; Fitzpatrick & Ellingsen; 2013; Jirotka et al., 2013; Schmidt & Bannon, 2013). The study presented in this thesis of socially, institutionally and disciplinarily distributed scientific work in the settings of global multi-sited scientific projects – referred to in the thesis as *intensely distributed scientific work* – fits well with this CSCW research agenda and provides a meaningful contribution to the discipline.

This PhD is specifically concerned with the study of distributed work of a particular nature: scientific work i.e. the work that scientists engage in to investigate scientific problems and to devise innovative solutions. Scientific work is work that is driven, in principle, by the scientific method i.e. the construction of theory to explain a phenomenon based on the iterative experimental manipulation and observation of nature and materials (Betz, 2011). Scientific work refers to activities that scientific practitioners – researchers, lab technicians, engineers or doctoral and postdoctoral students – undertake on a daily basis as part of their role, typically in a research project. These activities include formulating hypotheses, carrying out and producing characterisations (i.e. observations, measurements and definitions), making predictions and conducting experiments to test the formulated hypotheses, characterisations and predictions (Khan, 2015). Therefore, to clarify the terminology used in this thesis, *scientific research work* or *scientific enquiry work* or simply *scientific work* denote experimentally-driven work that typically takes place within a scientific lab, or a hospital imaging unit (as examples), and include a wide range of *experimental activities* driven by the scientific method. *Experimental activities* refer to those activities that encompass planning, designing, setting up and conducting experiments to investigate a phenomenon as well as assembling materials and instrumental resources necessary for the experiments to take place, and recording, interpreting and disseminating the results produced by the experiments.

To study distributed work of a scientific nature, this PhD also draws on Science and Technology Studies (STS), a discipline that has established a rich heritage of investigating scientific research work. STS is a multidisciplinary field concerned with of the study of the processes and effects of scientific enquiry and technological development. STS attempts to understand how scientific enquiry is performed, how technological development is accomplished and the implications that both these have on the wider society (Sismondo, 2011). Therefore, STS can offer an interesting viewpoint complementary to the CSCW stance that mainly frames the research in this thesis. One of the main tenets of STS is that scientific knowledge and technological development are actively constructed through social interactions and thus the conduct of scientific enquiry should be studied through a meticulous examination of the practical activities performed by the scientists, the social interactions between these scientists and the use of representations to support these activities and interactions (Bijker et al., 1987; Knorr Cetina, 1981a; Latour & Woolgar, 1979). This STS view of scientific enquiry therefore helps shape the research presented in the thesis.

Methodologically and analytically, a key starting point for this research study was Bruno Latour and Steve Woolgar’s (1986) *scientific anthropology*. Their influential book *Laboratory Life* (first published in 1979 then re-edited in 1986) was an important early inspiration for this research, and particularly their emphasis on the empirical investigation of scientific practice through *participant observation* and immersion from a stance grounded in anthropology (Latour & Shabou, 1974). Their work prompted further investigation into how approaches influenced by anthropology, such as ethnography, could be used in this research to probe scientific research work in the settings of multi-sited projects in biomedical science.

The methodological and analytical approach selected here is a *multi-method approach* informed by different orientations of ethnography, namely *design-oriented* (Randall et al., 2007), *interactionist* (Clarke & Star, 2003; Strauss et al.; 1964), and *multi-sited* (Marcus, 1995, 2011). Ethnography is a discipline concerned with the conduct of immersive studies of different groups of people to understand people’s practices and viewpoints from within the settings in which they operate (Dourish, 2006). Ethnographic fieldwork has had significant traction in CSCW as it is seen in the discipline as being able to provide the means of developing an in-depth understanding of “the sociality of work and organisation” (Hughes et al., 1994, p. 429) to inform the design of interactive systems better suited to the practices of their users in real life settings. A design-oriented ethnographic perspective can be drawn on to develop an *analytical sensibility* (Bjørn & Boulus-Rødje, 2015) towards the design of interactive information artefacts to support the co-ordination of the practices of scientists working in intensely distributed settings. The interactionist orientation is inspired by *Symbolic Interactionism,* a sociological framework and perspective concerned with the processes that emerge during social interactions and particularly with the ways individuals use objects to derive meanings from social interactions and act towards things based on these meanings. Finally, our approach draws on the multi-sited ethnographic orientation insofar as the field of enquiry is distributed across multiple sites, which requires for us to continuously (re)define and bound this field by selecting the relevant actors and artefacts operating in the settings under investigation (Blomberg & Karasti, 2013).

To sum up, deploying a multi-method approach inspired by multi-sited, design-oriented, and interactionist ethnography seeks to capture the rich artefact-mediated interactional practices in intensely distributed scientific settings. Ultimately, using this multi-perspective approach aims to help us understand the meanings ascribed to these practices and the mediating roles of artefacts, and subsequently to inform the design of supporting interactive technologies.

1.4 Research aim and objectives

The aim of this research is to probe and explain the practices of the conduct and co-ordination of intensely distributed scientific work within a multi-sited cross-disciplinary project with the intent to consider ways to design interactive technologies to support these practices. The research objectives listed below are key to the achievement of this aim.

1. To review the areas of co-operative work in CSCW and scientific work in STS and identify theoretical conceptualisations that can help shed light on how key information artefacts can be used to co-ordinate intensely distributed scientific work.

2. To identify an appropriate methodological approach for the study of intensely distributed scientific work in multi-sited cross-disciplinary settings.

3. To empirically explore the activities and challenges of intensively distributed scientific work in a multi-sited cross-disciplinary project, and the utilisation of key information artefacts to assist with these activities.

4. To develop a theoretical understanding of how intensely distributed scientific work activities are conducted and co-ordinated in a multi-sited cross-disciplinary project and of the roles played by information artefacts in the conduct and co-ordination of these activities.

5. To consider how the theoretical understanding of the artefact-supported co-ordination of intensely distributed scientific work can be used to inform work practices and the design of computerised co-ordinative artefacts.

In the closing chapter of this thesis, these research objectives will be revisited to evaluate the study and discuss the key contributions of this work.

1.5 Thesis organisation

The content of each subsequent chapter is described as follows.

Chapter 2 essentially reviews the area of CSCW to identify useful theoretical concepts to probe co-operative work in distributed settings and specifically the use of information artefacts to support the co-ordination of distributed work activities. The chapter also looks at various perspectives from STS on the study of scientific work and on the roles of information artefacts in scientific research.

Chapter 3 reviews a number of methodological approaches that emanate from anthropology and ethnography to identify the most appropriate for informing our study of intensely distributed scientific work. It also reviews several studies of co-operative work in CSCW, of scientific work in STS, and of the role of artefacts to support these two types of work, that have specifically drawn on ethnographic fieldwork. Finally, it defines the multi-method approach selected for our study of the roles of information artefacts in intensely distributed scientific work as methodologically and conceptually inspired by design-oriented, interactionist, and multi-sited fieldwork.

Chapter 4 constructs the multi-sited field and provides the methodological background of our multi-method empirical study of the NanoArth project, a globally distributed cross-disciplinary European project in nanomedicine at the centre of this research. First, the chapter seeks to explore and understand the wider settings of the field of enquiry by probing a network of five interconnected large EC-funded projects in biomedical translational research, at the heart of which the NanoArth project is located. Subsequently, the field of study is narrowed down and focused on the NanoArth project exclusively to investigate distributed scientific work activities and co-ordination practices. Lastly in this chapter, the design and the methods used in our empirical study to collect and analyse findings are discussed in great detail.

Chapter 5 and Chapter 6 present an analytical account of our multi-method multi-sited study of the ways scientific enquiry activities are conducted and the challenges they pose in the intensely distributed settings of the NanoArth project and how their co-ordination is supported using a number of key information artefacts. A number of *areas of scientific activities and interactions* are identified. For each of these, work practices, and the issues and difficulties with these practices, as acknowledged by the scientists, are discussed in great depth.

Chapter 7 unpacks the findings from the rich descriptions presented in Chapters 5 and 6 to construct a better theoretical understanding of the roles of the information artefacts to support the co-ordination of scientific activities in the NanoArth project. It presents a number of abstractions of the ways in which key information artefacts mediate social interactions between co-operating scientists and enable exchanges of scientific enquiry content to facilitate the co-ordination of distributed scientific activities. A framework of *sensitising tensions* is derived and implications for design and practice are presented.

Chapter 8 discusses the central findings of the research in relation to the thesis aim and objectives. It evaluates a number of key contributions that this research has been able to make. It also reports a number of limitations which are discussed as critical reflections and directions for future work.

Chapter 2 Distributed Work & Scientific Work

2.1 Chapter introduction

This chapter presents a review of scholarly research with a view to explore key theoretical conceptualisations that can help shed light on distributed co-operative work and on the conduct of scientific work, from the disciplinary perspectives of Computer Supported Cooperative Work (CSCW) and Science and Technologies Studies (STS). A particular emphasis is put on those concepts used to describe and explain how information artefacts are used to support the co-ordination of distributed work and of work of a scientific nature. The intent of this chapter is to identify key conceptual lenses that can help understand the roles of information artefacts with regards to the conduct, organisation and co-ordination of intensely distributed scientific work.

2.2 Distributed work: the CSCW lens

The work investigated in this PhD is denoted as *intensely distributed,* in the sense that it is distributed socially across several individuals operating in different research teams, laboratories, departments and institutions, who have expertise in different disciplines, and who all work on the same project towards the same goal. For instance, a typical work arrangement in a project of this kind may start with laboratory technicians synthesising nanoparticles in their university material science lab. These particles are then sent to a separate research centre for a bone biologist to conduct an *in-vitro* assay, as well as to a different hospital lab for a musculo-skeletal scientist to run a series of *in-vivo* experiments that also involve an imaging specialist taking MRI scans. A parallel can be drawn with what is referred to as *reach* by Gerson (2008; p. 193-194) i.e. the distribution of work activities across organisational divisions (“*hyper-distribution”)* that is assisted by instantaneous communication means across distances and jurisdictions (“*hyper-accessibility”).*

Intensely distributed scientific work is *co-operative* in nature as it entails people organising their work collectively and requires for the *co-ordination* of work practices to be carefully managed to achieve concerted action. The following sub-sections explore the areas of co-operative work and co-ordination of work practices from a CSCW disciplinary stance in an attempt to contextualise and clarify them, and subsequently highlight CSCW constructs relevant to this research study in these areas, i.e. the probing of how information artefacts are used to support the co-ordination of intensely distributed scientific work.

2.2.1 Co-operative work

Co-operation has been defined in HCI as the endeavour of individuals to operate together on joint activities by sharing physical and/or cognitive resources (Norman, 1992). As far as CSCW is concerned, co-operation is viewed as a way for individuals to interact to share the common objects of a collective activity, instead of each concentrating solely on separate actions (Bardram, 1998a). It involves a certain level of communication and interactions to achieve the synchronisation and the integration of the individual activities (Norman, 1992). Thus, co-operative relationships can be seen as socially defined arrangements for collective action which are continuously shaped by the actions and interpretations of the individuals involved in the joint activities (Ring & Van de Ven, 1994). This is the view of co-operation that is subscribed to in this thesis: it is based on collective action arrangements and involves actors interacting through the use of common objects.

From the early days of CSCW (the first CSCW conference was held in 1986), attempts were made to define *co-operative work* (Krasner & Greif, 1986). For Stasz & Bikson (1986), co-operative work can be characterised as the work undertaken by several individuals operating in different occupational groupings but who are united by a common purpose and a common flow of activities. Simone and Schmidt (1993) imply that a separate definition for co-operative work is not necessary as work is “always immediately social” (ibid.; p. 24) in the sense that work is inherently built upon a social structure (i.e. an organisation involving individuals undertaking tasks jointly). This view is shared by other leading CSCW originators such as Hughes, Shapiro, and Randal (1991) or Heath and Luff (1992).

Divergences also concerned the nature of the *co-operative* component of the *co-operative work* construct. Bowers (1991) sees the *co-operative* term as implying a sharing process through which a certain level of compromise is reached, and reciprocity is achieved. This view has been criticized for being somehow too simplistic and not considering the sometimes-conflictual reality of working situations (Howard, 1987; Schmidt and Bannon, 1993). Similarly, De Abreu (2000) warns against an all-encompassing ‘aseptic’ view which fails to take into account the complex social settings that are at the heart of co-operative work, such as distinct statuses, decision making processes and identities. Specific work arrangements are situated in organisational and social contexts and the intricacies of the local settings need to be highlighted when studying co-operative work (Schmidt, 1994), which is the stance taken in this thesis. However, co-operative work is not necessarily constrained by formal organisational structures as work practices may very well go beyond the limits of pre-defined groups working jointly and may involve a wide range of co-workers operating from a range of locations and configurations. This is the co-operative work of interest to our research study, i.e. work that is socially distributed across teams, sites, institutions and disciplines, and probing both the distributed and situated characters of this type of work is paramount to constructing an in-depth understanding of its nature.

This double view of co-operative work subscribed to in this thesis – both situated and distributed – entails that work is organised through *interdependent work arrangements* (Schmidt, 2011). Essentially, they are collective configurations that bring together work activities that are localised but that depend on each other for a particular job to be completed: “the concept of interdependence expresses the particular material, dynamic, and environmental characteristics of a particular cooperative effort” (ibid.; p 12). Co-operative interdependent arrangements tend to have a temporary existence as they exist only for the period during which the work needs to be done. Their size may vary in time as they can have a changing membership through their existence (Axtell et al., 2004). Interactions between the individuals involved in an interdependent work arrangement constantly evolve with the constraints and affordances of the settings in which the work takes place (Schmidt, 2011). An interdependent work arrangement is distributed across space and time and according to roles, specialities and expertise (Axtell et al., 2004). What makes this concept relevant to the study of complex co-operative work, as intensely distributed work in this research, is that interdependencies are observable and investigable (Schmidt, 2011). Hence, the careful consideration of interdependent arrangements provides a helpful starting point to examine the whole range of practices that co-operating agents put in place to support the organisation and alignment of their interlinked work activities, i.e. the co-ordination of work. This is explored next.

2.2.2 Co-ordination

In the view of co-operative work adopted in this thesis (inherently social and organised over interdependent work arrangements, as highlighted in the previous section), work activities are *distributed*. In the stance taken in our study and inspired by Schmidt, *distributed activities* indicate that the actors performing them operate in a semi-autonomous manner, with regards to the way they make decisions and handle both local and global issues, while at the same time these activities are interdependent with those of their co-workers (Schmidt & Bannon, 1992). This means that actors come into the co-operative work arrangement with their own agendas, perspectives and motivations, and that these drive the manner with which they carry out their own activities. Against it, they need to engage their efforts so that their activities are interconnected with those of their partners so that to ensure that everyone works towards the completion of a common objective. Understanding precisely how actors involved in a co-operative work arrangement engage in practices that support the co-ordination of their different activities towards the completion of the main objective is thus essential, even more so when the settings in which the interdependent arrangements are intensely distributed over several sites, organisations, and disciplines, as in this PhD research study.

The co-ordination of work practices has been a central research topic in CSCW and a rich corpus of scholarly work has made key contributions to understanding co-ordination in the workplace (Dourish, 2001; Schmidt, 2011; Star & Griesemer, 1989; Strauss, 1988). From a CSCW stance, *co-ordination* can be defined as “the act of managing the interdependencies between activities to achieve a shared goal” (Malone & Crowston, 1990; p. 361). As far as this thesis is concerned, co-ordination in the workplace is conceived as the meshing, interlinking, aligning or synchronisation of partners’ actions to complete jointly previously agreed goals (Gulati et al., 2012; Okhuysen & Bechky. 2009). It involves decision-making, the sharing of information, the negotiation and provision of feedback to unify the efforts of the co-operators and combine their resources effectively towards the accomplishment of the pre-determined objectives to achieve the common goal. Many efforts have been made in CSCW to construct a more precise understanding of co-ordination in the workplace to achieve concerted action; yet it remains a key challenge. Useful ways to examine how actors organise and co-ordinate their working practices to work together, as part of co-operative work arrangements, have been suggested by several influential CSCW studies focusing on the key concepts of *awareness* and *articulation work*, as discussed next.

2.2.3 Awareness

Awareness is an essential CSCW construct as it provides a helpful theoretical lens to look at how people interact around work and specifically how individuals' working practices shape and are shaped by the ways in which their partners in a co-operative work arrangement organise their own practices. However, awareness is a notion that has been used in a wide variety of ways within the CSCW communities to describe a range of phenomena. The following discussion seeks to clarify some of the meanings and usages associated with awareness and underscores the particular view of awareness subscribed to in this research.

In its broader sense, awareness refers to the ways with which individuals operating as part of a co-operative work arrangements make available – willingly or unwillingly – information about how they conduct their work to the other actors engaged in the same co-operative grouping so that they can use it to carry out their own work (Randall et al, 2007). In this stance, awareness is used to denote a general sense of alertness of the social context within which the working individual operates (Dourish and Bly, 1992; Bly et al., 1993). For Schmidt, "awareness is typically conceived of in very general terms as relating to various aspects of members' taking heed of the social context of action and interaction" (Schmidt, 2002a; p. 288). Essentially, it is about knowing implicitly who is active in the co-operative setting, what their role is, what tasks they have been assigned, how well they are performing these tasks and how they are interacting to accomplish them (Dourish and Bly, 1992). In short, in its broader sense, awareness is conceived as a sensitivity and alertness towards the social setting in which the actors operate that fosters informal interactions, spontaneous connections and a sense of shared purpose around the work to be done. When scrutinising more closely the dense CSCW research that has been conducted on the construct of awareness since the inception of the discipline, two main views emerge.

A key strand emphasises on the effortless character of awareness and defines it as something that occurs somehow naturally between co-operating actors who have developed a certain level of competence in their work. Influential research on shared workspaces at Rank Xerox EuroPARC in Cambridge, UK, and Xerox PARC in Palo Alto, California, USA by Dourish & Belotti (1992) and Dourish & Bly (1992) examines in detail how social and information cues are picked up effortlessly by competent co-workers, as they are engaged in co-operating activities. The process of picking up those cues essential to one's own activities is described as occurring in a way that is non-disruptive to neither of the co-operating parties' actions (Dourish, 1997). This conception of awareness has received a great deal of attention in the CSCW research community. Many attempts have been made to develop frameworks and/or design technologies that can support this type of awareness (e.g. Benford et al., 1995; Bentley et al., 1997; Bly et al., 1993, Prinz, 1999). These studies are concerned with finding ways to present co-operators with relevant information on their partners' activities to help both parties understand each other's practices and interlink one's own practices to those of others in an effortless manner (Gross, 2013).

Another stream of CSCW, which has also been influential, advocates a more active view of awareness and is the view subscribed to in this thesis. Several key ethnographic workplace studies were conducted to shed light on the work practices in a range of complex settings and specifically on the role of awareness. These include seminal studies of the London Underground control room by Heath and Luff (1992, 1996) and of an air traffic control centre by the Lancaster research group (Harper et al., 1989; Harper et al., 1991; Harper & Hughes, 1993). They focused on the ways in which controllers interact with one another to let their respective partners know which tasks are being carried out, and how, so as to guide their actions and allow them to make decisions. Work in these settings is distributed, as it involves many co-operating actors closely working together and co-ordinating their actions towards a common goal, and therefore has great resonance with our study. Particularly, the work of Heath and Luff has struck a chord as it presents a conceptualisation of two facets of awareness that can provide a very useful lens to help understand how co-workers in intensely distributed settings co-operate and articulate their practices: these facets are *displaying* and *monitoring.*

In the view promoted by Heath and Luff (1992), co-operating actors *display* features of their activities which are relevant to their partners by designing and regulating those activities with those partners' benefit in mind. They carry out tasks in a way that their co-workers can pick up that a certain job is being done, how it is being done and that they are managing specific contingencies, so that to let them know of these contingencies and how to handle them (Heath & Luff, 1992). Furthermore, co-operating actors *monitor* their colleagues' activities to determine the level of accomplishment of particular tasks and compare them to the agreed plan of action. This informs whether one's own activities need to be regulated and altered so that they can be better aligned with those of the co-workers (ibid.).

This interplay between *displaying* and *monitoring* is the key to an effective interlinking of work practices (Schmidt, 2002a). With experience, individuals acquire the ability to modulate how obtrusive both their *monitoring* of others' activities and *displaying* of their own is, to better align themselves with their partners (Heath & Luff, 1992). Schmidt (2002a) refers to this as *appropriate obtrusiveness* and sees it as a highly competent ability that is increasingly developed as co-operators get to work more with each other. In Schmidt's stance, this explains why awareness is often conceived as a highly competent effortless process: with experience co-workers acquire this crucial ability to make sense of the cues provided and align each other's practices in a way that it does not interfere with the work at hand. As far as our research study is concerned, going beyond the view of awareness as an effortless process acquired with competence is essential, and understanding its finer mechanisms is key to examine and explain the inner-workings of co-ordination. However, this two-dimensional view of awareness (that relies on *displaying* cues to others and *monitoring* other's cues) is only suited to work activities that are co-located and take place synchronously between co-operating parties, *in real-time.* Spatially-dispersed work that can take place asynchronously, at *different times*, like the one of interest in this PhD requires other models of awareness.

2.2.4 Awareness for distributed and asynchronous work

The conception of *awareness* as the interplay between *displaying* and *monitoring* discussed in the previous section was developed in relation to distributed work that was co-located and synchronous (Heath et al., 2002; Luff et al.; 2017) in specific environments referred to as "centres of coordination" (Heath et al., 2002; p.319). These include workplaces such as control rooms that have been configured so that co-workers need to continuously monitor each other's activities to achieve concerted action (ibid., 2002) and so that they provide co-operators with a great variety of cues to this effect (Schmidt, 2002a; Robertson; 2002). The work in these *centres of coordination* tends to be mainly co-located and organised synchronously according to well-defined strict divisions of labour (Heath et al., 2002; p.319). However, in the types of projects in which scientific work is increasingly being conducted and of interest to this PhD, work can be fragmented and distributed across geographical locations, institutions, and disciplines; and activities, such as experiments and simulations, often takes place asynchronously as well as synchronously. Therefore, new awareness models are required to study and understand co-ordination in complex settings in which distributed work is remote and asynchronous and that offer many challenges to awareness support (Gross, 2013; Leinonen et al., 2005; Steinmacher et al., 2013). In brief, new complex forms of work call for new models of awareness (Heath et al., 2002; Luff et al., 2008; Schmidt, 2002a).

The concept of *workspace awareness* has been influential in the study of geographically-distributed co-operative work mediated by technological tools (Gutwin & Greenberg, 2002). It provides a timely understanding of the various co-operators' interactions with a shared-workspace virtual system i.e. their location in the workspace, their current actions and their intentions. It supports the co-ordination of distributed events insofar as "it informs participants about the temporal and spatial boundaries of others' actions" (ibid., 2002; p.429). Leinonen et al. (2005) also looks at global virtual teams and suggests the notion of *awareness of collaboration* as particularly helpful for coordination in dispersed settings. It goes beyond *workspace awareness* and refers to the actor's perceptions of their co-operative arrangements with regard to shared goals and collaborative processes. They posit that this *awareness of collaboration* can be supported by the design of visualisations of project information (e.g maps to externalise understanding) and visualisation of distributed team interactions to provide better information of the activities of the partners working remotely (Gutwin et al., 1996).

Regarding the support of distributed work of an asynchronous character, new awareness models were adapted from *workspace awareness* and conceptualised as *asynchronous change awareness* (Tam & Greenberg, 2006) or simply *asynchronous awareness* (Schumann et al., 2013). These concepts refer to the ability of actors to track the changes made to information artefacts in cooperative work setups. This can be achieved by providing the actors with different views of the co-operative environment and the changes that can be made to it e.g. an artefact-based view, a person-based view and a workspace-based view. Co-operators can thus be easily made aware of the information that is modified and the impact this has on the shared work and thus facilitate asynchronous co-ordination between different parties (Tam & Greenberg, 2006).

Finally, the most recent view of awareness developed in CSCW to consider co-ordination in complex distributed work configurations has been conceptualised as *we-awareness*. In brief, *we-awareness* is a repositioning of awareness to a more shared and mutual perspective. It denotes an awareness of *shared intentionality* i.e. the understanding that co-operating actors have of their own respective goals and of each other's goals in relation to their common objective (Tenenberg et al., 2016). It refers to "the socially recursive inferences that let collaborators know that all are mutually aware of each other's awareness" (Greenberg & Gutwin, 2016; p. 279). Therefore, the underlying idea is that co-workers must not only be oriented towards the same features of their co-operative arrangement, but also reciprocally and iteratively know that the other person is so oriented to co-ordinate their respective actions towards concerted action (Tenenberg et al., 2016).

If this new stance offers a great potential to explore the inner workings of co-ordination in distributed work, it has also been heavily critiqued. For Schmidt (2016), *we-awareness* is based on the same premises as *mutual awareness* (discussed in Schmidt, 2011). Robertson (2016) sees *we-awareness* as a problematic theoretical construct that is confused, contradictory and ambiguous. Both Schmidt (2016) and Harper (2016) have issues with the philosophical foundations of *shared intentionality* that underpins *we-awareness*. Clearly, the concept of *we-awareness* appears to divide the CSCW disciplines and all scholars agree that additional research ought to be conducted to examine it closer.

Alongside *awareness*, another construct related to co-ordination has received a great deal of attention in CSCW and is considered next: *articulation work*.

2.2.5 Articulation work

The concept of *articulation work* was first formulated and developed by Anselm Strauss (Strauss, 1985; 1988) to help understand the interactions between staff organising project work in medical settings. It was also developed by Gerson and Star in their work on office automation systems (Gerson & Star, 1986) and further expanded by the work of Schmidt, both theoretically (Schmidt, 2002b, Schmidt & Bannon, 1992) and empirically, in a variety of settings (Bannon et al., 1993; Bannon & Schmidt, 1993; Schmidt & Simone, 1996; Simone & Schmidt; 1994).

Strauss (1985) defines articulation work as the *supra-work* that needs to be carried out to ensure that the efforts from the various co-operating actors result in more than what is accomplished by the different segments of work of the separate individuals. It refers to the actual mechanisms of assembling and integrating individual tasks, as well as sequences and groups of tasks and larger units of work, into an operating workflow. Essentially, in Strauss' view, it consists of the means put in place to combine and interconnect three aspects:
(1) the different tasks and clusters of tasks to be carried out;
(2) the efforts of the co-operators involved in undertaking these tasks;
(3) the actors with the various tasks and units of work to be completed.

This view of articulation work is somehow problematic for CSCW as it considers individual tasks as just blocks that can be simply assembled, i.e. *articulated*, but ignores the actual details of what occurs exactly as the task is carried out. This failure to grasp the complexities of the inner details of work is a limitation for the study of the co-ordination of work practices from a CSCW perspective. Indeed, it is contended in this thesis that, in line with the CSCW disciplinary stance, a thorough understanding of the inner workings of work is crucial for the researcher to construct a detailed understanding of the work practices in place in order to be able to design technological solutions that can best support these work practices.

The view of articulation work advocated by Gerson (2008) addresses these issues to a certain extent by making a conceptual distinction between two levels of articulation work: *local articulation* and *metawork*. *Local articulation* refers to what needs to be done to ensure that all the resources are available and operational for activities to be undertaken "*in the local situation"* (ibid., p. 196). *Metawork* is about ensuring that different types of activities function together as expected, using pre-defined specifications and representations, to align different units of work. There is a certain overlap between these two facets and, in Gerson's view, they are particularly useful construct to investigate *reach*, i.e. "the distribution of tasks across organizational, spatial, and temporal boundaries" (ibid., p. 196).

When applied to the study of intensely distributed scientific work, it is argued that the constructs of *local articulation* and *metawork* defined by Gerson can offer a useful lens to examine the finer details of the coordination of activities. In this thesis, *metawork* refers to the work that needs to be done to make sure that everything functions between the different units or groups at the *macro-level* (Andonoff et al., 2004), i.e. the level of the broader interdependent work arrangements, larger units of co-operative work or the entire project. It can help understand what needs to be done to organise, manage and monitor the activities between different groups, units, or teams using a range of information artefacts such as pre-defined plans, schedules, procedures, lists, etc. On the other hand, *local articulation* helps ensure that everything is in place at the *micro-level* (Andonoff et al., 2004), i.e. the local setting where situated activities take place, and at the right time to get the job done and deal with any contingencies that may arise.

Articulation work (and particularly Gerson's distinction between *local articulation* and *metawork*) provides a good theoretical basis to study the co-ordination of work that is of co-operative nature, i.e. work that is both situated and distributed across interdependent work arrangements. Since our investigation is specifically concerned with understanding the roles of information artefacts in the support of the co-ordination of intensely distributed work activities, various CSCW artefact-oriented operationalisations of articulation work are given particular attention and are discussed in detail in section 2.3. Before considering these, the innovative areas of e-science, infrastructuring and synergising are considered.

2.2.6 E-Science, infrastructuring & synergizing

E-science is a field of research that probes the design and use of innovative infrastructure-based technologies to support new form of collaborative practices towards scientific discovery in global distributed arrangements (Jirotka et al., 2006; Bietz et al., 2010). It is specifically concerned with the design and development of powerful computer-based research infrastructures to help investigate complex problems in the large-scale and cross-disciplinary co-operative settings that are becoming ever more prominent in scientific research (Jirotka et al., 2013). Thus, the *e-science vision* is about constructing a clear understanding of the co-operative scientific practices in which the designed collaborative IT infrastructures will be embedded to assist with the sharing of resources and the co-design of experimental investigations across geographical, disciplinary, and institutional boundaries (Jirotka et al., 2013; Jirotka et al., 2006).

E-science has logically attracted a great deal of attention from the CSCW community (six special issues in the CSCW journal; see Bansler & Kensing; 2010; Jirotka et al., 2006; Karasti et al., 2018; Pipek et al., 2017; Ribes & Lee, 2010; Spencer et al., 2011). CSCW scholars have shown particular interests in implementing the e-science vision by helping understand the nature of multi-institutional cross-expertise scientific work and identifying ways in which scientific data can be generated, shared, and used across organisational and disciplinary lines (see afore-mentioned special issues for instance). To this end, they acknowledge that complex challenges need to be overcome, such as tackling concerns of trust between co-operators, finding ways to design representations that can be shared among globally distributed teams, and dealing with issues of usability in relation to the design and evaluation of e-science infrastructures (Jirotka et al., 2006)

Infrastructuring has been specifically defined as an approach that can assist with probing some of these key areas and challenges. It refers to both the ongoing process and long-term aim of investigating, creating and developing scientific research infrastructures (Karasti & Baker, 2004; Karasti & Syrjänen 2004; Pipek & Wulf, 2009) but also as a methodology to help design, implement, and deploy information infrastructures and understand their appropriation and use by scientific practitioners (Young & Lutters, 2017). The infrastructuring approach seeks to find ways to assemble and integrate together the various components of complex clusters of human infrastructures and socio-technical systems on top of an existing infrastructure base (Bietz et al., 2010; Bossen & Markussen, 2010). For Young & Lutters (2017), it involves iteratively identifying *points of infrastructure* to extend existing infrastructure work.

Bietz et al. (2010) draw on the concept of *synergising* to better understand how infrastructures can become embedded in other systems and existing infrastructures. It denotes the active work of managing social, organisational, and technological relationships, and the strategies put in place by the co-operators to achieve more effective co-ordination by combining and integrating the different human and social-technical entities into an e-science infrastructure than if they operate on their own. Parallels have been drawn with the concept of *articulation work* (see previous sub-section 2.2.4)*;* however, Bietz et al. argue that it goes way further as it is not only concerned "with modifying and coordinating an existing common field of work, but with *creating the field of work itself*" (ibid., 2010; p.276).

The next section considers artefact-oriented operationalisations of articulation work first and then e-science information infrastructures.

2.3 Information artefacts to support co-ordination: Schmidt's stance

Right from its early days, scholarly work in CSCW has sought to understand the roles of the devices and resources designed, used and shared by co-operators to co-ordinate their activities. CSCW studies have focussed on a variety of tools, including timetables (Heath & Luff, 1992), blueprints and diagrams (Henderson, 1991; 1999), patient records (Luff et al., 1992), reporting forms (Carstensen & Sørensen, 1996), work schedules (Bardram & Bossen, 2005; Bardram & Hansen, 2010a) or scientific models (Sundberg, 2007; Egmond & Zeiss, 2010). When investigating those devices collectively created and maintained by co-operators to work together, researchers have used a range of terms, such as *artefacts* (Bardram & Bossen, 2005; Halverson & Ackerman, 2008; Schmidt & Wagner, 2004), *information artefacts* (Star et al., 2003; Turner, 2000), *symbolic artefacts* (Carstensen & Sørensen, 1996), *common objects* (Rogers; 1993), *work objects* (Bossen, 2012) or *information objects* (Eckert & Bouju, 2003). The concept of *information artefacts*, inspired by Star et al. (2003), is the one considered in this thesis to designate the information-carrying resources designed and managed co-operatively to organise collective work and integrate different work trajectories. It encapsulates the tools, means, media and devices used to store, track, display and retrieve information in paper or electronic format that are used as part of a collaborative work arrangement.

A comprehensive body of work by Schmidt and collaborators has caught our attention for carefully investigating the ways information artefacts are used to support articulation work and the co-ordination of work activities in co-operative settings. This work has led to the formulation of three concepts that seek to provide an in-depth understanding of the different processes involved in the articulation of co-operative working activities, the roles played by various information artefacts to mediate these processes, and the complex interplay between these processes and the mediating artefacts.

The Schmidtian concepts are summarised in table 2.1. The table provides a brief overview of the theoretical constructs considered, briefly outlines the empirical studies conducted to help define and shape them and identifies essential scholarly work that inspired their development.

Concept & main source	**Brief definition & overview**	**Key empirical studies, helped define concept**	**Significant work drawn from**
MECHANISMS OF INTERACTION (Simone & Schmidt, 1994)	Modes of organising interactions based on a protocol conveyed by a symbolic artefact.	Study of software design and testing project as part of large industrial design project: bug form, platform period schedule and augmented bill of materials.	• Office procedures (Suchman, 1983) • Plans and situated action (Suchman, 1987) • Classification & standardisation (Bowker & Star, 1991) • Awareness (Dourish & Bly, 1992; Harper et al., 1991; Heath & Luff, 1992)
COORDINATION MECHANISMS (Schmidt & Simone, 1996)	Co-ordinative protocol imprinted upon a distinct artefact that stipulates and mediates the articulation of co-operative work.	Study of multiple manufacturing firms: bill of materials, routing schemes, processing schemes for planning and control, etc.	Mechanisms of Interaction (Simone & Schmidt, 1994)
ORDERING SYSTEMS (Schmidt & Wagner, 2004)	Cluster of more or less loosely coupled protocol / artefact	Study of architectural work: CAD plans, CAD drawing, sketches, metaphorical text, association images, physical models, photographic material	Coordination Mechanisms (Schmidt & Simone, 1996)

Table 2.1: Schmidt's concepts for co-ordinative information artefacts

The next three sub-sections introduce and discuss these concepts in depth. The immediately following one explains how they have been used in the CSCW literature to investigate the co-ordinating roles of information artefacts in a variety of co-operative settings. Section 2.3.5 examines how these conceptualisations can help investigate how information artefacts are co-operatively created, maintained and utilised to co-ordinate intensely distributed scientific activities and help think of ways to design interactive systems to support this co-ordination.

2.3.1 Mechanisms of interactions

"A mechanism of interaction can be defined as a device for reducing the complexity of articulating distributed activities of large co-operative ensembles by stipulating and mediating the articulation of the distributed activities." (Simone & Schmidt, 1993, p. 6). *Mechanisms of* *interactions* refer to modes of organising interactions around co-operative activities which are based on a class of information artefacts that define and assist articulation work (Schmidt, 1994). More specifically, a mechanism of interaction is a protocol that consists of a set of clear conventions and procedures and that is represented by a symbolic and standardised artefact (Simone & Schmidt, 1994). They are "artifactually embodied 'mediating structures' that are used to constrain the articulation of distributed activities in co-operative work settings" (ibid., p. 102).

The theoretical development of the concept of mechanism of interaction was inspired by several studies regarded as seminal in CSCW (Bowker & Star, 1991; Dourish & Bly, 1992; Harper et al., 1991; Heath & Luff, 1992; Suchman, 1983; 1987). These include the work conducted by Lucy Suchman on protocols and operating procedures within the context of office automation (Suchman, 1983) in which she explored issues around the status of procedural specification and particularly the relationship between the use of prescribed procedures and the handling of contingencies when undertaking work activities. This study highlighted the fact that operating procedures not only provide detailed specifications for routine tasks but also that they have a problem-solving role in non-ordinary situations and that thus they should be formulated in a way to allow for the handling of non-routine cases.

This idea of an appropriate level of ambiguity which should be built in a protocol or a procedure is also pervasive in Bowker and Star's work on classification and standardisation, which also helped define and operationalise the Schmidtian construct of *mechanisms of interaction* (Bowker & Star, 1991). This study examined the International Classification of Diseases (ICD) as a classification scheme which is developed and managed internationally over time, and which helps mediate and coordinate the distributed activities conducted by a wide range of medical specialists from a variety of backgrounds and perspectives. Bowker and Star's findings underscore that if standardisation is needed to collect and code the information so that it is can be usable by all parties, the standardised information artefact cannot be entirely homogeneous and fulfil everyone's local requirements. To manage this tension between the necessity for standardisation and the suitability to local circumstances, the appropriate level of vagueness needs to be a principle that drives the design of such a procedural scheme.

The concept of *mechanisms of interaction* was further developed empirically by Schmidt and collaborators when investigating the roles of various co-ordinative artefacts within in large-scale software design and testing project for a manufacturing organisation: namely the bug form, the platform period schedule, and the augmented bill of materials (Schmidt & Bannon, 1992; Simone & Schmidt, 1994). Their analysis points out that protocols should be specialised for a well-defined area of action and that they should specified explicitly only to the extent that they are relevant for the purpose for which they have been designed. When they are well adapted to the local conditions in which they are utilised, they are used as a vehicle for social interaction by conveying certain constraints to the behaviours of the co-operating actors. Not only does the interaction mechanism protocol stipulate how work is articulated, but "it mediates articulation work as well in the sense that the artefact act as an intermediary between actors that conveys information between them about state changes to the protocol under execution." (Simone & Schmidt, 1994, p. 105). This idea of being fit-for-purpose and of being used to communicate changes in the state of the operating procedures to co-operators is key to the usefulness of this conceptualisation.

The mediating role of the mechanism of interaction – pertaining to its ability to communicate information about the state of enactment of the protocol – is seen by Simone and Schmidt (ibid.) as having the capacity to develop and maintain *awareness* between the various co-operating actors. This view can be interpreted by the fact that the actors may update the 'protocol-carrying' artefact to convey information on the state of execution of the procedures prescribed by the protocol and are in turn able to pick up cues on the state of execution of these procedures. Thus, the mechanism of interaction is able to support the two facets of awareness that were highlighted as essential to the view of awareness subscribed to in this thesis: *displaying* and *monitoring*. On one hand, it may assist the *displaying* of information related to the completion of certain tasks for the others benefit; on the other hand, it may enable the *monitoring* of the level of advancements of their co-operators' activities to regulate their own ones.

The theoretical concept *mechanisms of interactions* was subsequently developed further and expanded into the second Schmidtian conceptualisation of articulation work relevant to our study, presented in table 2.1 and discussed next: *coordination mechanisms.*

2.3.2 Coordination mechanisms

The motivation for extending *mechanisms of interactions* into *coordination mechanisms* was to provide a more functional understanding of the co-ordinating roles of information artefacts and to apply this understanding to the design of computerised technologies in the CSCW tradition (Schmidt, 2011). Effectively, a coordination mechanism can be interpreted as a mechanism of interaction that is *computable*, i.e. formulated in a manner that supports the design of computational technology (Cabitza & Simone, 2013)

The concept of *coordination mechanisms* was shaped over a great number of years by Schmidt and various collaborators during a series of field studies of production planning and control in manufacturing firms (Schmidt, 2011). In these studies, they probed how various constructs such as bills of materials, routing schemes, processing schemes, etc. were used to help manage the interdependencies between the co-operating workers. More specifically, these studies explored how such information artefacts were used in real-life situations and adhered to or deviated from in these situations to subsequently analyse whether computer systems could be designed to support their utilisations. They established that these schemes are continuously designed, modified and adapted by the actors to suit their needs, that the ability to alter and adjust them is critical to the effectiveness of the work and that information technologies have a crucial role to play in supporting the capacity to make these alterations and adjustments. Thus, the notion of *coordination mechanisms* (like its predecessor *mechanisms of interaction*) seeks to provide a concise conceptual framework to shed light on how various artefacts can be co-operatively designed and continuously modified to manage work interdependencies. But in addition, *coordination mechanisms,* as a construct, seeks to provide the basis for the analysis and design of requirements for IT systems to support the creation, manipulation and management of these coordinating artefacts to support the interdependencies in a co-operative work arrangement (Schmidt & Wagner, 2004).

Description

Essentially, a coordination mechanism consists of a tightly connected dyad *coordinative protocol* / *coordinative artefact*. The *coordinative protocol* is a set of rules that have a bearing on and steer the interactions between the co-operating actors, such as accepted ways of operating, recognised courses of actions, guiding principles, formal policies, standard operating procedures, or organisational processes. The *coordinative artefact* is a standardised information construct that has a stable, tangible and visual representation and that instantiates the protocol (Schmidt, 2011).

The *coordinative protocol* part of a *coordination mechanism* stipulates the articulation of distributed activities by constraining or enabling the co-operating actors, it goes further than that. It also provides “a pre-computation of task interdependencies [...] to reduce the space of possibilities by identifying a valid and yet limited set of options for coordinative action in any given situation” (Schmidt & Simone, 1996, p. 174). In Schmidt and collaborators’ vision, the *coordinative protocol* should be viewed in a flexible manner. It should be thought as an interactional device that can vary from one situation to another, depending on the interdependencies that characterise a co-operative work arrangement. It may play the softer role of a map in a distributed decision-making situation and be used as a guide to problem-solving. It may play a stronger script-like role in a situation which is defined by clear sequential or temporal interdependencies. Whatever the level of precision of the stipulations that the *coordinative protocol* conveys, it needs to embrace the idea of under-specification in the sense that it cannot be overly detailed to try to cater for all possible circumstances. Whether it is a *weak* or a *strong protocol*, its utilisation may be required in situations where actors need to diverge from the stipulations it provides, and it needs to be designed with this flexibility in mind.

The *artefact* component of a *coordination mechanism* aims to instantiate the *coordinative protocol* so that it can be made accessible to the various actors who may need to make use of it. This instantiation should be dynamic in the sense that the artefact should be able to actively represent and communicate the continuously changing state of the protocol to the various actors who use it in a distributed work arrangement, potentially in different geographical locations and over a period of time, which is of high relevance to this research. Thus, not only should the artefact provide a tangible platform to stipulate the work tasks to be articulated but should also enable the mediation of articulation work by informing the various agents of the state of the execution of the protocol as it is being enacted (Schmidt & Simone, 1996).

Limitations

A number of limitations need to be highlighted with regards to *coordination mechanisms*. The main driver behind the elaboration of the notion was simplicity: one *coordinative protocol* imprinted upon one *artefact* to provide a pre-computation of task interdependencies, as the basis for the design of computerised systems to define and mediate articulation work. However, the emphasis was mostly put on those *coordinative protocols* with a strong temporal structure, as illustrated by the types of information artefacts they investigated empirically to develop their model: bug form, platform period schedule, routing schemes, processing schemes. In other words, “the concept of coordination mechanisms was developed on the paradigm of pre-established workflow” (Schmidt, 2011, p. 19) which disregards other co-ordinative systems of crucial importance such as maps, templates, classification schemes, ranking schemes, validation procedures, coding schemes, notations, etc. Likewise, Schmidt (ibid.) expresses the concern that a wide range of diverse artefacts may be overlooked by his own framework such as bulletin boards, work allocation plans, production plans, product specifications, drawings of components, etc., thus making it not sufficiently inclusive. Besides, the linkage of one *coordinative protocol* with just one *artefact* may be too restrictive. Indeed, there may be *protocols*, in the *coordination mechanisms* sense, that exist without necessarily being associated to a tangible artefact. For instance, a global company policy may provide a set of rules and guidelines that workers follow, without being clearly instantiated by one specific document. On the other hand, a complex *coordinative protocol* may be effectively represented by a collection of various artefacts that are all necessary and need to be interconnected and used in conjunction for the prescribed procedure to be executed successfully.

A clear tension emerges in Schmidt’s work between developing a conceptual framework that is sufficiently rich so that to take into account the complexity of the real situated co-ordinative practices but also simple enough so that to provide the basis for the design of computerised systems to support these co-ordinative practices and the associated articulation work. The third Schmidtian conceptualisation that operationalises articulation work (presented in table 2.1) attempts to address this tension and is considered in the next sub-section: *ordering systems.*

2.3.3 Ordering Systems

Ordering systems go beyond the simple pairing of *coordinative artefacts* and *coordinative protocols*; they refer to organised clusters of interconnected specialised co-ordinative practices and associated artefacts (Schmidt & Wagner. 2004). Hence, for the *ordering systems* conceptualisation, the *coordinative protocol* component of *coordinating mechanisms,* discussed in the previous section, is extended to *coordinative practices*. These are defined by Schmidt and Wagner as the elaborate specialised practices used expertly by actors to manage their work interdependencies which have a co-ordinative function. These co-ordinative practices may involve one or several interrelated standardised information artefacts, ranging from protocols or procedures (to temporally organise distributed activities) but also a range of other "interrelated artifacts, classification schemes, notations, nomenclatures, standard formats, validation procedures, schedules, routing schemes, etc." (Schmidt & Wagner, 2004, p. 402). The key aspect of this framework, however, is that it does not consider these various practices in a discrete manner but rather, it offers to assemble them in structured clusters of protocols – in the wider sense – and carrying artefacts and explore their roles in supporting the articulation of distributed co-operative work in interconnection with each other.

The purpose of the integrative approach advocated by Schmidt and Wagner when defining *ordering systems* is to harmonise, standardise, and synchronise local practices in a coherent manner for all parties involved. Thus, ordering systems need to be designed and developed so that to ensure consistency between local practices, to monitor the changes made to these practices, to track the repercussions of these changes on the distributed work arrangement and to enforce accountability between the different participants. At the same time, ordering systems need to be open-ended so that they can be modified, updated and customised to allow the handling of local contingencies.

2.3.4 Schmidt’s co-ordinative concepts in CSCW and critiques

This sub-section briefly explores how the frameworks developed by Schmidt and collaborators have been used in CSCW to probe the co-ordinating roles of information artefacts in a variety of settings. It also points out a number of critiques formulated in CSCW with regards to some of these concepts.
The three interconnected concepts developed by Schmidt and collaborators to operationalise articulation work – *mechanisms of interactions*, *coordination mechanisms* and *ordering systems* – have been used in several ways in CSCW studies to probe how co-operating actors organise their distributed work activities and how technologies can be designed to support the articulation of these activities.

For several CSCW scholars, *coordination mechanisms* offer a good theoretical lens to examine various utilisations of information artefacts to assist co-ordination. For instance, Grinter et al. (1999) investigated how “interface specifications, development processes, reliable plans, standards and protocols for product design” (p. 315) are used to manage the interdependencies between the actors involved in a multi-sited product Research & Development project. They establish that within this environment, project plans are used as mechanisms to co-ordinate product features and releases while standards and interface specifications are used to articulate activities across various product components. For other CSCW researchers, *coordination mechanisms* have been used as part of a set of conceptual tools to develop a greater understanding of artefact-mediated co-ordinating practices. For example, in their analysis of distributed translation services in a multinational software development firm, Doherty et al. (2012) incorporated *coordination mechanisms* with *awareness mechanisms* and *communication patterns* to shed a light on the way co-operators used digital systems to articulate their translation work across internal organisational boundaries and on the challenges that they encountered in doing so. Other CSCW studies have used the concept of *coordination mechanisms* as the basis for designing digital systems to support co-ordination. For example, Boden et al. (2014) designed and developed an *articulation space*, i.e. an interactive visual system for a small software company to allow the sharing of heterogeneous information from different sources to enable the coordination of software projects. In this platform, they incorporated a variety of *coordination mechanisms* ranging from those articulating activities formally, such as meeting plans or reports about the work progress, to those doing so more loosely, such as questions to team members or announcements of customers/visitors. Their observations highlighted that the system facilitated exchanges and thus made the articulation work more visible so that to help guide the co-ordination process between the different team members.

The development of the *coordination mechanisms* construct has also been the object of criticisms. Bardram (1998b) posits that this conceptualisation emphasises too heavily the temporal organisation of work activities and asserts that probing the temporal unfolding of these activities is perhaps not sufficient to fully understand co-operative work (see section 2.3.2). This concern was addressed to a certain extent by Schmidt and Wagner (2004) through the development of *ordering systems* which, not only include workflow-driven procedures, but also a range of other supportive work practices (see section 2.3.3). Furthermore, Bardram (1998b) raises questions about the notion at the core of *coordination mechanisms* (and by extension *ordering systems*) – *interdependencies*. *Coordination mechanisms* concentrate on understanding how protocols and their associated carrying artefacts support articulation work by helping stipulate and mediate interdependencies between co-operating actors working interdependently. However, in Bardram's view, the interdependencies between the participants of a work arrangement are difficult to pin down and to define as they can be very dynamic and changeable. For instance, some of these interdependencies can be only temporally initiated in response to a particular event; others are semi-permanent and are activated intermittently while a range of interdependencies may exist on a more permanent basis. A co-operative work arrangement may require a certain set of interdependencies at a given time and a very similar work arrangement may require a different array of interdependencies in a slightly different situation. Therefore, there is a need for additional enquiries and clarifications of the ways information artefacts can assist with the co-ordination of work practices in settings that offer a wide array of complex interdependencies, such as the one of intensely distributed scientific work of interest here.

The Schmidtian concept of *ordering systems*, i.e. the clustering of information artefacts with co-ordinative practices to ensure the articulation of co-operative work, has been used in fewer CSCW studies. A notable example is the use of ordering systems by Redaelli and Carassa to conceptualise “the study of tools and practices necessary to coordinate the execution of flights with the accomplishment of ground activities” (Redaelli and Carassa, 2015; p. 175). The concept helps them understand how consistency is ensured across the distributed activities related to the planning of flights and the other activities on the ground, and also how the various artefacts used as part of these activities can be maintained to maximise the execution of the plans.

The following section considers the relevance of the theoretical constructs of the co-ordinative roles of information artefacts discussed so far to our study of intensely distributed science.

2.3.5 Schmidt’s co-ordinative concepts for intensely distributed science

This section explores how the Schmidtian constructs can help investigate how information artefacts are co-operatively created, maintained, and employed to co-ordinate intensely distributed scientific activities and, can potentially help probe how interactive systems can be designed to support this co-ordination.

The fact that the original Schmidtian concept of *mechanisms of interaction* is based on the idea that an artifactually embodied *protocol* can help support articulation work, presents our study with a very interesting parallel. From a very initial understanding of science, scientific enquiry work is procedural in nature and scientists use experimental protocol to specify the various phases of their experimental-based investigatory work. Thus, the construct of *mechanisms of interaction* can be an entirely appropriate starting point to explore whether a procedural information artefact like an experimental protocol can play a key role in the co-ordination of work practices in intensely distributed settings.

It is contended that the *coordination mechanisms,* as a coordinative protocol/artefact dyad, can offer an even more useful theoretical construct for this research to develop an understanding of the co-ordinating roles of the many different information artefacts used in science and also help think of innovative ways to design interactive systems to support these roles. **Experimental protocols used in scientific work are imprinted and conveyed by documents that define the resources to be used and the experimental procedures to be executed.** They tend to be developed iteratively and refined in co-operation with various members of a laboratory or a team who may bring in their various knowledge and expertise. The use of laboratory notebooks to capture observations, thoughts and intermediate results *in situ* is pervasive in bench-based experimental work. Different logs may also be used co-operatively to record and monitors exchanges of materials, substances and samples. **The idea that a co-ordination mechanism can help pre-compute tasks interdependencies to identify a limited number of options for co-ordinative action, albeit in a flexible manner, may offer valuable insights on how these scientific artefacts are used co-operatively to enable the articulation of intensely distributed activities.** Furthermore, the computable nature of co-ordination mechanisms may help us consider interesting approaches towards the design of interactive information artefacts to support intensely distributed co-ordination.

Finally, *ordering systems* provide this research with a useful perspective because this construct considers a wider range of information artefacts than *coordination mechanisms*. *Ordering systems* go beyond procedures with a strong temporal dimension and aim at "embracing coordinative practices in their endlessly rich multiplicity" (Schmidt, 2011, p. 20). Thus, they have the potential to help probe the situated utilisations of a great variety of information artefacts which can be found within a distributed experimental-driven scientific project to assist the articulation of different activities and which may include experimental notes, lab books, equipment inventories, material sample logs, experimental data sheets, etc. Ordering systems "enable co-operative, coordinated interactions of greater complexity and scope than otherwise possible" (Bossen, 2012, p78). In addition, *ordering systems* also appears to offer a good vantage point to explore possible ways to design useful computerised systems to support the articulation of distributed scientific enquiry work. The study deployed in the following chapters seeks to clarify how this exploration of interesting design perspectives can be achieved.

The next sub-section presents the perspective from e-science on information infrastructures

2.3.6 Information infrastructure in e-science

Following the earlier discussion on the concept of *ordering systems*, we argue that the notion of *information infrastructure* (or simply *e-science infrastructure*, see section 2.2.6) also offers an interesting theoretical lens on the clustering of social and technical systems that can be configured and designed to support co-ordination in complex intensely distributed settings.

An information infrastructure denotes here a grouping of technical tools and systems, social norms and protocols and organisational practices (Edwards et al. 2007; Karasti et al. 2010) defined by a complex set of relationships embedded in and constrained by other systems (Bietz, 2010). Its properties emerge progressively as the result of continuous negotiations and adjustments (Star, 1999) to find innovative ways to support cross-disciplinary and distributed scientific cooperation, which is its primary purpose. It is open, interconnected and dynamic (Monteiro et al., 2013). It should be locally constructed and globally assembled (Jackson et al., 2007), it should focus on interoperable modules (Edwards et al., 2007), and it should be thought for the future to support current needs and anticipate future requirements (Karasti et al., 2010; Ribes & Finholt, 2009). Yet, designing an information infrastructure to foster co-operative research and facilitate distributed co-ordination offers several challenges: an information infrastructure is complex and layered (Hanseth & Lyytinen, 2008); it continuously evolves in terms of scale, scope, and functionality (ibid., 2008); and it holds very different meanings for different practitioners in their local settings (Edwards et al. 2007; Karasti et al. 2010).

The concept of *information infrastructure,* and the related notions of *infrastructuring* and *synergising* (see section 2.2.6), can be drawn upon in this PhD insofar as they offer a suitable theoretical lens that can inform the design of complex technology-driven cooperative arrangements in intensely distributed scientific settings. However, information infrastructure tends to be built on an existing infrastructural base (which does not exist for our research as the projects under consideration tend to be created from scratch) and tend to be designed very progressively for the long-term (while the projects considered in our research run only for short period of times e.g. a few years). Our emphasis is perhaps more on probing the roles and interconnections between key artefacts that are designed and used by the co-operating scientists to co-ordinate their work across disciplinary and organisational boundaries and on finding ways to design interactive tools that can support this artefact-driven co-ordination.

So far, this discussion has presented several useful CSCW and e-science conceptualisations to shed light on how to assist the co-ordination of work practices within distributed and interdependent co-operative work arrangements with a specific emphasis on understanding the ways information artefacts are used, configured and managed to support this process. It is essential to note, however, that the distributed work that concerns this research is of a particular nature. Our study is looking at scientific work i.e. the work that scientists undertake to investigate scientific problems and to come up with innovative solutions. The next section considers the Science and Technologies Studies (STS) perspective.

2.4 Scientific work: the STS lens

STS offers an interesting perspective complementary to the CSCW stance to frame the research presented in the thesis. STS proposes that scientific knowledge and technological development are actively constructed through social interactions and thus the conduct of scientific enquiry should be studied through a meticulous examination of the practical activities performed by the scientists, the social interactions between these scientists, and the use of information artefacts to support these activities and interactions (Bijker et al., 1987; Knorr Cetina, 1981a; Latour & Woolgar, 1979).

In the following sub-sections, STS is first considered in its broader context, laboratory studies are presented for their key influence on the study of scientific work and Actor Network Theory is critically discussed. Subsequently, conceptualisations that originated in STS and that emphasise on the roles of information artefacts in bridging across diverse communities are considered. The intent is to develop a better understanding of how these information artefacts are used to co-ordinate activities in settings in which the work is distributed between heterogeneous groups of scientists, with diverse expertise and modes of operating.

2.4.1 Science and Technologies Studies

Science and Technological Studies (STS) (also referred to Science, Technology and Society) is a dynamic, diverse and interdisciplinary programme that aims to study the processes and outcomes of science and technology. It stems from the work undertaken in academic fields as varied as social science, history of science and technology, philosophy and anthropology, among others. STS offers a range of interesting insights on how science is conducted, how technology is developed, and on the implications that both science and technology may have on society (Sismondo, 2011). This section briefly introduces the STS field and identifies and discusses the STS insights into conducting scientific work and developing technology that are relevant to this thesis, particularly with regards to the role of information artefacts in the conduct of distributed science.

The main premise of STS is that science and technology are inherently social and that the origins, dynamics, and effects of science and technology of interest to STS need to be understood through the studies of the activities of and interactions between the actors who do science and technology. This stems from the work of Thomas Kuhn in his influential book *The Structure of Scientific Revolutions* (1970, first published in 1962), a seminal work in STS. In opposition to prevalent views of science at the time that advocated for systematic accumulations of empirical measurements (*locigal positivism*) or for a strict process of conjecture and refutations (*falsificationism*) to develop scientific theories, Kuhn (1970) argued that the focus should be put on the activities of the scientists as part of their communities to understand how scientific facts are actually created. During periods of time he calls *normal science,* members of a scientific field share a *paradigm,* i.e. a common understanding of the main problems in their field and of the key theoretical frameworks and methodological approaches to resolve these problems. These are periods of *puzzle-solving,* during which problems are resolved within the frame of the paradigm and this contributes to the structuring of science. However, at times, the problems faced by scientists cannot be resolved within the existing paradigm any longer and new theoretical models and methods need to be developed. When these theories and methods become more stable and robust they form the basis of a new paradigm. Thus, in Kuhn’s stance, scientific discovery is not the accumulation of scientific knowledge but it is the continuous creation of partial views by scientific actors that are subscribed to by communities of scientists. The social nature of scientific work as articulated by Kuhn had a strong resonance in our research study.

Beyond the social nature of scientific work, another major tenet of STS is that science and technology are not only social but also an active process, and that therefore scientific activity can be viewed as the *social construction* of scientific facts, representations and theories (Latour & Woolgar, 1986; Knorr Cetina, 1981a), while technological development can be seen as the *social construction* of technological products (Pinch & Bijker, 1987). In their work on the Social Construction of Technology (SCOT), Pinch and Bijker (ibid.) formulated a framework to shed light on how technology is socially developed. They posited that a *technological artefact* (i.e. a piece of technology) may be created for a single purpose but that users can find many ways to use it and use it for a multitude of goals. The definition of a particular technological artefact may vary according to the meanings given to it by users and, ultimately, the acceptance of that technological object depends on the size and the influence of the group that takes it up and endorses it: this is referred to as *interpretive flexibility*. Early adopters who take up a piece of technology may often adapt it to their own needs and make innovations, which technology designers and producers can pick up and feed back into the development process. Bijker (1995) extended the ideas of the interweaving of the technical and the social further by developing the concept of *technological frame*. A technological frame can be defined as “the set of practices and the material and social infrastructure built up around an artifact or collection of similar artifacts – a bit like Kuhn’s paradigm” (Sismondo, 2011, p. 102). The idea behind a technological frame is that it should promote *interpretive flexibility* by reflecting both the understandings of the engineers of the key issues of the piece of technology, and the understandings of the users of its potential functionalities, and thus encourage the development of products that are well adapted to and successfully accepted by users. These ideas have also permeated our research study.

The advocates of a social construction of scientific knowledge also promote an active view of scientific discovery, and posit that substantial work is necessary for scientific claims to become important and be accepted as scientific facts. In short, they posit that scientists undertake a fact construction process. For instance, Latour and Woolgar (1986) describe the steps taken by researchers to determine a hormone produced by the hypothalamus and follow the many different stages the hypothesis made for this hormone went through from *near nonsense*, to *possible*, to *false*, to *possibly true* and finally to a *solid fact*. In this view, scientists are seen as actors who work actively to develop methods to transform data into representations (i.e. accounts, models and theories based on this data) which are the most adequate for the phenomenon, while still taking into account the local circumstances (Knorr

Cetina, 1981a). This view of the social construction of science has found particular resonance in a strand of STS which is of particular interest to this research – laboratories studies.

2.4.2 Laboratory studies

In the 1970s and 1980s, a number of scholars adopted a new approach which consisted of conducting ethnographic studies in scientific laboratories to observe first-hand the practical work and day-to-day activities of the scientists on site in their laboratories (Collins, 1991, Knorr Cetina, 1981a; Latour & Woolgar, 1986; Lynch, 1985; Traweek, 1988; Zenzen & Restivo, 1982). The influential book *Laboratory Life* by Latour & Woolgar (first published in 1979, then re-edited in 1986), which provides an account of the ethnographic work conducted in a high-profile biochemistry laboratory, is considered seminal by many laboratory-based studies of the social construction of science (Berg & Bowker, 1997; Hine, 2007; Mody, 2005; Oleksik et al, 2014) and was a key starting point for our research. In their study, the two scholars meticulously analysed the actions and interactions between scientists operating in a lab. In this work, Latour and Woolgar contended that scientists construct facts they consider to be close to the truth through their practical activities, their interactions and actions. "Scientific activity is not 'about nature', it is a fierce fight to *construct* reality. The laboratory is the workplace and the set of productive forces, which make construction possible." (Latour & Woolgar, 1986, p. 243).

Latour and Woolgar's seminal work, and subsequent studies, provided more insights on how what occurs in the labs shapes the formulation of accepted scientific facts. The actions that take place in the lab, and the scientific reasoning which accompanies these actions, are linked to the local circumstances and are not predictable from the outset. Social interactions between researchers decide what needs to be investigated, negotiations determine what claims are worthy to be published in scientific papers and rhetorical manoeuvring help mould findings so that can be accepted by other members of the community (Knorr Cetina 1981a; Lynch 1985). Laboratory work is not only about defining the most suitable representations of the observed phenomenon or identifying the clearest patterns from the collected data, but it is about the active manipulation of materials (Hacking, 1983). Objects are placed in artificial situations and subjected to experiments to see how they react and to characterize their properties – as referred to as *trials of strength* by Latour (1987). However, this experimental process is rarely straight-forward as manipulations often do not work the way they are intended to, pieces of equipment fail or materials do not behave the way they are meant to. Therefore, laboratory work requires a large amount of *tinkering* (Knorr Cetina, 1981a) or *bricolage* (Lynch & Woolgar, 1988). Prior systematic planning cannot forecast all the contingent situations faced in the laboratory and needs to be complemented with sound scientific reasoning tailored to every problem encountered (Pickering, 1995).

The view of scientific work and the conduct of scientific enquiry advocated by the proponents of laboratory studies is influential in this thesis. The idea that scientific facts are socially constructed as the result of complex interactions and negotiations between different scientists, and between the scientists and the objects they manipulate, is key in this research. It greatly motivates and influences the meticulous investigation in our research study of the fine details of social interactions between (and manipulations of materials by) co-operating scientists in the settings of complex global projects.

To summarise, the idea of the social construction of science has had great resonance in the STS research community, and laboratory studies have had a far-reaching impact. They led to many attempts to better understand and shed light on how scientific facts are socially established and accepted by scientific research communities. A number of key contributors to laboratory studies subsequently developed Actor-Network Theory (ANT), which has received a great deal of attention, and has become an essential theoretical underpinning of the STS discipline. It is considered next.

2.4.3 Actor-Network Theory

ANT is an integrative theoretical framework that aims to provide an overarching understanding of how both scientific facts and technological objects are socially constructed (Callon, 1986; Latour, 1987; Law, 1987). ANT is centred on *technoscience*; in this view, the conceptual distinction between technology and science is avoided as technology and science are deemed to be interdependent, and to involve similar processes, while scientists and engineers are seen as being only separated by disciplinary divisions (Latour, 1987). ANT depicts the work of technoscience as the creation of heterogeneous networks of relations which involve human and non-human entities (scientists, equipment, institutions and external partners) and which seek to become sufficiently large and stable so that to result in a successful piece of technoscience being generated (Sismondo, 2011). The *actants*' role is to manage these networks so that they work towards a common goal; this implies making all the components of the network act together to make a *machine* function or to have a scientific *fact* convincingly recognized and accepted. The activity of technoscience thus consists of understanding the *interests* of the various actors and the *translation* of these interests so that all the actors work together towards the common goal (Callon 1986; Callon and Law, 1989).

This translation work entails the conversion of actions and forces from one form into another. It involves the reconfiguring of the actions of the actors so that they are *made to work* together, the manipulating of materials so that they are made to fit to the environment, and the shaping of raw data into different forms of representation. "Data-level representations are themselves juxtaposed to form new relationships that are summarized and otherwise manipulated to form higher-level representations, representations that are more general and further from their objects (Sismondo, 2011, p. 83). Techniques are applied to handle data i.e. to extract it, summarise it or make relevant groupings. Materials are acted upon using various pieces of equipment. Interactions occur to make sense of the manipulated materials and data and create representations that have a relevant meaning in the local environment but that can also be applicable to other circumstances through a set of new manipulations.

ANT has been the object of a series of criticisms. A major objection concerns the assumption made by ANT that human and non-human agents have the same roles within the network of relationships and act in symmetric ways (Collins & Yearley, 1992). This has been refuted by ANT proponents who insist that, however symmetric ANT was designed to be with regards to human and non-human agents, a particular attention is given to scientists and engineers (Sismondo, 2011). Another critique of the ANT approach is the over-emphasis on the minute details of the local networks, as heterogeneous as they are meant to be, which can lead to an exclusion of the effect of external factors on scientific work arrangements (ibid.). In particular, in an established laboratory, the institutional and disciplinary perspectives and work practices that may motivate and drive the actions of the scientists and engineers may be overlooked in this ANT approach, and thus interesting aspects of the development of science and technological artefacts may be disregarded.

In the stance adopted in this thesis, the heterogeneity of scientific and technical perspectives that come from the diversity of the actors involved in the intensely distributed arrangements of a cross-disciplinary and multi-sited project is essential and cannot be ignored. Scientists in this type of distributed projects would all have very different ways of operating that are influenced by a range of external factors, such as the institutional *modus operandi*, disciplinary assumptions and expectations or individuals' technical proficiencies. Consequently, ANT was not selected for this investigation. Rather, additional theoretical conceptualisations, that originated in STS, and which focus on the roles of information artefacts, and that can take into account the heterogeneity of work practices, are considered next – *boundary objects.*

2.5 Co-ordinative artefacts across heterogeneous perspectives

Intensely distributed scientific projects require a range of co-operating actors from a variety of scientific backgrounds and technical expertise to come together, interact and articulate their practices to successfully complete complex experimental and analytical activities and thus develop scientific ideas and technological solutions. This may be particularly challenging when work is greatly distributed between very heterogeneous groups or teams which assemble individuals with a diversity of scientific profiles, geographical and professional backgrounds, prior experiences, technical specialities and very different perspectives and ways of operating. A rich body of academic research has been conducted to explore how various coordinating artefacts are used to support diverse groups of co-operating actors with very diverging practices and perspectives to work together. These include *boundary objects* and their extensions to *boundary negotiating artefacts, boundary specifying objects* and *boundary negotiating objects* and are presented in table 2.2. The table gives a brief definition of the theoretical construct, presents empirical studies conducted to help formulate these concepts and identifies key scholarly work that helped inspired their development.

Concept & main references	**Brief definition & overview**	**Key empirical studies of boundary objects & extensions**	**Significant work drawn from**
BOUNDARY OBJECTS (Star & Griesemer, 1989), Star (1989), (Bowker & Star, 1999)	Information objects which help organise interactions and link up perspectives of the intersecting communities of shared knowledge and practices.	• Engineering: sketches, diagrams, drawings and blueprints (Henderson, 1991, 1999) • Scientific models (Sundberg, 2007; Egmond & Zeiss, 2010) • IT System design specifications (Eckert & Boujut, 2003; Stacey & Eckert; 2003; Boujut & Blanco, 2003) • Medical records (Berg & Bowker, 1997; Bossen et al., 2014)	• Social worlds (Strauss, 1978) • Classification & standardisation (Bowker & Star, 1991)
BOUNDARY NEGOTIATING ARTEFACTS (Lee, 2007)	Information objects which are used to negotiate and define the areas of influence of various perspectives and the zone of co-operation.	Museum exhibition design: range of artefacts and social practices (Lee, 2007)	Boundary objects (Star & Griesemer, 1989)
BOUNDARY SPECIFYING OBJECTS (Pennington, 2010)	Information objects that interrelate various perspectives to enable seamless co-operation even without direct interaction.	Standardisation of methods in the cross-disciplinary development of scientific cyberinfrastructures (Pennington, 2010)	Boundary objects (Star & Griesemer, 1989), Boundary negotiating artefacts (Lee, 2007)
BOUNDARY NEGOTIATING OBJECTS (Pennington, 2010)	Information objects which are used to articulate the co-operating parties' working practices and create a space for co-operation.		

Table 2.2: Boundary objects and related concepts

2.5.1 Boundary objects

Boundary objects (Star & Griesemer, 1989) offer a flexible concept for understanding communications and interactions across heterogeneous communities of shared knowledge and practices, in what has been referred to as *social worlds* (Strauss, 1978). A *Social world* is defined as a group or collectivity of individuals organised around a particular activity or issues of mutual concerns and sharing resources, viewpoints, and commitment to action. "The framework [of social worlds] is relentlessly ecological, seeking to understand the nature of relations and action across the arrays of people and things in the arena, representations (narrative, visual, historical, rhetorical), processes of work (including co-operation without consensus, career paths, and routines/anomalies), and many sorts of interwoven discourses." (Clarke and Star, 2008). Examples of social worlds include academic disciplines and groups of expertise or professional bodies.

Boundary objects are essentially information artefacts that exist at the junction between different social worlds, at the point where social worlds meet around an area of common interest, and which help organise interactions and link up the perspectives of these intersecting social worlds. The concept was originally developed in STS as a way to understand how communities of scientists, and other affiliates with very different practices and needs, were able to co-operate using the same objects (Jirotka et al., 2013). In the historical case study of Berkeley's Museum of Vertebrate Zoology, Star and Griesemer (1989) investigated how the members of the different social worlds involved in the museum (amateur and paid collectors, taxidermists, research scientists, curators, administrative staff, philanthropists, adherents of scientific clubs) interacted around specimens of animals despite having very different visions of the museum, of its goals and of the work to be done in priority. All had diverging concerns about the animals that needed to be addressed and articulated for the collection to work appropriately for all parties. For instance, standardised records that kept information of the specimens in the museum were identified as essential key boundary objects that connected the various social worlds together. Despite these records having different meanings, the various groups of interest involved in the running of the museum could use them and contribute to them. Record keeping thus allowed the various groups to interact and articulate their actions while maintaining their working practices and their identities.

Boundary objects are sufficiently flexible to be adapted to the local requirements and constraints of the actors using them but can also help individuals retain their identities when used across communities (Star & Griesemer, 1989). When looking in more detail at how boundary objects cross through heterogeneous practices, two processes have been identified (Star, 1995). They highlight the importance of the role of standardisation in allowing the actors in different social worlds to work together co-operatively. First the representation of the object needs to be abstracted to produce standardised and decontextualized data that can be transported across to another setting without the carried information being lost or modified. Then a process of *re-representation* needs to occur so that the abstract and standardised representation is re-adapted to a particular working situation. This is a challenging process, in Star’s view (1995), as there is a continuous tension between producing standardised and abstract representations and undertaking real-time work.

The intrinsic flexibility of the concept of *boundary object* – i.e. its *plasticity* (Star & Griesemer, 1989; Bossen et al. 2014) – has made it a very attractive concept to both the STS and the CSCW disciplines. *Boundary objects* have been adopted to provide a theoretical conceptualisation for a wide range of information artefacts used by actors emanating from different perspectives and working together in an array of co-operative arrangements. In STS, these include information objects as varied as engineering sketches, diagrams, drawings and blueprints (Henderson, 1991, 1999); scientific models such as climate model parameterisations (Sundberg, 2007) or ecological simulations (Egmond & Zeiss, 2010); and even data produced by censors in a research centre (Mayernik et al., 2012). In CSCW, boundary objects have denoted use-case scenarios (Bødker & Christiansen, 2006); industrial or commercial design specifications (Boujut & Blanco; 2003; Stacey & Eckert; 2003); workflow systems (Herrmann & Hoffmann, 2005) or hospital medical records (Berg & Bowker, 1997; Bossen et al., 2014).

As illustrated by some of these examples, the notion of *boundary object* has gained a huge popularity due to its intuitive appeal to explain how specific objects are used to bridge across the practices of diverse communities (Lee, 2007). As explained, their *plasticity* of meaning is what makes them attractive as it is their inherent flexibility to be interpreted in multiple ways that enables them to be used to translate ideas and perspectives across community boundaries, organisational boundaries, or institutional boundaries, otherwise difficult to cross (Lutters & Ackerman, 2006). However, concerns have been expressed about *boundary object* being an overly loose concept that can be applied to pretty much anything that conveys information in the setting in which collaborating actors operate, whether it is a tangible object or a more conceptual entity (Bossen et al., 2014; Lee, 2007). From its inception, Star and Griesemer

(1989) introduce a variety of examples of boundary objects which included, not only the specimen of animals under consideration and the standardised records that characterise them, but also the zoology museum itself and the wider geographical area where it is located. Kim and King (2000) view the engineering problem around which various engineers interact as a possible boundary object. Whereas for Lutters and Ackerman (2006), it is the over-emphasis on boundary objects as physical artefacts that limits the analytical potential of this conceptualisation to help understand how mediation can be supported in routine work. In their view, the fact that any form or list can be seen as a boundary object is restrictive and fails to grasp the more complex mechanisms of how these artefacts are used to bring together different perspectives or act as points of negotiations between different practices. Lee (2007) concurs with this view and see the problem with boundary objects as being two-fold: it is an incomplete theoretical model in the first place but in addition it is used superficially without considering the finer points of its definition.

As a response to these various criticisms, a finer but also more flexible conceptualisation is provided by one of the originators of the *boundary objects* construct, Susan Leigh Star (2010), twenty-one years after her 1989 seminal paper with James R. Griesemer. She defines *object* in this context as something that people can act towards, and explains that in this view the question of its materiality is not essential as it derives from the action that it allows people to take. In her stance, boundary objects are things that form boundaries between groups through flexibility and shared structure and that essentially enable action between the various participants in and between groups. Thus, she advocates a dynamic view of boundary objects, in the sense that they can be specified with different levels of granularity depending on how they are used. The boundary object should have the capacity to be modified locally to maintain its vague identity as a common object when it is used in an interdisciplinary setting or be made more specific and tailored to local situations when it is just used internally (Star, 2010). Despite these attempts by Star to clarify the *boundary objects* construct, several conceptual extensions have been made to the original construct. These are discussed next.

2.5.2 Boundary negotiating artefacts

Lee (2007) contends that the main issue with the *boundary objects* conceptualisation is that too often it is adopted mechanically to refer to any information artefact used in a co-operative work arrangement (and generally an information artefact with a physical existence). Thus, in her view, the notion lumps together all information objects without differentiating them. She maintains that a clear conceptual distinction should be made between *boundary objects* and *boundary negotiating artefacts.*

In her stance, *boundary objects* are those artefacts that are used as gateways through which knowledge can be exchanged across diverging perspectives. Essentially, they are information artefacts that are defined and utilised because of the need for the standardisation of practices from diverse components of a work arrangement. In contrast, *boundary negotiating artefacts* are used to actively negotiate and define the areas of influence of the various interrelated perspectives and thus the sphere in which co-operation occurs. They are used to "record, organize, explore and share ideas; introduce concepts and techniques; create alliances; create a venue for the exchange of information; augment brokering activities; and create shared understanding" (Lee, 2007; p. 333). In doing so they actively participate in the setting up of standardised processes that allow for different work practices to be aligned.

2.5.3 Boundary specifying objects and boundary negotiating objects

Pennington (2010) expands on the idea expressed by Lee (2007) that boundary objects can play different roles in the way they can be used by co-workers from very different perspectives to interconnect and organise their work co-operatively in a shared arrangement. She re-positions slightly the conceptualisation formulated by Lee and explains that *boundary objects* should be viewed as an overarching notion that encompasses both *boundary specifying objects* and *boundary negotiating objects*. In her stance, *boundary specifying objects* are those information artefacts that interrelate the different perspectives in ways that the actors from these perspectives can co-operate smoothly and may not even require direct interaction. Conversely, *boundary negotiating objects* are used to actively articulate the co-operating parties' working practices and create a space for co-operation.

Pennington (2010) explores in depth the inter-relationship between these types of boundary objects but also their relationship with the concepts of standardisation and articulation work (both key to this thesis) in multi-perspective co-operative settings. By probing the work of scientists, engineers and computer scientists in the context of the cross-disciplinary development of scientific cyberinfrastructures, a study of relevance to our research, she puts forward a dynamic model of boundary objects. This model contends that co-operating actors iteratively consider ideas from different perspectives using boundary negotiating objects so that to create conceptual connections which allow them to align their methods and standardise their work practices. **Boundary negotiating objects are used iteratively to mediate the articulation of the working practices of the different parties to enable progressively the alignment and the standardisation of the various methods in use.** "Task and approach articulation work are accomplished by recursive mediation and negotiation processes nested within each of these" (Pennington, 2011, p. 193). **This alignment and standardisation of methods in turn leads to the creation of more stable boundary specifying objects that allow the group members to work independently and synergistically.** However, these boundary specifying objects are not static as they are continuously reconfigured to respond to the ever-changing nature of the setting and need to be flexible depending on the type of work under consideration. "Routine sequential collaborative work necessitates rigid boundary objects that require no context or additional information for use. More complex, integrated work, such as scientific collaboration, necessitates more flexible boundary objects" (Pennington, 2011, p. 194).

This conceptual distinction between *boundary specifying objects* and *boundary negotiating objects* has a great deal of resonance with the work in our study. It has the potential from the outset to help construct a detailed understanding of the inner mechanisms of how various information artefacts are used in intensely distributed co-operative arrangements to interconnect diverging perspectives and work practices to support the co-ordination of complex distributed work.

A different stance than the one in STS described in the previous section has been adopted by the inter-disciplinary academic field of Organisation Studies and is discussed as follows.

2.5.4 Sociomateriality of co-ordinative artefacts

The issues around organising and co-ordinating distributed work activities in global organisations, and the roles that technological and information artefacts in *organising*, have been of particular interest to a strand of Organisation Studies referred to as Practice-based

Studies (Nicolini 2011; Orlikowski 2002, 2007; Osterlund & Carlile 2003). They suggest moving away from the STS perspective as, in their view, STS offers an overly narrow perspective on technology that considers technological artefacts as merely a set of tools used by organisation members to process work inputs (Carlile et al., 2013). Nicolini et al. (2012) advocate also going beyond the artefact-centric notion of *boundary objects,* as they regard it as a concept that has been over-used and has seen its theoretical influence diluted (also see section 2.5.1). In contrast, practice-based study proponents look at organising in terms of practices that encompass material and social aspects completely enmeshed within each other (ibid., 2012), as captured by the idea of *sociomateriality*.

The *sociomateriality* perspective has been developed in organisation studies in parallel to practice-based studies as a perspective to specifically investigate the roles of objects and artefacts in organisational activities (Carlile et al. 2013). It can help investigate how information artefacts play an active part in doing the work involved in setting up and maintaining relationships and how in turn social interactions shape and effects the way artefacts are used in the practice of work (Carlile et al. 2013; Leonardi, 2012). The advocates of sociomateriality posit that the materiality of artefacts is tightly connected with their social use in the actual practice of work (Barad, 2003; Orlikowski, 2007). This view suggests that "the social and material are constitutively entangled" (Orlikowski, 2007; p.1437) as they emerge from situated practices. Meanings and materialities of artefacts are enacted together through their social use in everyday practices (Barad, 2003; 2007; Introna, 2007; Suchman, 2007).

The notion of *materiality* refers to a combination of matter and form that constitute intrinsic properties of objects and artefacts that are stable across space and time, at least for a certain duration. This stabilisation of the constituent properties of the artefact is what allows people to cooperate in the way that these fixed properties affect what actors consider essential for their work (Leonardi, 2012). Materiality enables social action by offering capacities for action that relational distributed and enacted (Orlikowski, 2009). The construct of *affordances* is used by the organisation studies scholars with an interest in sociomateriality to designate *materiality in practice.* Affordances are a set of contingent material capabilities of an artefact

(Keane, 2005) that can be selected and deployed by actors to facilitate or constraint certain aspects of their work (Alcadipani & Islam, 2017).

These ideas of *sociomateriality*, *materiality* and *affordances* (from a sociomaterial stance) can offer a different but interesting stance on our study and theoretical understanding of the co-ordination of intensely distributed scientific work of concern to this PhD. Despite not being central to this thesis, these can help us look at the ways the sociality of work and the materiality of artefacts are closely interweaved and how the materialities of artefacts can be enacted in practice, through a number of affordances, to ultimately support distributed co-ordination in global scientific settings.

2.6 Chapter conclusion

In line with the doctoral research aim and objectives, this chapter has reviewed major CSCW and STS scholarly efforts in the areas of co-operative work and the co-ordination of work practices and with regards to the conduct of scientific enquiry. This has been done with the specific intention to identify key conceptualisations from CSCW and STS that can provide useful theoretical lenses to shed light on how information artefacts are used in complex work arrangements, set up for scientific investigation, to support the co-ordination of work practices to achieve concerted action.

The view of co-operative work subscribed to in this research is social, highly situated and organised over interdependent work arrangements that are dynamic and distributed across individuals, groups and expertise. In our perspective, *awareness* is an active process by which co-workers are kept informed of the spatial and temporal confines of each other’s actions (Gutwin & Greenberg, 2002), of each other’s perceptions of the co-operative arrangement in relation to the shared goals and collective activities (Leinonen, 2005; Tenenberg et al., 2016) and of the changes made to the information artefacts in the co-operative setup (Tam & Greenberg, 2006).

The view of *articulation work* advocated in this research makes a distinction between two complementary facets. At the macro-level of the interdependent arrangement, *metawork* denotes the work that needs to be undertaken to organise and monitor the activities between different co-operating groups, and ensure they work well together, using pre-defined specifications and representations e.g. plans, schedules, procedures, lists, etc. At the micro-level of the local settings where the activities take place, *local articulation* refers to the work of assembling of all necessary resources at the correct time and place to ensure that situated tasks are accomplished and arising contingencies can be dealt with.

Coordination mechanisms and *ordering systems* are CSCW operationalisations of *articulation work* that are adopted in this research to theoretically explain how information artefact can be used to mediate *metawork* and *local articulation* using information artefacts. A *coordination mechanism* is essentially a *coordinative protocol* (a set of conventions and/or procedures) represented by a *coordinative artefact* (a symbolic and standardised representational artefact). It stipulates the work to be done and mediates articulation work by conveying the state of and changes to the execution of the stipulations it carries. The concept has been developed with computerisation in mind to provide a pre-computation of task interdependencies and the required flexibility to deviate from them. *Ordering systems* extend *coordination mechanisms* to consider all *coordinative practices* (i.e. the actors' specialised practices to manage their work interdependencies) using a cluster of protocol / artefacts dyads including procedures to temporally organise distributed activities, in conjunction with as notations, nomenclatures, classifications or standardised formats.

In parallel, the view of scientific work in this research is significantly informed by STS, and particularly *laboratory studies*. In this view, scientific outputs (scientific facts, representations and theories) are *socially constructed* through a process of continuous interactions and negotiations around the validity of the produced outputs and around the active experimental manipulation of materials that is inherent to scientific enquiry work. Tinkering or bricolage is embraced in this experimental manipulation to deal with continuously arising contingencies that result from the situatedness of experimental activities. As part of this social construction of scientific facts, information artefacts are used to mediate the interactions and negotiations between different scientists, and between the scientists and the materials they manipulate.

Several constructs developed in STS to understand the mediating roles of information artefacts, and related to the notion of *boundary objects* are also key in this thesis. These theoretical approaches suggest various ways in which information artefacts can be used to support the co-ordination of practices distributed across different *social worlds* (heterogeneous communities of shared knowledge, viewpoints and commitment to action) as it is very much the case in ever increasingly complex scientific projects. Specifically, the interplay between *boundary negotiating objects* and *boundary specifying objects* is of great relevance to our study, as it is well aligned with the view of scientific work as driven by social interactions and negotiations. *Boundary negotiating objects* are used by different co-operating parties to create conceptual connections with their partners from different perspectives to enable the alignment and standardisation of methods. This alignment leads to the creation of *boundary specifying objects* that allow the group members to work independently, yet synergistically, and contribute to the common aim of the co-operative arrangement.

In order to study scientific work that is intensely distributed over co-operative interdependent work arrangements set up across various social worlds, and the ways in which information artefacts are used to support the co-ordination of the different efforts, a methodological approach needs to be carefully selected. A review of such approaches that has the potential to offer valuable insights in this area are reviewed in the next chapter and a selection is operated.

Chapter 3 Methodological orientations

3.1 Chapter introduction

The issue under investigation in this PhD – the co-ordination of intensely distributed scientific work and the ways information artefacts support it – is exploratory in nature. The complexities of the interdependences in global cross-disciplinary work arrangements call for a multi-method, multi-perspective, and multi-sited approach that can help us understand these complexities, as well as the richness of the interactions between the actors in these settings and how these interactions occur through the information artefacts they use in their daily work practices (Crabu & Magaudda, 2018; Espinosa et al., 2002; Malhotra & Majchrzak, 2014; Marcus, 1995; Mikalsen et al., 2018). This multi-method approach draws on multiple perspectives that originate from ethnography.

The main aim of ethnographic fieldwork is to uncover the real-world and real-time social character of a particular setting. It is a research approach that relies on material extracted from the first-hand experience of a researcher *in the field*, i.e. in a specific setting (Hughes et al, 1995), and that is concerned with the production of meticulous in-depth descriptions of the activities of the social actors within this setting (Hughes et al, 1993). Ethnographic fieldwork emphasises the direct involvement of the researcher in a setting to depict the lives of people in this setting, from their perspectives, to understand them in their own terms: "the intention of ethnography is to see activities as social actions embedded within a socially organised domain and accomplished in and through the day-to-day activities of participants." (Hughes et al., 1995; p. 20). There have been very rich traditions of conducting ethnographic fieldwork studies in both CWCW and STS, and ethnographic fieldwork appears to be a good fit for our study to probe how the co-ordination of intensely distributed scientific work is supported by information artefacts, with a view to inform the design of interactive co-ordinating systems.

This chapter reviews several ethnographic fieldwork perspectives and underlying ideas to identify the most appropriate approach for informing our study of intensely distributed scientific work that can help uncover in-depth insights into the co-ordinative roles of information artefacts. The chapter first presents a brief reflective review of various ethnographic perspectives that we think can be influential, to various extents, towards our own research approach. It also briefly covers alternative ethnographically-informed approaches that could have been drawn on for inspiration but that were not selected. The chapter then focuses on how ethnographic fieldwork has been used in CSCW to probe co-operative work, the co-ordination of work practices, and the design of computerised systems to support these, and in STS to investigate scientific enquiry work and the development of technological artefacts. The final section of the chapter then defines and describes the multi-method approach adopted in our study of the roles of information artefacts in intensely distributed scientific work as methodologically and conceptually inspired by three orientations of ethnography: design-oriented, interactionist, and multi-sited.

3.2 Ethnographic fieldwork: key perspectives of interest

The term *ethnography* is ambivalent as it often refers to a discipline, the active process of conducting research in situ, *in the field*, as well as the final textual output of this research process, i.e. the written report or monograph that describes the research practice, presents a resulting analysis, and provides some in-depth insights into the issues of investigation. To clarify this right from the outset, the term *ethnography* is used in this thesis to describe the discipline or a particular orientation in this discipline while *ethnographic fieldwork* or *fieldwork study* or simply *fieldwork* are used to denote the set of activities conducted by the researcher in the field to probe a specific area of interest following an ethnographic perspective (Atkinson et al., 2001; Gellner & Hirsch, 2001).

3.2.1 Briefly defining ethnographic fieldwork

Ethnographic fieldwork denotes a methodological approach central to social research that originates from anthropology. Essentially, it is based on the first-hand experience and empirical investigation of a particular social or cultural setting, through immersion in this setting (Atkinson et al., 2001; Hammersley & Atkinson, 2007). *Participant observation* is often underscored as a key method in fieldwork and can be defined as follows: “participant observation is a method in which a researcher takes part in the daily activities, rituals, interactions, and events of a group of people as one of the means of learning both the explicit and tacit aspects of their life routines and culture. Participant observation is considered almost universally as the central and defining method of ethnographic research." (Musante, 2014; p. 251). Thus, in this view, the *ethnographer* (i.e. the researcher in the field) conducts *fieldwork studies* that entail them to participating in the investigated people's lives for a substantial period, observe the events that unfold, listen to the conversations, ask numerous questions formally or informally and generally gather whatever data is available that can shed light on the focus of enquiry.

Hammersley & Atkinson (2007) provide a list of well-recognized common features of ethnographic fieldwork which gives a useful practical way to characterise and frame this methodological approach for our study.

- People's actions and accounts are probed in the everyday setting in which people operate;
- Data is collected from a wide variety of sources including from formal and informal conversations, participant observations and documentary evidence;
- The gathering of data is flexible in the way that it does not necessarily require a fixed research design to be specified at the start and for pre-determined themes to be built from the outset. The research design can evolve and the categories used for the interpretation can emanate from the data collection process and be defined through the data analysis;
- The focus is generally on a fairly contained setting or group of people to enable in-depth study;
- The analysis of the collected data entails the interpretation of the meanings, the purposes and the implications of people's actions and organizational practices within the local settings within which they operate and possibly within wider contexts.

In summary, ethnographic fieldwork is a relatively open-ended approach that aims to investigate people's lives in a particular social or cultural setting, how they view the situations they faced and how they view themselves and one another in these situations. It is firmly rooted in the first-hand exploration of research settings and data collection from a wide range of heterogeneous data sources in 'natural' settings – the *field*. Based on these premises, there have been many different academic schools, different interpretations of how ethnographic fieldwork should be conducted, and different foci that this methodological approach has adopted. The following sections aim to provide a brief and non-exhaustive overview of some of these strands and interpretations of ethnographic fieldwork to help better contextualise the approach selected in this thesis.

3.2.2 The Chicago School of ethnography

The Chicago School of ethnography has been widely influential both theoretically and methodologically. It encompassed a number of essential fieldwork studies in a wide range of settings and is considered as a key root of interactionist ethnography of interest to our study and covered in the next section. This section briefly introduces the Chicago orientation and highlights several of its methodological contributions.

The so-called Chicago School of ethnography (and interactionist ethnography discussed in the following section) was largely inspired by the work of the philosopher, sociologist and psychologist George Herbert Mead who was an influential figure in the University of Chicago from 1894 until 1931. Mead's seminal book *Mind, Self and Society* (1934) is often considered a major theoretical underpinning of both the Chicago and interactionist ethnographic schools. It defined an elaborate model of human behaviour that permeated the ethnographic work of both these schools, helped shape the role of the social scientist – and thus the ethnographer – and laid the methodological foundations in both these streams of study.

Mead's thesis, as developed over the years, is essentially that individuals become human through interactions with others. The individual's self, their thoughts and community all have a social nature and are the products of human meanings and interactions. Participating in human society requires developing a sense of oneself as a unique individual while at the same time integrating into the community's wider set of rules and shared understanding (Sharrock et al., 2003). Thus, within their communities, humans learn social and institutional patterns which are determined by shared languages and symbols (i.e. signs, characters, features representing ideas, objects or relationships) (Deegan, 2001). For them to operate collectively, they need to interpret the shared meanings allocated to gestures, acts and representations within a particular social setting (Sharrock et al., 2003). In this view, and significantly for our study, human intelligence is essential not only for making sense of representations and the actions of others, but also for reflective behaviour. Hence, the field researcher has a fundamental responsibility to observe, to collect and interpret data about people, and also to actively take the role of others to understand how humans learn to become part of society (Deegan, 2001).

This model of human behaviour as developed by Mead over several years influenced the work of several scholars who worked in or around the University of Chicago. These include the urban sociologists William Isaac Thomas and Ernest Burgess (both students of Mead), as well as Robert Ezra Park (who studied with the philosopher, psychologist and educationalist John Dewey by whom Mead was greatly inspired). Following Mead’s intellectual approach, Thomas, Burgess, Park and colleagues conducted what is often referred to as the core Chicago Ethnographies, from the late 1910s to the early 1940s. These encompass a series of significant sociological studies, primarily in urban settings, to get first-hand insights into the realities of a range of people and of how they perceived their own lives from the inside. Their ultimate goal was to develop an understanding of different forms of social organisations with the intent to contribute to social reform. Thus, these studies focused on a great variety of human experiences (primarily in Chicago, USA) to probe the diverse patterns of behaviours of various categories of people and understand how they made sense of their own actions in their specific situations. When conducting their field studies, the ethnographers would completely immerse themselves in the settings studied and collect vast amounts of data on the people and on the contexts of their lives in these settings (Deegan, 2001).

Each study provided a detailed discussion of the approaches used for collecting data, which typically included multiple methods, both quantitative and qualitative, often used jointly to construct an in-depth understanding of how people acted and interacted in their natural environments, and made sense of their actions and interactions. The various data collection techniques adopted by the Chicago School of ethnography for empirical research are described in detail in the seminal methodological textbook (Palmer, 1928). These include:

- *Mapping*. This is a quantitative method that consists of the use of large maps of the city along census data to characterise accurately the various “natural social areas” (Palmer, 1928, p. 70-74) of the Midwestern metropolis.

- *Observations*. This is defined as a process by which the investigator selects certain aspects of the event, based on his/her background, interests and attitudes which "all affect the validity of his scientific observations", and pays a particular attention to these aspects (p. 162).
- *Social research interviews*. It is employed to obtain "a vivid, accurate, and inclusive account of the events as they are reflected in personal experiences" (p. 170). The emphasis is on the attitudes of the interviewed individuals as they are representative expressions of the group they are a member of.
- *Diaries*. It is recommended that two types of diaries should be kept. One should be used to meticulously record details of the behaviours of the studied group to objectively report on the investigator's observations and experiences with this group. This should provide the "backbone of sociological data" (p. 106). A second one should be more reflective and be used to capture the investigator's experiences with the collecting of data from *inside* and to highlight the issues encountered.
- *Case analyses*. Fully documented case studies are deemed to be a valuable source of data to construct social generalisations. The ability to formulate these conceptual findings depends on the investigator's capacity to detect new relationships in his data.

In summary, the Chicago School of Ethnography has had a great influence on sociology and beyond both for its philosophical underpinnings and its methodological implications. Both its theoretical foundations and the methodological perspectives it advocates have had great resonance in both CSCW and STS, as illustrated further in sections 3.4 and 3.5. The underlying perspective it promotes of individuals as defined by their interactions with others has helped shape the view of ethnographic fieldwork as an approach that aims to interpret the shared meanings of people's actions within a specific setting to develop an understanding of the social organisation within which they operate. It has informed the production of a large corpus of essential studies of a range of human experiences which have relied on the deployment of a variety of methods and techniques, largely drawing on the approaches advocated by Palmer (1928), that have permeated ethnographic work to this day. Symbolic interactionism was derived from the Chicago orientation and is considered next.

3.2.3 Interactionist ethnographic fieldwork

This section briefly introduces the interactionist ethnography stream, discusses its distinctiveness and intellectual contributions and explains how it inspired our study.

Interactionism and *symbolic interactionism* are sociological traditions that are tightly interconnected, if not one and the same. If for some scholars, *interactionism* is a broader perspective than *symbolic interactionism* (Atkinson & Housley 2003), others acknowledge that both terms have often been used interchangeably (Fisher & Strauss, 1978). In line with Susan Leigh Star and Adele Clark, self-proclaimed *interactionists,* who adopt a *symbolic interactionist* perspective in their study of science, technology and medicine (Clarke & Star, 2003), both the terms *interactionist* and *symbolic interactionist* are used in this thesis to refer to the same tradition. The next paragraphs introduce *symbolic interactionism,* discuss the relevance of an interactionist approach for this research and briefly underlines methodological implications for our research.

Symbolic Interactionism

Symbolic Interactionism is a sociological framework and perspective concerned with the processes that emerge during social interactions and particularly with the ways individuals use objects to derive meanings from social interactions and act towards things based on these meanings (Blumer, 1969). The name was coined by the American sociologist Herbert George Blumer in 1937 to refer to a distinctive style of sociological reasoning and methodology that emerged gradually out of the studies conducted by the followers of the Chicago School of Sociology (Blumer, 1969). Herbert studied and taught with Mead and was directly inspired by his ideas on human behaviour. He was also influenced by the work of the Chicago Sociologists Thomas and Park, which led him to develop and shape symbolic interactionism as a coherent sociological perspective. His departure point was the idea formulated by Mead that humans have the ability to engage in a process of self-interaction, i.e. the reflexive capacity to treat themselves as if they were others to establish the best possible course of action in a given situation and to adjust their action as events unfold. Thomas' concept of the *definition of the situation*, i.e. the process by which individuals align their actions in relation to the actions of others to ensure that their actions comply with what the others are doing or intending to do, also helped shape symbolic interactionism (Sharrock et al., 2003).

These considerations led Blumer to conceptualise symbolic interactionism based on three main points (Blumer, 1969):

(1) People act towards things depending on the meanings these things have for them. The active process of interpretation and definition that people engage in to make sense of their own actions, of those of others, and thus of the world in which they operate, is an essential trait of human social life.

(2) The meaning of things emerges from the social interactions that people have with each other rather than being inherent to these things. Meanings are thus social products, i.e. “creations that are formed in and through the defining activities of people as they interact” (ibid., p. 5).

(3) The meanings of things are handled and adjusted through the interpretive process that people use to deal with things they encounter. Meanings are viewed as interpretive actions from the actor: the actor gives meanings to objects, acts on the basis of the meaning that has been allocated to an object, and then adjusts this meaning to guide future action.

To sum up Blumer’s view, the meanings one allocates to the conduct of others emanates from social interactions and these meanings are continuously modified through an interpretive process when dealing with others. At the core of the interactionist perspective lies the idea that the process of interpretation and definition that people engage in to make sense of the social world they live in is fundamentally collaborative. This idea that the attribution of meaning arises from the interpretation of the uses of objects as part of collaborative endeavours resonates with our research: our study is indeed concerned with how scientists allocate meanings to, and interpret meanings from the information objects they design and use when conducting scientific work collectively in complex globally distributed settings.

Methodological considerations

The formulation of the interactionist perspective has had a substantial impact on ethnography, not only theoretically but also methodologically. Interactionists promote an ethnographic fieldwork approach based on the premises that knowledge is not the sole product of reasoning, but rather that knowledge is locally and temporally constrained, and that it is shaped by the perspectives, goals, and experiences of the investigator and by the encounters that they have in the setting of their studies (Rock, 2001). Thus, the interactionist investigation is an active process that requires the engagement in an ethnographic fieldwork approach that satisfies three requirements (Baszanger & Dodier, 1997):

(1) It needs to be empirical. Phenomena need to be observed empirically and cannot be deduced, as pure reasoning is not sufficient on its own.
(2) It needs be open to elements that cannot be predicted ahead of the study. The investigator needs to be ready to pick up unexpected aspects of the phenomena which may come to light and nor be overly constrained by the arrangements of the study.
(3) It needs to ground the observed phenomena in the field. The features that are observed need to be related to the backdrop against which they take place. A detailed understanding of specific social and cultural settings, and of the actors' viewpoints within them is required.

In this interactionist perspective, the ethnographer seeks to understand the ways actors attribute meanings to the settings in which they operate, i.e. their interpretations of their actions and behaviours in the situations in which they find themselves. It is the actors' interpretations that the ethnographer is seeking to uncover, and the investigator's own interpretations of these interpretations are what constitute the fundamental materials of the ethnography. Hence, an essential method advocated by the interactionist tradition is *participant observation*. By attempting to enter the world of their participants, the ethnographer can attempt to construct an understanding of their subjective logic, while by simultaneously being an external observer, the investigator can provide an external viewpoint and analyse the observed phenomena in a way that may be foreign to the actors that are being investigated. This dual approach is the cornerstone of interactionist ethnography (Sharrock et al., 2003).

It is this insider/outsider duality in the interactionist orientation that has given interactionist ethnographic fieldwork a strong resonance in fields like CSCW and STS. This duality has also inspired our research. Our study is concerned with unpacking the meanings of the actions and interactions of the actors within particular settings (multi-sited settings of scientific work) as they are seen from their own viewpoints and to provide a range of interpretations for these meanings. Methodologically, *participant observation* inspired by interactionism is at the centre of our study of intensely distributed scientific work to probe the actions and interactions of the co-operating actors empirically 'from the inside' as mediated by information artefacts. It aims to produce detailed descriptions and interpretations to shed light on how these artefacts are *meaningfully shaped* (i.e. given meaning) through social interactions to drive the scientists' conduct and co-ordinate their actions towards the completion of the project goal.

Several other strands of ethnographic fieldwork have had a strong bearing on the study of co-operative work in CSCW, and the study of science and technology in STS, and could have been selected to frame our study, but ultimately were not. A number of these approaches are discussed next and a justification is provided of why they were not considered.

3.3 Ethnographic fieldwork: other significant perspectives

As for the interactionist approach explored above, the advocates of the other two perspectives considered in this section have their own defined views on both the methodological approach to be followed to conduct ethnographic fieldwork studies and on the theoretical orientations that help make sense of the collected data. Both orientations are closely connected to symbolic interactionism, and this justifies why they are discussed here briefly. The following sub-sections briefly highlight the main tenets of these approaches, both theoretically and methodologically, and explain why they are considered not entirely suitable to our study of intensely distributed scientific work in this research.

3.3.1 Grounded theory

Grounded theory is an abductive approach whereby the researcher moves back and forth between empirical materials and conceptual ways of articulating them with the aim to generate theoretical conceptualisations and possibly formulate theories from the collected data (Clarke & Star, 2008). It was developed by Barney Glaser and Anselm Strauss, who were both associated with the Chicago School tradition, with the latter being a student of Blumer and closely related to the symbolic interactionists. Their pioneering work *The Discovery of Grounded Theory* (1967) was an attempt to address criticisms expressed in relation to ethnographic research for not being sufficiently systematic and rigorous, and for over-emphasising on the production of descriptive accounts rather than contributing to the formulation of theoretical concepts (Charmaz, 2000). Through grounded theory, they advocate the use of analysis methods whereby theoretical conceptualisations are generated from the collected data, as opposed to collecting empirical materials to test pre-defined theoretical constructs (Glaser & Strauss, 1967). Their approach relies on the joint coding and analysis of the collected data to generate different categories or concepts which in turn have several properties. It essentially uses a comparative approach (referred to as the *constant comparative method*) by which the researcher explores a number of events, situations and facts and identifies those that appear similar.

In practice, the researcher using grounded theory shifts between collecting data, analysing it and collecting further data, as guided by emerging conceptual categories until the theory is formed, in a process referred to as *theoretical sampling* (ibid.). The analysis of the collected data and generation of theoretical constructs can be broken down in four main stages (Randall et al., 2007):

(1) Identification of categories, i.e. conceptual groups that describe the phenomena in the data.

(2) Identification of properties within categories, i.e. for each category, several descriptors, events that made the phenomena happen and ensuing consequences.

(3) Delimitation of the theoretical constructs based on those categories and properties that are more prominent and more stable.

(4) Formation of the theory. Formulation of a theoretical conceptualisation in a way that it is useable by others in the same field.

Grounded theory has had significant resonance in CSCW. For instance, Fitzpatrick et al. (1996) used insights from Glaser and Strauss to probe the complex work of systems administrators and Grinter (1997) was inspired by grounded theory to investigate the development of a workflow system. Bayerl and Lauche (2010) drew on grounded theory to investigated distributed teamwork between staff on offshore oil platforms and workers operating onshore. Susan Leigh Star has relied on grounded theory as an organising method in her studies of the uses of information objects (Star & Griesemer, 1989), infrastructures (Star, 1999), and classification systems (Bowker & Star, 1999) in organisations. Thus, grounded theory is considered an important development in the use of ethnographic methods in CSCW as it emphasises that pre-determined theoretical constructs are not necessary useful to enter the field, that fieldwork is continuously unfolding, and that the development of theoretical conceptualisations such as constructs or models is an essential part of fieldwork research in CSCW and needs to be given sufficient attention.

Grounded theory has also been widely adopted in STS. For instance, general principles of grounded theory to code and analyse data were used by Fujimura (1987) in her study of how several levels of work organisation needed to be aligned to construct and tackle biomedical problems in cancer research. Similarly, these principles informed Shostak’s (2005) examination of how the development of molecularised toxicological research tools and work practices in an institute of environmental health sciences fostered the emergence of a new scientific discipline. In his enquiry of how biotechnologists view the characteristics of scientific knowledge production in their institutions, Fochler (2016) used the basic logic of grounded theory coding to conduct data analysis, as did Felt and co-authors in their study of work practices and challenges in transdisciplinary sustainability research (Felt et al., 2016). As for CSCW, it is the idea of interweaving the coding and categorising the raw data with the progressive generation of theoretical constructs that has made this perspective attractive to many STS researchers, as it helps structure and guide the analysis of empirical materials towards the formulation of theoretical conceptualisations.

Despite its influence in both CSCW and STS, grounded theory was not considered as a methodological perspective to frame our research study. When used thoroughly, grounded theory is an exhaustive process that relies on a laborious process of open-coding and a difficult abstraction phase (Cutcliffe, 2000; Myers, 2009). Thus, the practice of iteratively collecting data and developing categories, driven by *theoretical sampling* and the use of *constant comparison* to generate theoretical concepts as the data is being collected, may seem to us slightly intricate, somewhat inflexible (Jeon, 2004; Melia, 1996), and could potentially stifle creativity (Seldén, 2005). However, several methodological devices relied upon in grounded theory are used in our study. *Sensitizing concepts* (which denote a construct that originated in symbolic interactionism (Blumer, 1954; Menzies, 1982)) can be used in grounded theory to draw attention to key features of social interactions and guide the overall research (Charmaz, 1990). As far as our study is concerned, *sensitizing concepts* inspired the development of *sensitising tensions* to represent a number of salient features of intensely distributed work that emerged from the analysis and that informed technology design (these will be discussed in detail in section 7.6).

Another perspective that also has had a great deal of influence in both CSCW and STS, but that was not selected for this thesis, is discussed next: ethnomethodology.

3.3.2 Ethnomethodology

Ethnomethodology has intellectual roots in symbolic interactionism, as well as in phenomenology (the study of direct experience and how it influences behaviour) and linguistics (the study of the form, meaning and context of language). It is concerned with understanding how people make sense of everyday mundane activities and how they employ a range of shared methods to make these activities visible, observable and accountable to others in order to organise action and ultimately to produce social order (Garfinkel, 1967; Randall et al., 2007). Hence, researchers in this tradition advocate the empirical study of the most commonplace activities of everyday life and of the mechanisms adopted by people to sustain and make sense of interactions such as assumptions, conventions and practices (Cohen et al.; 2011). Ethnomethodology has had a particular resonance in workplace studies and ethnographers of work influenced by this perspective recommend a number of analytical approaches to probe the *ethnomethods*, i.e. the everyday practices through which actors order and make sense of their world and their work (Suchman, 2007). These approaches include conversation analysis, to embrace both verbal and non-verbal conduct, and detailed field studies of specialised work domains and of the situated organisational settings in which these work activities take place (Trace, 2011).

Ethnomethodologically-informed ethnography has had a far-reaching influence on CSCW. Its proponents claim that it is a well-suited approach to scrutinise the co-operative aspects of working life in detail and to probe how actors continuously reconfigure their work arrangements when facing situated contingencies so as to inform technology design for the workplace (Randall et al., 2007). Ethnomethodologists in the workplace consider that the value of this type of detailed enquiry is the ability to capture the details of situated contingencies of work as they arise and to suggest ways in which they can be resolved through the design of technological solutions (ibid.).

Ethnomethodology has also been influential in the STS community with regards to the investigating and the uncovering of the local and situated details of everyday scientific practice and technological development. A specific area in which ethnomethodological ideas have been applied is the probing of argumentation and persuasion in scientific enquiry work (relevant to our research) to understand the mechanisms used by scientists to convince each other of the significance of particular experimental work (Knorr Cetina 1981a; Lynch 1985). For instance, Lynch (1985) categorises the ways in which neuroscientists manage to reach agreement on the interpretation of data. Similarly, Livingston (1999) establishes that the methods relied upon by mathematicians to convince others of the validity of a proof are embedded within the social practices of the community of mathematicians. Ethnomethodology has also been drawn from in various STS studies of visual representational practices (Hackett et al., 2008). Visual objects and representations are relevant to our study, as they are particular types of information artefacts employed by collaborating scientists to co-develop scientific understanding. Several studies (see examples in Lynch & Woolgar (1990) and in Coopmans et al. (2014)) have found that scientists' representational practices cannot be understood in isolation from the situated circumstances in which they are used, but that they are embedded within particular scientific cultures and are relied upon to define, shape and convey scientific knowledge within specific settings.

If the adoption of an ethnomethodological orientation has allowed the uncovering of interesting aspects of both scientific work and co-operative work, it is not the orientation of choice for this research, primarily for reasons of scales and foci. First, an ethnomethodological approach tends to concentrate mainly on the lower levels of local and situated activities to probe the everyday practices through which social order is accomplished and tends to neglect the broader structural level (David & Hester, 2004). Second, the focus of ethnomethodology is the mundane details of social interaction, i.e. the specifics of daily communications and observable conducts of actors, to probe how social order is accomplished (Martin & Sommerville, 2004) while the interactional roles of information artefacts do not tend to be a core concern for this orientation. In contrast, the fieldwork approach put forward in this thesis seeks to shift its attention between the local concerns of situated scientific experimenters and their multiple interactions within and across multiple sites and disciplines. Moreover, the fieldwork in our study relies on an artefact-centric ethnographic approach, as its main focal point is the use of information artefacts to support co-ordination of intensely distributed scientific activities, to ultimately inform the design of computerised co-ordinative artefacts

Up to this point in this chapter, an overview of ethnography has been presented, a preferred ethnographic orientation for our research has been discussed and a number of alternative orientations have been considered and discarded. The next sections examine the use of ethnographic approaches within the disciplines of interest in this research: CSCW and STS.

3.4 Fieldwork in CSCW

This section aims to provide an overview of the ways ethnographic fieldwork has been used in CSCW to probe in depth instances of co-operative work and of the co-ordination of work practices as mediated by information artefacts in a variety of settings. It does not attempt to differentiate between different ethnographic orientations (indeed, most CSCW scholars do not tend to specify it) but rather highlights how and in which settings fieldwork has been relied upon to provide insights into keys areas of interests for CSCW, and more specifically for our research study.

3.4.1 Fieldwork studies of co-operative work

Since its inception in the late 1980s, ethnographic fieldwork has played a central role in CSCW research. As discussed in section 2.2, CSCW is concerned with providing in-depth insights into situated co-operative work arrangements and into the social nature of the work under consideration with the aim to design computerised systems that can best support these working arrangements. CSCW has become increasingly prominent in the past 30 years as the result of the realisation that a large number of computerised systems have failed to provide the right level of support to the organisations that commission them. CSCW scholars have continuously argued that these failures emanate from the inability of traditional information system design and development approaches to capture the complexities and the intricacies of situated work arrangements, and thus fall short of meeting the real needs of the actors involved in these organisational setups (Hughes et al., 1994; Randall et al., 2007). Researchers in the CSCW tradition, which is multidisciplinary in nature, have actively promoted the view that social sciences should have a much greater involvement in the research on how large computerised systems can support the co-operating actors organise and articulate their work practices. CSCW scholars advocate that a much better understanding of “the sociality of work and organisation” (Hughes et al., 1994, p. 429) and the real interactions between the co-operating actors should provide designers with the ability to design interactive systems that are much better suited to the needs of the co-operating actors on the ground and that ultimately contribute to the reduction of IT system failures.

This “turn to the social” (Hughes et al., 1994, p. 429) (the acknowledged need to study the real nature of work through social sciences) has made ethnographic fieldwork the natural method of choice to provide a deeper understanding of how social interactions, and how they are artifactually-mediated, shape co-operative work. Ethnographic fieldwork has been widely adopted to obtain insights into the practices of co-operating workers and into the ways they interact with each other using the various objects and resources they need to do the work together such as information artefacts and technological systems (Greif, 1988). This has resulted in the conduct of a large number of fieldwork studies of very varied organisational set-ups and complex work arrangements which have greatly contributed to construct a deeper understanding of co-operative work and of the use of information artefacts to support the co-ordination of working practices (Schmidt & Bannon, 2013).

This considerable body of ethnographic studies produced over the years by CSCW researchers has helped provided a deeper understanding of co-operative work (ibid.), and it is claimed that “ethnographic studies have changed our understanding of work by highlighting its sociality and materiality” (Blomberg & Karasti, 2013). In particular, the ethnographic approaches adopted in these studies have played a key role in developing the major CSCW theoretical concepts of interest to our research and discussed earlier in chapter 2. These are *awareness* (i.e. *displaying* and *monitoring*), *articulation work* (i.e. *local articulation* and *metawork*), co-ordinative roles of information artefacts (i.e. *coordination mechanisms* and *ordering systems*) and *boundary objects* (i.e. *boundary negotiating objects* and *boundary specifying objects*). The next sections briefly review several ethnographically-informed studies of these theoretical constructs in CSCW, underline the role of fieldwork, highlight some of their findings, and discuss the relevance to our research.

3.4.2 Fieldwork studies of awareness

A number of seminal ethnographic studies have contributed to define and characterise awareness and to show how awareness can be *configured* (Heath et al., 2002). Of particular relevance to this research and discussed previously in section 2.2.3, the comprehensive fieldwork investigations of air traffic control (Harper et al., 1989; Harper et al., 1991; Harper & Hughes, 1993) and of the London Underground traffic control (Heath and Luff, 1992; 1996) have played a significant role in shaping the conceptualisation of awareness and forming the view of awareness as an active and dynamic construct, which is ascribed to in our study. These meticulous ethnographic examinations probed how traffic controllers interact with each other using various resources to convey to each other how they conduct their activities and to what extent these activities are completed or require further interventions. They found that co-workers use a complex array of procedures, information artefacts and orientations, in parallel with speech, gestures and accepted conventions, to let others know what is being done and how it is being done (*displaying*) so that the partners can pick up cues and orient their own actions in consequence (*monitoring*) (see section 2.2.3).

Other design-driven ethnographic studies were undertaken in CSCW with the specific aim to design and possibly develop technologies to support awareness, particularly in the health-related sector directly adjacent to the settings of interest to this research (translational research). Whether these attempts have been successful in doing so is still open for discussion; nonetheless, these studies have contributed to a more refined understanding of particular dimensions of awareness. For instance, in-depth studies were undertaken by Bardram and co-autohors of surgical wards to design interactive displays to inform the unfolding of the different activities (Bardram et al., 2006) and a communication system to assist the real-time coordination of the execution of operations at a large operating room suite (Bardram & Hansen, 2010a; 2010b). These studies contend that these systems can support *social awareness* (i.e. what other actors are currently doing or planning to do), *spatial awareness* (i.e. where things are happening), *temporal awareness* (i.e. when things are happening) and *activity awareness* (i.e. what the level of completion of a particular task is). Similar but more recent examples include the in-depth fieldwork investigations of time-critical medical teamwork in regional emergency departments to identify ideas to design information displays that support teamwork-based awareness (Kusunoki & Sarcevic, 2015; Kusunoki et al., 2014). These studies offer a micro-level perspective to further refine the previously mentioned facets of awareness “in the context of ad hoc, multidisciplinary and collocated medical teamwork” (Kusunoki et al., 2014, p. 17). These are “(1) team member awareness (i.e., social and spatial awareness), (2) elapsed time awareness (i.e., temporal awareness), (3) teamwork-oriented and patient-driven task awareness (i.e., activity and articulation awareness), and (4) overall progress awareness (i.e. process awareness)”.

Fieldwork or ethnographically-informed approaches have also been used to study work that is geographically distributed and/or asynchronous. Multi-sited ethnography (ethnographic study for which the field is extended to spatially-dispersed settings, see Marcus, 1995) was deployed to examine various awareness strategies in a mobile workplace (Orre & Watts, 2006). Several qualitative methods that draw on ethnography including user workshops, site visits and team discussions, were used to probe awareness information requirements in distributed asynchronous work (Mark, 2002). Both these approaches are entirely in line with the multi-method and multi-sited methodological approach adopted in this PhD to study intensely distributed scientific work and discussed at the end of the chapter.

To sum up, the use of ethnographic fieldwork has contributed to refining the understanding of awareness and has assisted with designing, developing and evaluating technologies that support awareness within the situated environment of the workplace in which they are deployed. For our study, this brief review has provided useful examples of how fieldwork research has been undertaken to develop a greater understanding of the different dimensions of awareness and to inform the design of technologies to support them. Fieldwork has also been used in CSCW to probe how different co-operating parties articulate their efforts.

3.4.3 Fieldwork studies of articulation work

The co-ordination of distributed work practices has been the object of much attention in CSCW scholarly research and these research efforts have contributed to the elaboration of the theoretical conceptualisation of *articulation work* (see section 2.2.5). Articulation work (and to a lesser extent the various ways of operationalising it to enable coordination of work practices through the use *coordination mechanisms* and *ordering systems* as discussed in section 2.3) have been the analytical focus of a number of ethnographic enquiries. Notwithstanding the view expressed by certain CSCW scholars, e.g. Bardram (1998b), that articulation work is embedded within work activities of co-operating actors and thus difficult to study and extract from situated work practices, a number of fieldwork investigations have attempted to describe different types of articulation work and also to assist the design of systems that explicitly support the articulation of work activities such as workflow systems. For instance, Boden et al. (2014) probed how *articulation spaces* were designed and implemented in a small software company to integrate both formal articulation practices (such as organising meetings or reporting on application development progress) and informal ones (such as asking questions to staff or announcing the visit of partners or clients). Their ethnographic-inspired fieldwork study and the testing of the platform showed how digital systems can provide useful computerised coordination mechanisms to support the formal articulation of the various activities involved combined with more informal modes of communication.

Other studies have emphasised the issues of co-ordination emanating from the distribution of work activities across departmental or organisational divides, which is of direct interest to our research. For instance, Abraham and Reddy (2013) have identified and characterised different categories of articulation work that are used to mitigate cross-departmental coordination breakdowns in a large hospital and have derived empirically-driven and theoretically-based design principles for workflow tools to be used across the different units of the institution. The challenges of co-ordinating work specifically across different organisations (also of particular interest to our research) have attracted a fair amount of attention in the CSCW community. A number of fieldwork-driven investigations have explicitly looked at instances of cross-organisational work and identified how the two facets of articulation work (see section 2.2.5) are used by co-operating actors to help them organise and align their work activities in these distributed settings. These are *local articulation* (ensuring that everything is in place locally for the work to be done) and *metawork*. (aligning work activities between separate units). When probing the development of a national e-infrastructure for biometric identity, Johri and Srinivasan (2014) found that centralised system designers and enrolment operators in local stations continuously managed their "socio-technical relationship" (p. 698) around local articulation and metawork using process workflows and other organising artefacts. Rolland et al. (2014) established that in large virtual scientific research networks, local articulation is ubiquitous and carried out by all members, while funding agencies undertake most of the metawork and delegate part of it to staff specialised in project co-ordination. Lastly, in their study of language translation in large software development, Doherty et al. (2012) found that distributed workers relied on a range of artefact-based co-ordination mechanisms, as well as informal communications and *bricolage* practices (Büscher et al., 2001), to support metawork and local articulation.

The examples in this sub-section are useful for our research as they show how field studies have been conducted to improve the theoretical understanding of articulation work, and in some instances, of how digital systems can be devised and set up to support the different facets of the articulation of work practices. Examples of how fieldwork research has shed light on how information artefacts can help disparate groups to co-ordinate their efforts across boundaries is considered next.

3.4.4 Fieldwork studies of boundary objects

The probing of the ways in which co-operating actors in heterogeneous groups organise their work and use a range of information artefacts to support the co-ordination of efforts across these disparate groups has also relied extensively on ethnographic fieldwork. *Boundary objects* (see section 2.5) have been the subject of many ethnographic studies. In-depth fieldwork investigations of complex co-operative settings have helped provide insights on how these information artefacts are used to interconnect diverging perspectives but also to define the respective limits and the zones of co-operation between these perspectives.

In-depth fieldwork studies of the use of sketches, diagrams, drawings and blueprints employed by engineers involved in very different parts of industrial production have shown that the representations carried by these information artefacts not only provide aids to visual communication, and assist with the alignment of diverging viewpoints, but also that they are used actively as points of negotiations to make decisions on the design to be implemented (Henderson, 1991; 1999). Similarly, fieldwork has revealed how meteorologists and climate simulation modellers rely on the parameterisations of climate models and the variables used to align these models with the real weather to interconnect their different understandings and co-ordinate their efforts (Sundberg, 2007). Along the same lines, ethnographic fieldwork has unpacked how other scientific models, such as ecological simulations for the sustainability of animal populations and simulations in the healthcare sector, are used by both scientists and policy makers to work with each other but also to make themselves accountable to their own respective groups (Egmond & Zeiss, 2010).

Using ethnographic methods, Mayernik et al. (2012) found that the data produced by sensors in a research centre dedicated to the development of wireless sensing systems was used as a boundary object by the scientists and the technology developers, who interpreted it differently for their own needs, but also used it to work together. Using an approach adapted from a self-reflective ethnographic investigation of an office space, Bødker and Christiansen (2006) probe how use-case scenarios are used as boundary objects by groups of prototype designers and users to communicate, negotiate and finalise decisions about design ideas. Again, ethnographic studies of industrial and commercial production settings have illustrated how design specifications can be viewed as boundary objects between designers and production engineers (Eckert & Boujut, 2003; Stacey and Eckert; 2003) as they are adopted to conduct negotiations and to influence decisions about the design elements to be selected (Boujut & Blanco, 2003). Hermann's and Hoffmann's fieldwork investigation (2005) of a network of scientific projects – of particular resonance for this thesis – depicted how workflow systems can be considered as boundary objects if they are sufficiently flexible to allow for each department to organise their own work but also to intersect with the work of the other departments. Last but not least, a number of important fieldwork studies of hospital environments have shown how medical records, whether paper-based or electronic, can be viewed as boundary objects that have the capacity to cross the boundaries and help interconnect and negotiate the practices of physicians, nurses, administrators and managers (Berg & Bowker, 1997; Bossen et al., 2014).

This rich corpus of CSCW studies illustrates the ways in which fieldwork has been used to shed light on the many utilisations of information artefacts among disparate groups operating in more or less complex work arrangements to organise, negotiate and define common understandings in their differing work practices to achieve concerted action. More generally, this entire section has highlighted useful examples for this present research of how CSCW scholars have conducted fieldwork studies to probe and further elaborate theoretical concepts that are of relevance to this thesis in a variety of settings: *awareness*, *articulation work* and *boundary objects*. These studies have established that actors co-operating in a work arrangement use a complex array of information artefacts to convey cues about their work to make their partners aware of how they are doing the work, to pick up cues of how these partners are managing their activities, to articulate their own activities with those of others (locally and with regards to the overall workflow) and to negotiate their understandings of each other practices and define a common ground for the respective practices to interconnect. Very much in the spirit of CSCW, some of these studies discuss how they have used the insights gained from the enquiry in the field to inform the design of technologies to support these theoretical constructs, which is useful for our research. The ways in which fieldwork is drawn on to inspire design implications is examined right at the end of the chapter. Prior to this, the following section looks at the use of ethnographic fieldwork in STS.

3.5 Fieldwork in STS

This section explores the influence of ethnographic research in the field of STS but particularly on the study of the social construction of scientific knowledge within the settings of the laboratory, as it is directly of interest to our research. It seeks to examine how ethnographic fieldwork was used as an integral part of the STS so-called *laboratory studies* programme (see section 2.4.2), the different underlying ethnographic and theoretical orientations that informed these studies, and the insights they produced on the ways scientific facts are produced, negotiated, and validated by co-operating scientists.

3.5.1 Laboratory studies and main orientations

This subsection explores examples of different utilisations of ethnographic fieldwork within the specific context of the construction of scientific knowledge in the laboratory environment. The ethnographic fieldwork-based studies that come under the umbrella *laboratories studies* (Collins, 1991, Knorr Cetina, 1981a; Latour & Woolgar, 1986 [1979]; Lynch, 1985; Traweek, 1988; Zenzen & Restivo, 1982) have been very influential in STS (see section 2.4.2). They were mainly concerned with the social construction of scientific knowledge, i.e. with exploring how the decisions about the validity of scientific facts and methods are made *in-situ* and how these decisions involve a blend of social and technical factors. The common ground for these studies is the exploration of how the core concerns of scientists such as the production of robust evidence and the consistency of their scientific practices are intertwined with locally situated events, decision-making processes, negotiations and the handling of controversies in order to develop a greater scientific and technical understanding (Hess, 2001).

These studies all rely heavily on ethnographic methods within the settings of the laboratory – mainly participant-observation combined with interviews and analysis of documents, such as protocols and draft scientific publications (e.g. Knorr Cetina (1981a) and Latour & Woolgar, (1986 [1979])). Ethnographic fieldwork has provided the magnifying glass to look at the inner details of the production of scientific knowledge as a constructive process in the laboratory. It allows for the study of real-time processes, practical activities, and social interactions *in situ* to shed light on how scientific facts are produced, discussed and verified (Knorr Cetina, 1995).

Despite the common ground and reliance on ethnographical fieldwork, there are often significant differences between these laboratory studies in terms of emphases, settings and ethnographic orientations. For instance, some concentrated on the interactions within a single laboratory (e.g. Knorr Cetina (1981a); Latour & Woolgar (1986 [1979]) and Lynch (1985)) while other studies went beyond the settings of the laboratory and probed the role of negotiation in broader research communities (e.g. Collins (1983) and Collins & Pinch (1982)). The methodological lens used in the latter studies is referred to as *participant comprehension*, i.e. “an interpretation of participant observation under which the field-worker tries to acquire as high a degree of native competence as possible and interaction is maximized without worrying about disturbing the field site” (Collins, 1998, p297). The concern here was for the ethnographer to acquire a certain level of competence in the science under consideration in the field, just like an anthropologist would want to develop an understanding of a very unfamiliar culture. In contrast, the key study of ‘laboratory life’ by Latour and Woolgar (1986 [1979]) focused on persuasion and on its role in the conversion process from observations to accepted scientific facts. As a result, their fieldwork concentrated on the practices in the laboratory and on the writing process and the methodological concern was to avoid “going native” (p. 39). Latour and Woolgar (ibid.) posited indeed that being a stranger to the experimental culture of the laboratory would enable them to understand and develop very valuable insights into the persuasion process surrounding the experimental activities.

In addition to the variations in foci and methodological approaches, the main laboratory studies also differed in relation to the theoretical perspectives they adopted and in relation to the conceptualisations that emerged subsequently. Knorr Cetina’s study (1981a) was very influential in shaping the constructivist position by which scientific knowledge is not given but constructed. In her view, the direct observations and detailed descriptions in ethnographic laboratory studies can unpack the regular workings of the laboratory, i.e. “the real-time mechanisms at work in knowledge production” (Knorr Cetina, 1995, p. 148). Latour and Woolgar’s ethnography (1979) also embraced the construction of scientific facts but they especially emphasised the social character of this construction. For instance, the analysis of the scientists' conversations and discussions in the laboratory conducted in their study brought to the fore the social mechanisms by which scientists convinced each other of the validity of their arguments. However, this work is widely acknowledged to have subsequently inspired an actor-network theoretical approach (Sismondo, 2011) (see section 2.4.3). Over time, Latour, Woolgar, and Callon refined their conceptualisations of a social construction of knowledge to theorise scientific work as consisting of heterogeneous networks of human and non-human entities acting together towards the acceptance and recognition of scientific facts (Latour, 1987; Callon 1987; Callon and Law, 1989). Consequently, the term *co-construction* or simply *construction* is used instead of *social construction* of knowledge. ANT is a key example of the rising concern with the issue of co-construction and the involvement of technology as it embraces the issue of how technical entities perform actions that have been assigned to them within socio-technical systems and how these in turn shape human action in the system (Callon, 1987; 1995).

The ethnomethodological orientation (see section 3.3.2), adopted by scholars such as Michael Lynch (1985, 1993) to study science, focuses on "the genealogical relationship between social practices and accounts of those practices", and is concerned with themes of "action, order, rationality, meaning and structures among others" (Lynch, 1993, p. 1). As mentioned in that previous section, ethnomethodology seeks to understand the methods and practices people employ in everyday activities to make sense of the world through an analysis of their descriptions of their daily experiences (Randall et al., 2007). Thus, the ethnomethodological study of science actively promoted by Lynch (1993) advocates the very detailed empirical investigations of the practices selected and used by scientists to *do science*, as it considers that the order of science emerges from the ordinariness of their activities in the laboratory (Sismondo, 2008). As discussed earlier, it has been greatly influential in the studies of persuasion and scientific representation.

The symbolic interactionist approach (of special interest to our study) looks at science and technology as work that takes place in a specific setting using specialised material and as scientific information as something that gets constructed through negotiations between actors who operate in organisational contexts (Fujimura, 1988). To act co-operatively, these actors use objects and information artefacts which serve as representations that enable the allocation of meanings to work activities and interactions and thus support a negotiated production of scientific knowledge and technical achievements (Star & Griesemer, 1989). Hence the interactionist perspective advocates a detailed examination of the interactions between the scientists/technologists as co-operators, but also of the interactions between them and the various materials and artefacts they use to support their scientific work, to understand their interpretations of these multiple interactions and the negotiated meanings that arise from them towards the production of meaningful scientific results. This is precisely what our research study is setting out to do.

Notwithstanding the variations in emphases, methodological approaches, and theoretical orientations, a certain number of common themes and useful insights have emerged from those influential laboratory studies with regards to how scientific enquiry is conducted and how scientific knowledge is produced. These are explored next.

3.5.2 Key insights of laboratory studies

This subsection highlights the findings made by the laboratory ethnographic studies as insights into the ways scientists manage their interactions within the confines of the lab to collectively construct scientific knowledge is a first step in understanding how scientists co-operate in complex multi-dimensional environments towards the resolution of complex problems. Ways in which the field of enquiry can be subsequently extended to consider multiple sites is discussed at the end of the chapter (see section 3.6).

Negotiability

The first noteworthy finding emanating from laboratory studies is the central role of negotiation and interactional exchanges in a very wide range of scientific practices. Discussions and negotiations can come into play to define what constitutes an artefact (Lynch, 1985), to establish what the best environment to undertake scientific work is (Traweek, 1988), to determine the quality of a scientist or the appropriateness of a method (Latour & Woolgar, 1986), to define what a proper experimental replication should be (Collins, 1991) or to ascertain whether a measurement should be replicated more than once (Knorr Cetina, 1981a).

An example is the study of how scientists used *articulation work* to manage the ambiguity of the investigation process through negotiating tasks with a range of partners, such as funding bodies and others (Fujimura, 1988). Through his ethnomethodological orientation, Lynch (1985) also scrutinised in great detail how scientists modify their account of scientific or technical understanding when facing others who disagree with them. To sum up, laboratories studies have demonstrated the “negotiability of the elements, the outcomes and the procedures in knowledge production” (Knorr Cetina, 1995, p. 152). The interactionist lens adopted in our study can be useful to focus on this idea of *negotiability* and the role of negotiation in intensely distributed scientific settings to provide additional insights. Creating opportunities for negotiability seems all the more important in settings in which very diverse parties are working together to resolve complex scientific problems.

Persuasion

The second main insight that emerged from the various laboratory studies concerns the role of the “representational techniques of persuasion” (Knorr Cetina, 1995, p 154) as part of the production of scientific knowledge. The laboratory is described by Latour and Woolgar (1986) as a location in which inscription devices operate. In their view, the scientists’ goal is to transform physical materials into written representations such as text, figures and diagrams which are used by scientists to persuade each other and the general public of the validity and superiority of their research work. The produced inscriptions or visual representations have great advantages over physical materials, in the way that they can be exchanged, compared, and combined (Eisenstein, 1979) and can be used to interconnect various participants (Henderson, 1995). Specific representation techniques have attracted the attention of the laboratory studies’ scholars who aimed to understand their roles in the production of knowledge. For instance, image design, image processing, and visualisation were examined in a range of areas (Amann & Knorr Cetina, 1988; Henderson, 1991; Knorr Cetina & Amann, 1990; Lynch, 1988). These various efforts have pointed towards the fact that these techniques can provide the scientists with additional means of persuasion to convince other practitioners and the public of the quality of their work. The use of representations and information artefacts that convey them is at the centre of our research and the interactionist perspective can help explore how they are used to persuade others and thus how meanings are allocated to particular aspects of the work, specifically through the use of these information artefacts.

Situatedness

The third insight towards which laboratory studies have contributed is the greater understanding of the situated nature of in-lab scientific research and of the practices adopted in-situ to manage the local contingencies and the variations between standardised processes and the day-to-day reality of the scientific work. Many of these studies provided real in-depth insights on how the scientists deal with the local circumstances of their working environment and produce knowledge with and despite the local means and resources, the equipment and materials at their disposal and the available technical skills and experience (Knorr Cetina, 1995). Different conceptualisations have been used to analyse the situated and contingent nature of laboratory practices. These practices have been described as *embodied*, *circumstantially contingent* and *unwitting* (Lynch et al., 1983) and the methods adopted by the scientists to implement these practices have been of great interests to the proponents of the ethnomethodological perspective. Similarly, Knorr Cetina (1981b) probed the effects of spatial and temporal contingencies on the decision-making processes in which lab practitioners engaged when working at the bench and highlighted the necessity for lab practitioners to deal with *local idiosyncrasies*. In her view, scientists tend to develop a *local know-how* when involved in laboratory activities in that they come up with ways to make things function when exposed to the realities of their daily working environments. In practical terms, she has found that scientists need to make *local interpretations* of the methodical rules that regulate their scientific operation to make them work within the setting in which they operate. In brief, laboratory studies have provided particularly useful insights into the process undertaken by lab practitioners to adapt the standard procedures essential to their practices, to make them fit into the settings in which they work, to the materials and equipment that are available to them, and to the experience and expertise they possess (Knorr Cetina, 1995). Our in-depth study in this PhD of the interactions between scientists in intensely distributed settings, through and with the various objects and information artefacts they manipulate, seeks to provide additional insights on how these *local interpretations* are made and managed to get the work done locally and articulate it with their partners.

Scientific cultures

The fourth aspect for which laboratory studies have provided valuable insights concerns the variations between different *scientific cultures* in different disciplines, and the effect they may have on the way the scientists conduct their scientific work. Knorr Cetina refers to these as *epistemic cultures* which she defines as “those sets of practices, arrangements and mechanisms bound together by necessity, affinity and historical coincidence which, in a given area of professional expertise, make up how we know what we know” (Knorr Cetina, 2007, p. 363). In her comparative evaluation of two disciplines (Knorr Cetina, 1999; 2007), she posits that scientists engage in different forms of construction of knowledge because of the different cultural specificities of their respective fields. Because of the absence of a body of comparative results in high-energy physics, physicists adopt a *liminal approach* that necessitates for them to constantly test, calibrate and question the results they get. They focus on “the disturbances, distortions, errors and uncertainties of research” (Knorr Cetina, 2007, p. 366) to define the boundary of the domain in which the physical process of interest is not found to progressively identify the domain within which it does occur. In contrast, microbiologists who manipulate and transform live materials to expand the already existing knowledge in their field, concentrate more on the results than on the measurements. They are more inclined to follow a *blind variation natural approach*, that consists of trying out various alternative procedures within one experiment until one is identified as the most fitting one and is thereby selected. These considerations are valuable for this thesis, as it probes scientists operating in cross-disciplinary work arrangements. Some of these findings on *epistemic cultures* influence our research study, which in turn seeks to provide additional insights on how the use of information artefacts can help manage the differences between epistemic cultures in a cross-disciplinary configuration to find negotiated ways to assign meanings to scientific facts, and thus further the collective scientific understanding aimed by the project.

To conclude, laboratory studies have been instrumental in constructing a better understanding of the ways in which co-operating scientists collectively organise their work to contribute to the construction of scientific knowledge. Interactions and negotiations play a key role in this process and they are continuously supported by an array of information artefacts that help in different ways the actors manage local contingencies and persuade co-operators of the validity of the arguments that are made.

The following and final section concludes the chapter and justifies the specific methodological approach selected for our research.

3.6 Chapter conclusion: a multi-method, multi-perspective, multi-sited approach informed by ethnography

The multi-method methodological approach selected in this PhD is inspired by ethnography as we think that fieldwork-informed qualitative methods can help investigate the intricacies of the interactions between participants through the information artefacts they use and produce rich descriptions of their activities and the roles of these artefacts in their scientific practices. In our view, a methodological approach that draws on some of the methods and perspectives associated with ethnographic fieldwork can help uncover the situated practices of the actors, from their own perspectives, and help us understand them in their own terms and ultimately inform the design of interactive technologies to support the co-ordination of these practices.

Our selected methodological approach is flavoured by three different orientations of ethnographic fieldwork: *design-oriented* (Randall et al., 2007), *interactionist* (Clarke & Star, 2003; Strauss et al.; 1964), and *multi-sited* (Marcus, 1995, 2011). The following sections discuss these orientations and how they influence our approach to the empirical study of the practices of intensely distributed scientific work and the roles of information artefacts to support its co-ordination. The specific components of our approach and the methods used in our empirical enquiry will be covered in chapter 4.

Interactionist orientation

The overall fieldwork approach adopted here draws on symbolic interactionism, both theoretically and methodologically, and is referred to as interactionist for greater clarity (see section 3.2.3). Theoretically, it provides a useful theoretical and analytical lens to consider the ways objects such as information artefacts, materials and equipment are attributed meaning and in doing so support interactions. The focus of the interactionist perspective is on the ways with which social actors allocate meanings to and develop commonly accepted characterisations for objects to help interpret each other's conduct in the exchange process (Bijker et al., 1987). The creation of objects and artefacts for co-operation is both contingent on social interactions and mediate these social interactions (Garrety & Badlham, 2000; Prasad, 1993). Indeed, the constructs of *articulation work* (see section 2.2.5) and *boundary objects* (see section 2.5.1) (used as theoretical lenses in our research to probe the co-ordination of work practices and the roles of information artefacts to support this co-ordination) originate from an interactionist intellectual tradition. Articulation work was initially elaborated by the interactionists Strauss (1985; 1988) and Star (see Gerson & Star, 1986), and emphasises the mediating roles of information artefacts to support the interactions required by the interweaving of tasks, efforts, and actors involved in a co-operative arrangement to get a job done (Trace, 2011). Boundary objects, initially formulated by Star and Griesemer (1989), conceptualise the ways in which information artefacts help organise interactions and link up different perspectives across multiple social worlds (with *social world* itself an interactionist concept developed by Strauss (1978)). Therefore, not only does symbolic interactionism provide the particular theoretical lens to look at how scientists allocate meanings to the information artefacts and objects they use when conducting scientific work and through which they manage their interactions, but it also informs the theoretical constructs used in our study to make sense of the various utilisations of these information artefacts to co-ordinate action.

Methodologically, our research study uses a number of methods including *participant observations* to allow the researcher to investigate the actions and interactions of the scientists *from within* and shed a light on how the information artefacts they use to co-ordinate action are given meanings through social interactions. Furthermore, interactionism assumes that organisational situations are likely to be the stage of multiple conflicting interpretations and meanings and highlights the necessity to produce a multifaceted representation of organisational life (Prasad, 1993). The interactionist perspective encourages the use of multiple research methods to capture the richness and the complexities of the situation i.e. the use of multiple "modes of knowing" (Glaser & Strauss, 1967). Our research study combines participant observations with a number of methodological practices to frame the data collection and analysis such as in-depth individual interviews, situated interviews, participatory learning exercises, regular participatory interactions and informal conversations. These will be discussed in great detail in chapter 4.

Design-oriented perspective

Ethnographic fieldwork has been widely adopted in both CSCW and STS to obtain insights into the work practices of and the interactions between co-operating actors and the ways in which the information artefacts are used to support these practices and interactions (see sections 3.4 and 3.5). In CSCW, those ethnographic insights have extensively been relied upon to *inform* the design of technologies to support the work practices that take place within co-operative work arrangements (Blomberg & Karasti, 2013). However, the way in which *ethnography informs design* has often been referred to as ambiguous (Bjørn & Boulus-Rødje, 2015; Blomberg & Karasti, 2013; Randall et al., 2007). This section briefly highlights some of the debates in CSCW on the relationship between ethnographic fieldwork and technology design, and discusses the stance adopted in our study on how ethnographic fieldwork is used to provide an *analytical sensibility* towards design (Bjørn & Boulus-Rødje, 2015).

Many scholars have warned against what they consider an overly restrictive use of ethnography in CSCW to simply define formal design specifications or prescriptive recommendations for the configuration of technologies (e.g. Dourish, 2006). In their view, the potential for ethnography is greater than merely providing a set of techniques to designers. Consequently, an increasing number of efforts have investigated the ways to connect fieldwork to design so that the true potential of ethnography can be realised (Bjørn & Boulus-Rødje, 2015). CSCW researchers from an ethnomethodological orientation advocate a tighter co-construction by which “design adopts the analytic mentality of ethnomethodology, and ethnomethodology dons the practical mantle of design” (Button & Dourish, 1996; p. 22). This implies the direct application of ethnomethodological principles to the process of designing systems (Crabtree, 2004; Dourish & Button, 1998). Other attempts to integrate ethnography and design include *participatory design*, by which designers actively engage with practioners in the field to design new practices and technologies with them (Kensing & Blomberg, 1998). Building on the two latter approaches, Hartswood et al. (2002) put forward *co-realisation* i.e.

"a synthesis between ethnomethodology and participatory design" (p. 9) to support the continuous (re)configuration of technologies and their integration with work practices.

We posit that our own methodological approach can benefit from a design-oriented perspective as it can help us develop an *analytical sensibility* towards the design of computerised artefacts to support the co-ordination of the practices of the scientists involved in a multi-sited cross-disciplinary project. *Analytical sensibility* in CSCW originates from anthropology and denotes the ability of the researcher to draw together the different experiences and insiders' perspectives and making connections between the situated work practices of individual actors, the practices of their co-operators and the potential changes that may result from the introduction of technological artefacts (Bjørn & Boulus-Rødje, 2015): "analytical sensibility includes the analytical work of connecting and demonstrating a comprehensive account for the collaborative yet individual and distributed engagement" (ibid.; p. 342). In our study, *analytical sensibility* is used to identify the key features of intensely distributed scientific work, and of the ways information artefacts are used to co-ordinate it, that must be considered when designing for computerised co-ordinative artefacts. It seeks to highlight the significant features of intensely distributed scientific work from the multiple viewpoints of the insiders involved to infer key design solutions that can better support their practices in interconnection with their co-operating partners' practices across global scientific work arrangements.

Multi-sited orientation

As our research aims to investigate scientific work distributed among teams operating in diverse disciplines and in specialised organisations at different geographical locations, our methodological approach has been strongly influenced by the multi-sited orientation of ethnography advocated by Marcus (1995; 2011) as we think it offers innovative ways to look at this type of complex situations.

Multi-sited ethnography has its origins in anthropology. Its purpose is to move out from the single localised site (such as the one considered in *laboratory studies*, see sections 2.4.2 and 3.5) and extend the settings of ethnographic enquiry to a spatially dispersed field through which the researcher pursues people, interconnections, associations and relationships across space and time (Marcus, 1995; 2011; Falzon, 2009). Applied to CSCW, multi-sited ethnography can help capture the features of co-operative work associated with ever more global processes, increased dispersion and mobility, and ever more complex flows, intersections, and continuities that characterise multi-dimensional work arrangements (Blomberg & Karasti; 2013), as it is very much the case in our study.

A key part of adopting multi-sited ethnographic principles to frame our empirical enquiry is to understand the field site as *constructed* (Amit, 2000). Constructing the field implies that the researcher needs to take a very active role in shaping the actual site of enquiry. The researcher needs to select, connect and bound the site of enquiry through the interactions in which they participate with the individuals and objects in their investigation and through the situations they encounter, the resources they have and the opportunities that arise from studying the phenomenon of interest (Blomberg & Karasti; 2013).

> "[…] we view the field site as a construct defined at the intersection of the developing research interests, the multi-sited object of study, and the particular engagement of the researcher. We argue for a willingness to pursue emerging and unfolding connections, flows, and discontinuities in constructing the sites, objects, and topics of ethnographic inquiry" (Blomberg & Karasti, 2013; p. 395).

In fact, the construction of the field of enquiry, as inspired by the ideas of the multi-sited ethnographic orientation, is what we first undertake in chapter 4.

To conclude this chapter, the interactionist, design-oriented, and multi-sited orientations offer interesting conceptual and methodological insights on which we draw to frame our own approach to set up our own empirical study of distributed scientific work in global cross-disciplinary translational projects, as discussed in the next chapter.

Chapter 4 Constructing & Deploying the Empirical Study

4.1 Chapter introduction

This chapter discusses how the multi-method multi-sited empirical study in this PhD was designed and deployed. In short, our overall study is broken down in three main stages: (1) the construction of the *multi-sited field of enquiry*; (2) an interview-based study of scientists in five global biomedical projects; (3) a multi-method empirical study of NanoArth a specific distributed project in the field of nanodiagnostics.

In the first stage, the field of enquiry is meticulously constructed. The terms *field of enquiry*, *field site* or just *field* are used interchangeably to refer here to the settings of our multi-sited ethnographically-informed investigation that are spatially, socially and organisationally dispersed (Marcus, 1995; Falzon, 2009), owing to the intensely distributed phenomenon under investigation in this research. The construction is here guided by the interests and motivations of this research and following the people, associations, relationships, and flows of information that form the settings. Access to several translational biomedical projects, to the organisations taking part in these projects, and to the participants working in those institutions is discussed in detail. To illustrate its different components, and the connections and interactions between them, the field is also meticulously mapped out.

The second stage consists of an interview-based study involving 21 participants that was first conducted between January and November 2012 to probe the ways in which the scientists organise and manage their scientific work in these settings and the challenges they meet. Initial findings that emerged from this stage of the overall study are briefly presented to help highlight the issues faced by the scientists when designing and carrying out intensely distributed experimental activities. It is to be noted that these initial findings do not provide the main analytical material for this research; rather they frame and support the main analysis presented in the next two chapters.

Finally, in the third stage, the field site is narrowed down on NanoArth, a specific project in the area of nanodiagnostics. Our main empirical study is deployed, focused on the NanoArth project, as it provides the basis for the main analysis in chapters 5 and 6. The research design of the various components of this multi-method study is presented. This project-focused study was conducted between March 2012 and December 2015 and involved participants from 7 different sites to closely probe the co-ordination of experimental activities within the settings of this specific project, with a particular emphasis on the roles of information artefacts to assist with this co-ordination.

4.2 First stage: shaping, bounding and mapping the field

This section documents in detail the initial stage of our study of intensely distributed scientific work co-ordination undertaken in this PhD, i.e. the construction of the field of enquiry. Drawing on the insights of multi-sited ethnography (Marcus, 1998), the active process of constructing the field was conducted continuously and iteratively throughout the duration of the study. The purpose of this construction was to shape the field meaningfully as driven by our research interests (i.e. the use and design of information artefacts to support the co-ordination of intensely distributed science). This entailed selecting, linking and bounding meaningfully the different elements of the site of enquiry, following the numerous opportunities that arose when making contact with the participants in the field, the multiple interactions that took place with these scientific practitioners and the resources they used and the diverse situations that ensued when managing these interactions (Blomberg & Karasti; 2013).

The following sections discuss this field construction process in detail. First, the way in which entry in the field of enquiry was gained through a number of key informants is discussed. Subsequently the field is organised in three layers for a clearer understanding. The *Project Layer* is considered initially to describe the five biomedical translational research projects under consideration that make up the settings of the overall study. Next, the *Organisation Layer* is explored to characterise the range of institutions that are involved in these five projects and to highlight those in which the participants in our study operate. Finally, the

Participant Layer is examined to provide detailed information on all the participants who took part in this investigation.

4.2.1 Entry in the field and gatekeepers

The starting point for the construction of the field of study was finding ways to gain access to a number of large cross-disciplinary translational research projects. Through personal connections, three key participants were contacted at the start to enquire about their involvements and experiences in multi-sited biomedical research projects. Their leading roles would not only give access to essential information about their own projects but also facilitate access to other participants working in or around other projects. These included fellow partners in the same project consortium as our three key participants, fellow scientists in different consortia but in the same project cluster, former partners they worked with previously or members of the European Commission (EC) overseeing their projects. Thus, these three key informants can be viewed as *gatekeepers* as they enabled and oriented access to essential information about the projects under consideration, to key information resources and artefacts used and to the participants who took part in our study (Gellner & Hirsch, 2001; Hammersley & Atkinson, 2007; Horst, 2009; Marvasti, 2004). In-depth details on these participants in our study is given in section 4.2.4 when examining the *Participant Layer* of the field of enquiry.

Table 4.1. summarises the roles of these gatekeepers, their involvements with the investigated projects and the access that they provided to the other projects and/or participants. A detailed description of the actual projects is presented in the next section.

Gatekeeper	Role	Project Involvement	Access to participants
Gatekeeper 1	Technical Project Manager	Nanodiagnostics for HPV project (NanoHPV)	• 6 Members of the NanoHPV project consortium. • 2 Research Programme Officers at the EC: 1 monitored NanoHPV project,1 monitored other projects • 1 Project Technical Advisor at. the EC, advised on the NanoHPV project.
	Leading Partner	Gastrointestinal Infection project (GastroInt)	• 7 Members of the GastroInt project consortium.
Gatekeeper 2	Project Manager	Nanodiagnostics for Arthritis project (NanoArth)	• 11 Members of the NanoArth project consortium.
Gatekeeper 3	Scientific Coordinator	Nanodiagnostics for Arthritis project (NanoArth)	• 2 Members of NanoInflam project consortium; same cluster as NanoArth. • 2 Members of the nanotechnology toolkit for cancer detection NanoCancer project consortium; same cluster as NanoArtg.

Table 4.1: Gatekeepers and further access to participants

The initial discussions held with these three gatekeepers and subsequent exploration of publicly available data online provided the basis for the information on the five considered projects presented in the next sub-section.

4.2.2 The Project Layer: five global European biomedical projects

An overview of the five EC-funded projects that constitute the *Project Layer* of the field of enquiry is presented in table 4.2, namely GastroInt, NanoHPV, NanoInflam, NanoCancer and NanoArth. The names of the projects have been changed to preserve anonymity and confidentiality but also to try to capture what these projects focus on with a simple designation. This table gives a brief description of the projects, their timeframes and budgets. It also provides information on the types organisations that are members of each project consortium i.e. that come together as partners for the duration of the project to resolve the scientific problem under consideration. Finally, table 4.2 indicates the framework programmes, thematic priorities, clusters or topics, and sub-clusters or sub-topics that the projects come under.

Project	Brief description	Timeframe & EC funding	Partner organisations in project consortium	FP	Thematic priority	Topic or cluster	Sub-topic or sub-cluster
Gastrointestinal infection project (GastroInt)	Investigation of the effects of different diets and lifestyles on risks of gastrointestinal infection and allergy in infancy.	01/2003-06/2006 €2.6 Million	12 partners from 7 countries • 2 SMEs specialised in food manufacturing for infants. • 3 research institutes. • 7 university departments or labs.	FP5	***Life Quality*** Quality of life & management of living resources	***Food, Nutrition & Health***	
Nanodiagnostics for HPV project (NanoHPV)	Development of a bioessay method to detect Human Papillomavirus (HPV) using nanoparticles.	10/2008-12/2011 €2.5 Million	7 partners from 5 countries • 2 SMEs specialised in biology, biomedelling and biochemistry. • 2 research institutes. • 3 university departments or labs.	FP7	***NMP*** Nanosciences, nanotechnologies, Materials and new Production technologies	***Nanomedicine***	***Nanodiagnostics***
Nanobiodevices for inflammatory diseases project (NanoInflam)	Development of a diagnostic/therapy approach using folate nanobiodevices to treat chronic inflammatory diseases.	12/2009-11/2013 €5.1 million	13 partners from 8 countries • 4 SMEs specialised in biotechnology; R&D and manufacturing of pharmaceuticals. • 5 research institutes. • 4 university departments or labs.				
Nanotechnology toolkit for cancer detection project (NanoCancer)	Development of a nanotechnology-based toolkit for multi-modal detection of biomarkers of common cancer types and cancer metastases.	06/2010-06/2014 €12 million	22 partners from 9 countries • 8 SMEs specialised in biomarkers, microfluids, immunodiagnostics. and nanotechnology. • 2 MNCs specialised in diagnostics & imaging. • 4 research institutes. • 8 university departments or labs.				
Nanodiagnostics for arthritis project (NanoArth)	Development of a superparamagnetic nanoparticles-based diagnostic tool to detect biomarkers of common types of arthritis.	02/2010-01/2014 €8.9 million	14 partners from 7 countries • 2 SMEs specialised in biotechnology, nanotechnology & diagnostics. • 3 MNCs specialised in nanotechnology and pharmaceuticals. • 1 research institute. • 8 university departments or labs.				

Table 4.2: Description of the 5 European biomedical projects in the Project Layer

The five biomedical translational research projects under consideration are all funded as part of the European Research Area (ERA), a pan-European structure of global scientific research programmes, referred to as *Framework Programmes* (FPs). Each Framework Programme is further broken down in a series of *thematic priorities.* Thematic priorities are themselves divided into several *clusters or topics* (depending on the Framework Programme). For more information on Framework Programmes, thematic priorities and clusters/topics, see Appendix A.

The five considered projects are related to the ERA structure as follows:

- The GastroInt project came under the *Life Quality* Thematic Priority in FP5 and belonged to a cluster called *Food, Nutrition & Health*.
- The NanoHPV, NanoInflam, NanoCancer and NanoArth projects were all in the FP7 *NMP* Thematic Priority (*Nanosciences, nanotechnologies, Materials and new Production technologies*) and were all part of the *Nanomedicine* cluster and the *Nanodiagnostics* sub-cluster.

The latter cluster and sub-cluster can be described in the following terms:

- The *Nanomedicine* cluster seeks to probe the application of nanotechnology to human healthcare and use of the physical, chemical, and biological properties of nano-sized materials to develop targeted nanopharmaceuticals, nanodiagnostics technologies or biomaterials for regenerative medicine. (European Commission, 2010b; 2011a; 2011b).
- The *Nanodiagnostics* sub-cluster is a targeted nano-pharmaceuticals and early diagnostics sub-cluster whose aim is to “develop innovative therapies, detection and diagnosis methods in the field of nanomedicine and cover a wide variety of diseases including cancer, rheumatoid arthritis and osteo-arthritis, diabetes, Alzheimer's and Parkinson's disease” (European Commission, 2011c).

To get a better overall representation of the field and to characterise precisely the different layers that constitute it, a thorough mapping process was undertaken. This was inspired by the Chicago School of Ethnography’s *natural social areas* maps (Palmer, 1928) and the interactionists’ *social worlds/arenas* maps (Strauss, 1978; 1979; Clarke, 20003; 2005). The

Chicago School's natural social areas maps delineate and describe in detail the various geographical but also social, cultural and political areas where a phenomenon is to be investigated (see section 3.2.2). Strauss and Clarke use their maps to represent the various groups and collectivities organised around particular issues of concern (sharing resources, viewpoints, and commitment to action; see *social worlds* in section 2.5.1) that thus constitute the *site* where actions, interactions, and negotiations occur, to develop an understanding of the respective roles and participations in those settings.

The mapping of the field in our study seeks to represent the complex multidimensional settings of the work arrangements under enquiry, i.e. the five multi-sited biomedical projects, the partner organisations involved where participants who took part in our study worked, and the participants themselves. This resulted in the iterative production of three field maps, with each building on top of the previous one, one for each of the identified layers. These maps are shown in figure 4.2, 4.3 and 4.4 and the key for all three is given in figure 4.1.

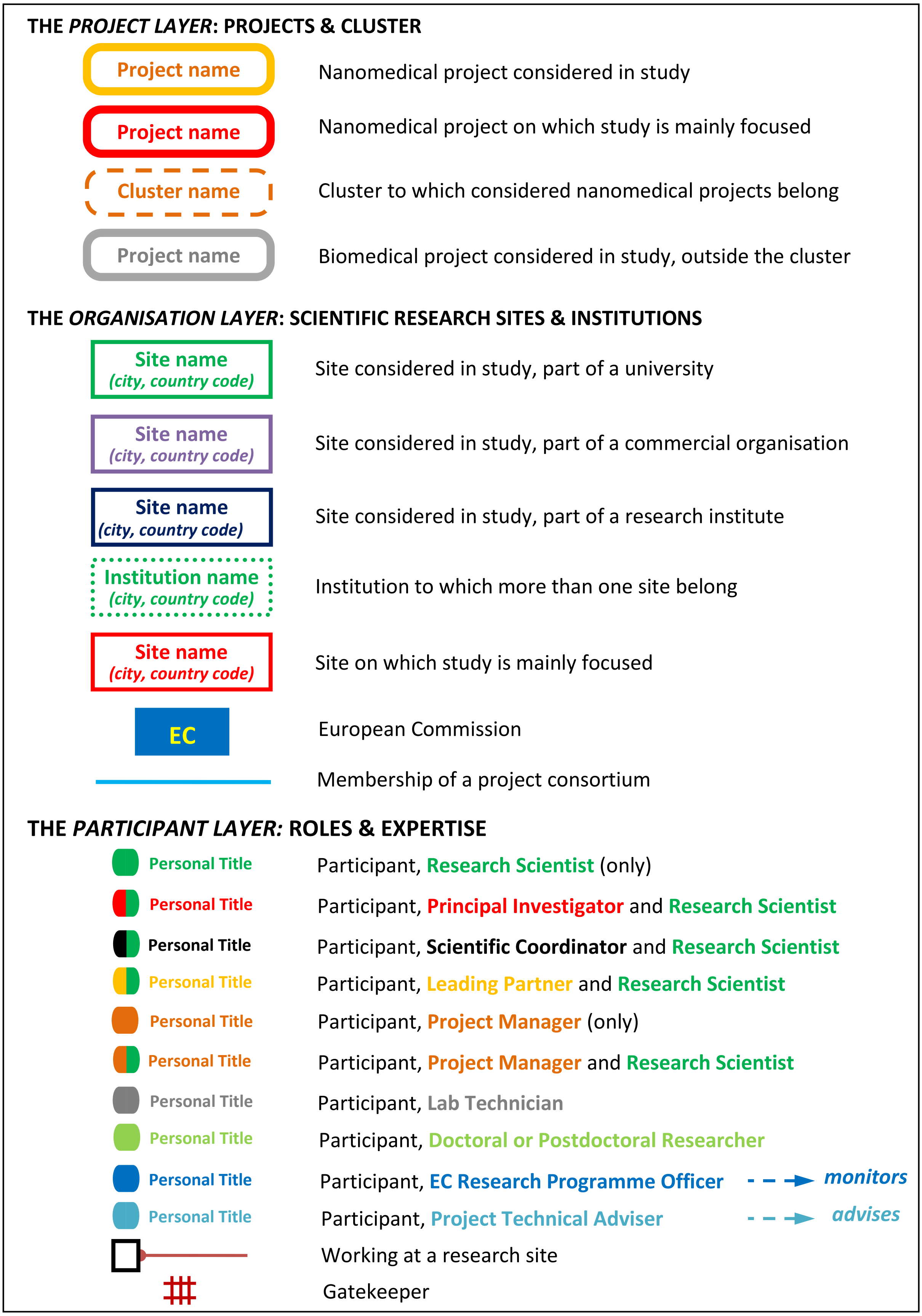


Figure 4.1: Key for the three field maps on fig. 4.2, 4.3 and 4.4

The first map shown in figure 4.2 represents the *Project Layer* of the field of study. It shows the four projects that belong to the Nanodiagnostics sub-cluster and the GastroInt project, which lies in a different thematic area.

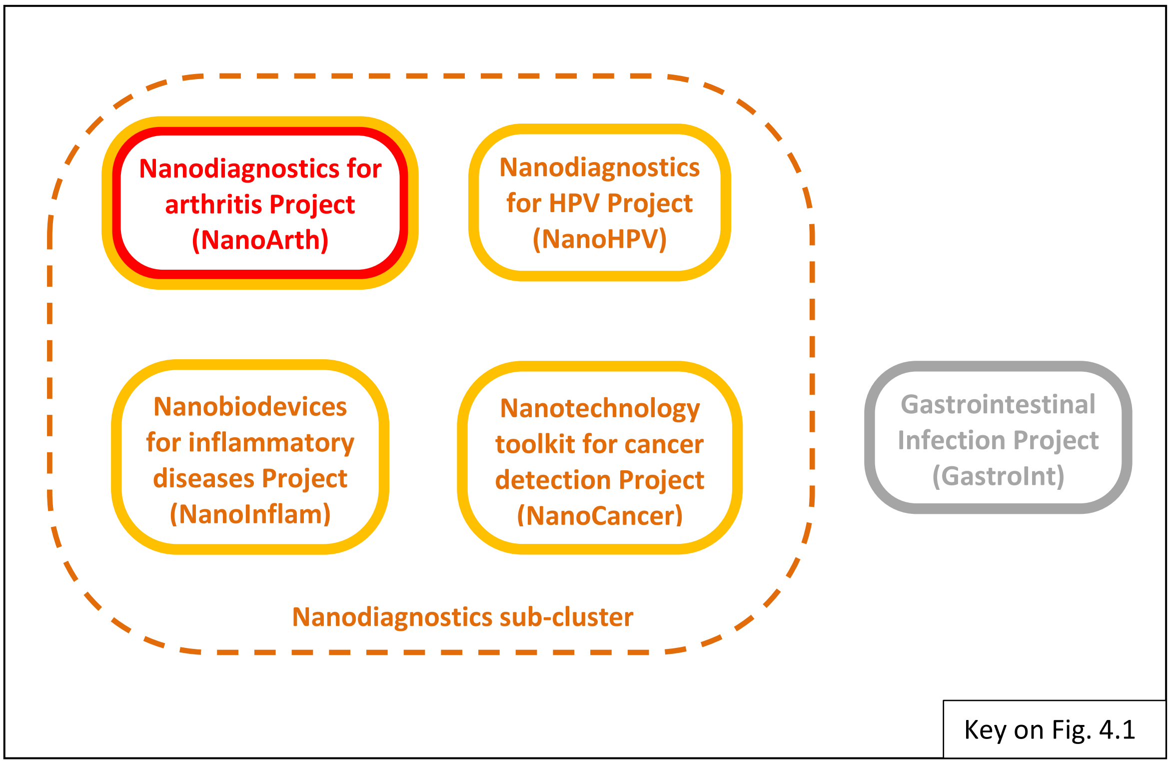


Figure 4.2: First field map – the Project Layer

The next section explores and maps the *Organisation Layer* of the field.

4.2.3 The Organisation Layer: cross-institutional project consortia

The prime motivation behind the setting up of large-scale European projects as part of the ERA is the bringing together of different institutions from across the European continent – and beyond – into scientific project consortia to implement joint research agendas. This aims not only to foster cross-border co-operation but also to encourage collaboration between institutions from different sectors, industries and disciplines to ultimately promote innovation (European Commission, 2014). This is particularly crucial in the field of translational biomedical research, and particularly of nanomedical research, which is cross-disciplinary in nature. The type of scientific problems tackled in this area requires the blended inputs of multiple industrial and academic co-operators, as shown by the very wide range of applications covered and the variety of innovative methods adopted by projects in the FP7 *Nanomedicine* project cluster and in the *Nanodiagnostics* sub-cluster (European Commission, 2011a; 2011b). In the context of the field of enquiry considered in our research, these include bioassay methods using nanoparticles for the detection of specific infections (NanoHPV), nanobiodevices-driven diagnostic and treatment of certain inflammation diseases (NanoInflam) and nanotechnology-based detection of the biomarkers of cancer (NanoCancer) and of arthritis (NanoArth). These endeavours necessitate the formation of project consortia that bring together the complementary knowledge and expertise of a diversity of institutions with different specialities, such as research intensive Small Medium Enterprises (SMEs), large pharmaceutical Multinational Companies (MNCs), university laboratories, hospital services and research institutes, as shown in table 4.2.

The pool of participants who took part in our study came from eighteen different institutional units e.g. private for-profits companies, university departments or academic research laboratories, and research centres in research institutes. These institutions constitute the *Organisation Layer* of the field of enquiry and are described in table 4.3.

Project	Institutional units considered in the field in which participants operated
GastroInt	• microbiology and food institute in a large agronomic research institute in France. • cell and microbiology department in a university in Sweden. • paediatrics department in a university hospital in Germany. • biochemistry & molecular biology department in a university in Spain. • food development department university in Ireland.
NanoHPV	• firm specialised in the engineering, manufacturing and retailing or medical diagnostics equipment in Italy; co-ordinated the project. • optical sensors laboratory in a university in Ireland. • biochemistry department in a university in Italy. • spectroscopy laboratory in a university in Italy. • company specialised in mathematical biomodelling in Hungary. • computational genomics laboratory in same large agronomic research institute in France as for GastroInt.
NanoInflam	• bioengineering research centre at a university in Portugal; co-ordinated the project. • environment & biotechnology laboratory at a technical university in Austria.
NanoCancer	• research centre in nanostructures and nanodevices in a university in Ireland.
NanoArth	• research consultancy SME specialised in material science & nanotechnology in Switzerland; in charge of the scientific coordination and operational management of the project. • material and powder research lab at a university in Switzerland. • radiology and imaging unit at a university in Switzerland. • applied R&D firm specialised in micro- and nanotechnologies, ICT and system engineering. • rheumatology and skeletal biology research lab at a university in Sweden. • rheumatology research lab at a university hospital in Germany. • musculoskeletal research centre at the same university hospital in Germany.

Table 4.3: Description of the Organisation Layer of the field

A second field map was drawn as an expansion of the first map to illustrate both the *Project Layer* and the *Organisation Layer* assembled together. It is presented in figure 4.3 and shows the institutional units and countries in which participants were located and the projects to which these units are associated. The European Commission has been added as three participants from the EC took part in our study.

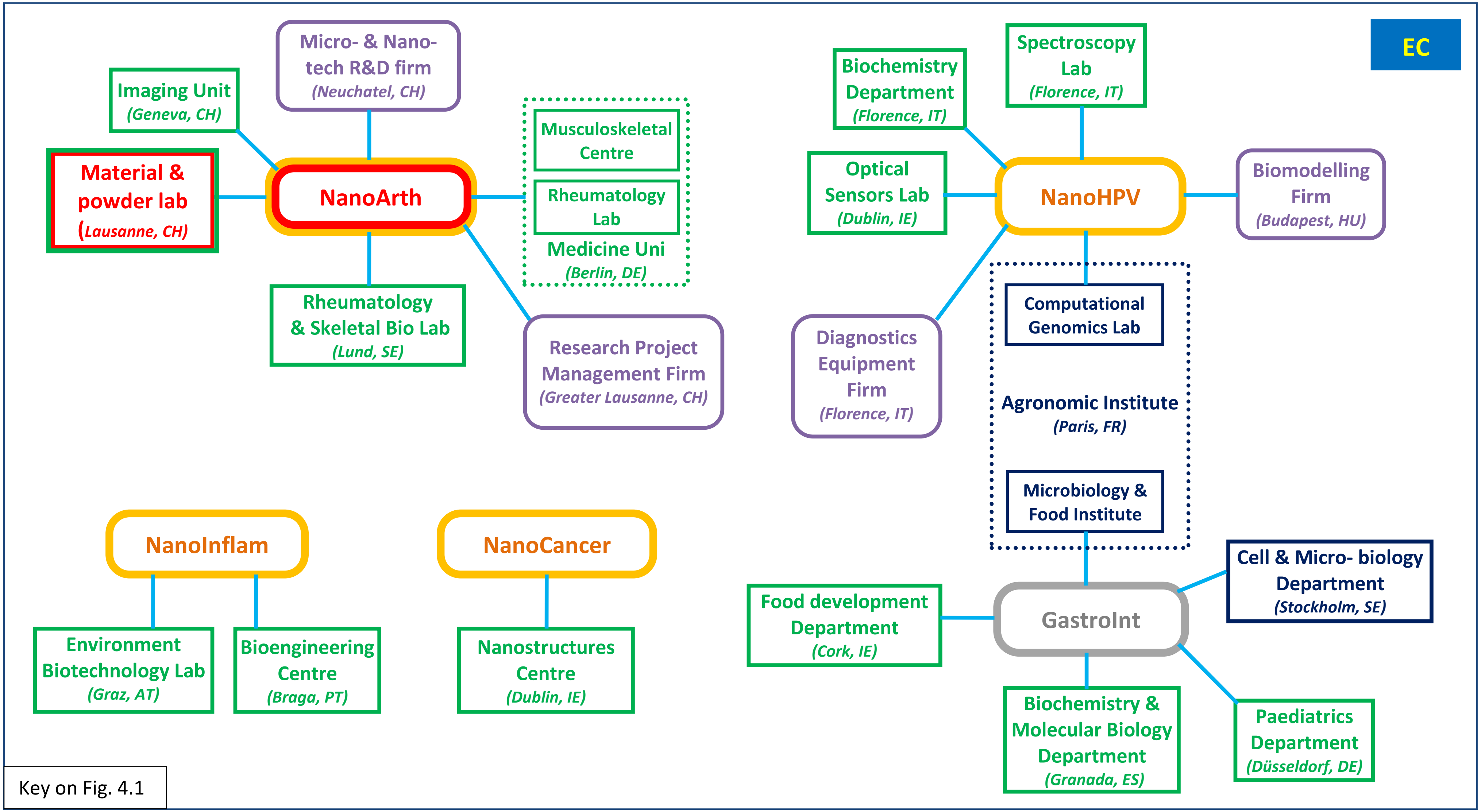


Figure 4.3: Second field map – the Project Layer & Organisation Layer

The *Participant Layer* is considered and mapped next.

4.2.4 The Participant Layer: a variety of roles and expertise

As mentioned in section 4.2.1 and summarised in table 4.1, access to the entire pool of 34 participants involved in our overall study was gained through three key participants who acted as gatekeepers, as follows:

- The first gatekeeper enabled access to 7 partners on the GastroInt project, to 6 partners on the the NanoHPV project, and to 3 members of the EC with advisory and monitoring roles towards the NanoHPV project and other projects. Following his guidance, these 16 participants were all contacted directly by email and accepted to take part in this enquiry.
- The second gatekeeper (i.e. the NanoArth Project Manager) facilitated access to 11 partners on the NanoArth project while the third gatekeeper (i.e. the NanoArth Scientific Coordinator) allowed for 2 partners on the NanoInflam project and 2 partners on the NanoCancer project to also take part in our study. Following their lead, contact was established with these 15 participants either by email or in person, during one of the field trips that took place as part of the overall study.

Additional information on these field trips and the precise nature of the participation of these 34 practitioners (including the 3 gatekeepers) in our study are presented in sections 4.3 and 4.4 when considering the other stages of the study.

Participants' roles and responsibilities

A key part of constructing the *Participant Layer* of the field was to develop a clear understanding of what the remits of the participants considered in our study were in their respective projects. This required the identification of their *project titles* and the analysis of their different roles and responsibilities in relation to the five projects under enquiry. These *project titles* were used directly by the participants to define themselves in relation to their projects, either verbally or on their various online personal profiles (e.g. institution's web sites, http://www.linkedin.com, etc.). Several of them could also be located on the project web sites or on the project's documentation on the EC portal. Table 4.4 provides a summary of the main participant's titles as identified in each project.

Project ***Project Title***	GastroInt	NanoHPV	NanoCancer	NanoInflam	NanoArth	Other
Principal Coordinator/ Principal Investigator			1	1		
Scientific Coordinator					1	
Project Manager/ Technical Project Manager		1			1	
Leading Partner	5	4		1	3	
Research Scientist	8	5	2	2	5	
Doctoral Researcher/ Postdoctoral Researcher		1			6	
Laboratory Technician					1	
EC Research Programme Officer		1				1
EC Project Technical Advisor		1				

Table 4.4: Breakdown of the participant numbers

It is to be noted that the *project titles* identified to denote the main roles and responsibilities on a project can appear to be somehow fluid and the meanings that are assigned to them can vary between different projects but also within a project. For instance, some project partners referred to the main individual who is responsible for the overall project and steers the project in a certain direction as Principal Investigator, others as Principal Coordinator. Hence, Principal Coordinator and Principal Investigator have been merged in table 4.4 as they typically tend to be used interchangeably. Similarly, Project Manager and Technical Project Manager have also been agglomerated. The Project Manager is sometimes referred to as Technical Project Manager (e.g. in NanoHPV) even though their remits are roughly the same: ensure the smooth running of the day-to-day activities of the project. The *Technical* label added to the latter title just denotes that the overall aim of the project is to develop a technical platform, and therefore the Technical Project Manager is responsible for the daily operations required by the technical implementation of this tool. On other projects, the Project Manager can be officially further specialised to be assigned the management of a particular dimension of the project; the Technical Project Manager is thus responsible for all technical aspects of the project while for instance the Scientific Project Manager is particularly concerned with scientific matters.

To get an even greater understanding of the different roles of the participants in the field under investigation, the *project titles* were further grouped and organised in different levels – *overall management of the project*; *management of day-to-day project activities*; *conducting in-lab scientific & experimental activities*, and *external monitoring & advice.* Table 4.5 gives the breakdown of the various titles identified for each of these levels, as well as a brief description of the associated roles and responsibilities, and the number of participants who come under each of these.

Level	Project Title	Description of roles and responsibilities	Numbers
Overall management of the project	Principal Coordinator/ Principal Investigator	• responsible for the overall project • initiates the project • assembles the project consortium • answers to the EC	2
	Scientific Coordinator	• internal scientific consultant • responsible for the scientific content • reviews the scientific documentation to ensure its coherence and validity	1
Management of day-to-day project activities	Project Manager/ Technical Project Manager	• responsible for the day-to-day running of the project • enforces milestones and deadlines • assembles documentation • first point-of-call when problems occur • answers directly to the Principal Coordinator	2
	Leading Partner	• responsible for the contribution of a site to the project • leads a team or a lab at this site • represents the site in meetings that bring partners together • answers to the Project Manager and Principal Coordinator	13
Conducting in-lab scientific & experimental activities	Research Scientist	• researcher in long-term position • undertakes scientific work in a lab or research unit at a site • answers to Leading Partner	22
	Lab Technician	• researcher in short- to mid-term position • specialised in specific techniques • undertakes scientific work with a research scientist • answers to Research Scientist & Leading Partner	1
	Doctoral Researcher/ Postdoctoral Researcher	• graduate student or researcher in short-term position • undertakes scientific work at a site under the direction of a research scientist • answers to Research Scientist & Leading Partner	7
External monitoring & advice	Research Programme Officer	• representative of the EC for the project • monitors progress and completion	2
	Project Technical Advisor	• external expert contracted by the EC • provides technical advice	1

Table 4.5: Breakdown of the participants' roles and responsibilities

It is to also to be noted that there could be some overlap between *project titles*, and thus roles. For instance, Principal Coordinators managed their overall projects, but they could also be Research Scientists, in the sense that they were fully involved in the scientific enquiry work at the heart of the project. In fact, it is because they were trying to solve a scientific problem in the first place that they assembled a global cross-disciplinary project consortium to secure funding and collaborate with others towards resolving it. Similarly, a Leading Partner tended to be primarily a Research Scientist who was given the responsibility to coordinate the efforts of their site and to represent it in cross-consortium endeavours.

Expertise and disciplines

The next step in the field construction was to carefully examine the participants' respective subjects of expertise and to map the *Participant Layer* of the field. The whole idea behind assembling large cross-disciplinary scientific projects is to set up co-operative work arrangements that can benefit from the cross-fertilisation of specialists from different disciplinary areas coming together to tackle challenging problems. The final field map in figure 4.4 shows the *Project Layer*, the *Organisation Layer* and the *Participant Layer* all together. It is built on top of the previous two maps and shows the five projects, the partner organisations, as members of the project consortia, and the participants who work in these institutions along with their project roles and responsibilities and *work titles*. Every participant is represented as a coloured 'participant bubble', as follows:

- The colour-coding of each 'participant bubble' indicates their *project title,* that encapsulates their roles and responsibilities within the project (and is explained on the map key given in figure 4.1).
- The label in full letters next to the 'participant bubble' refers to their *work title*, that specifies the nature of their involvement in their respective projects, from the perspective of their disciplinary expertise. These *work titles* have been slightly modified from their real ones to maintain anonymity, and to capture what at times can be complex expertise with a simple label. These *work titles* were also made unique as they are used to refer to specific individual from now on in the rest of this thesis, particularly in the analysis chapters 5 and 6.

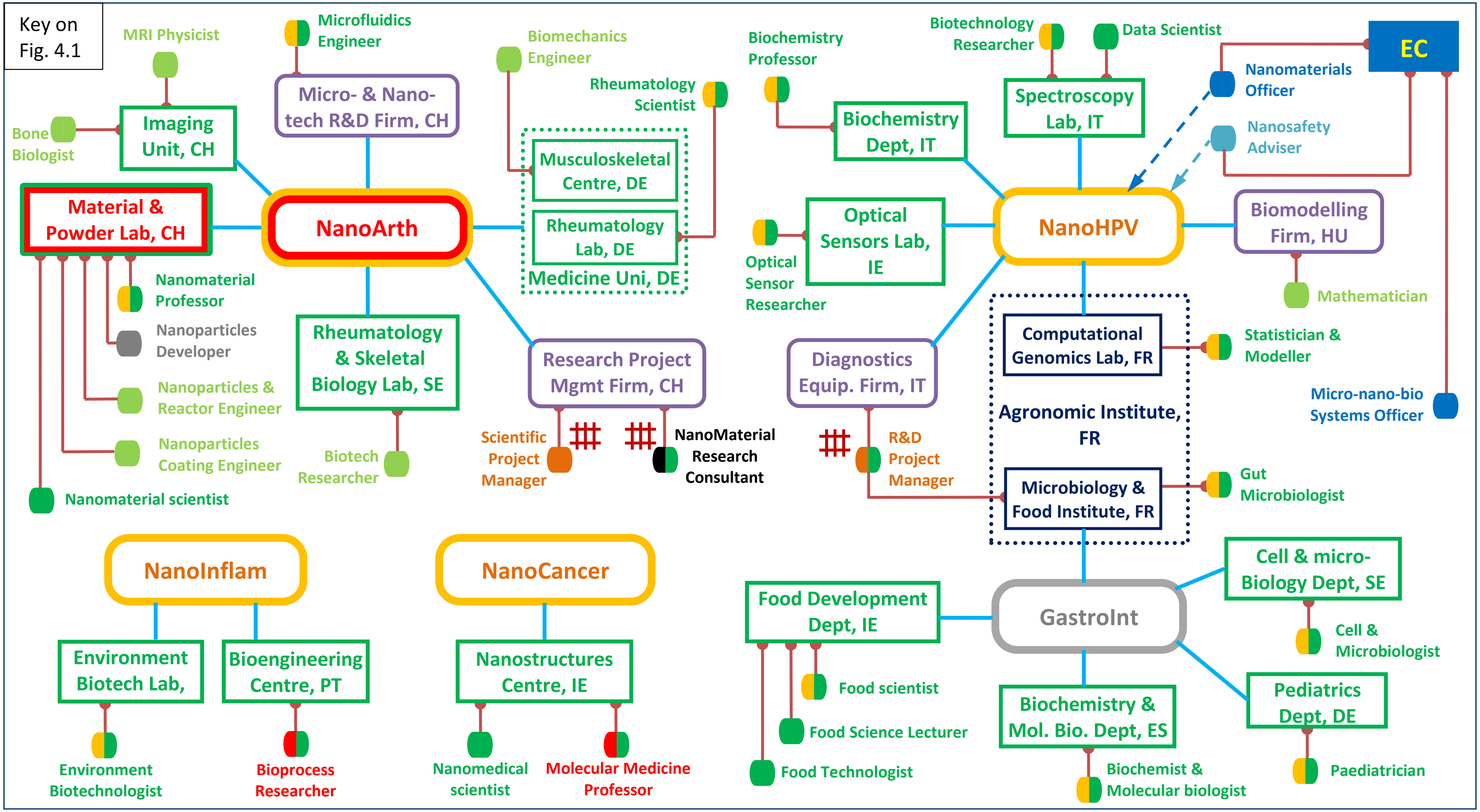


Figure 4.4: Third field map – the Project Layer, Organisation Layer & Participant Layer

To develop a greater understanding of the numerous and varied disciplinary backgrounds of the participants in our study, a simple categorisation task was carried out. The purpose of this was to organise the different disciplinary fields into groups and sub-groups to get a clearer picture of all the areas of expertise involved and how they inter-related with each other. Based on all the participants' on-line profiles, their main disciplinary areas were identified and organised into several levels from the more general to the more specific. Thus, the first level denotes what can be characterised as more general disciplinary areas such as biology, chemistry, medicine, etc. The next level represents sub-areas, and so on and so forth, based on definitions and descriptions of the fields in question. This process resulted in the creation of a *relationship map*, as shown in figure 4.5. It illustrates the interconnections between all the disciplinary areas identified to get an overall picture of the pool of expertise available in the five projects under consideration. This map is not intended as a scientifically accurate picture of the participants, or structures accepted within the scientific communities, but it seeks to illustrate broad competencies and the spread of activities carried out by the participants.

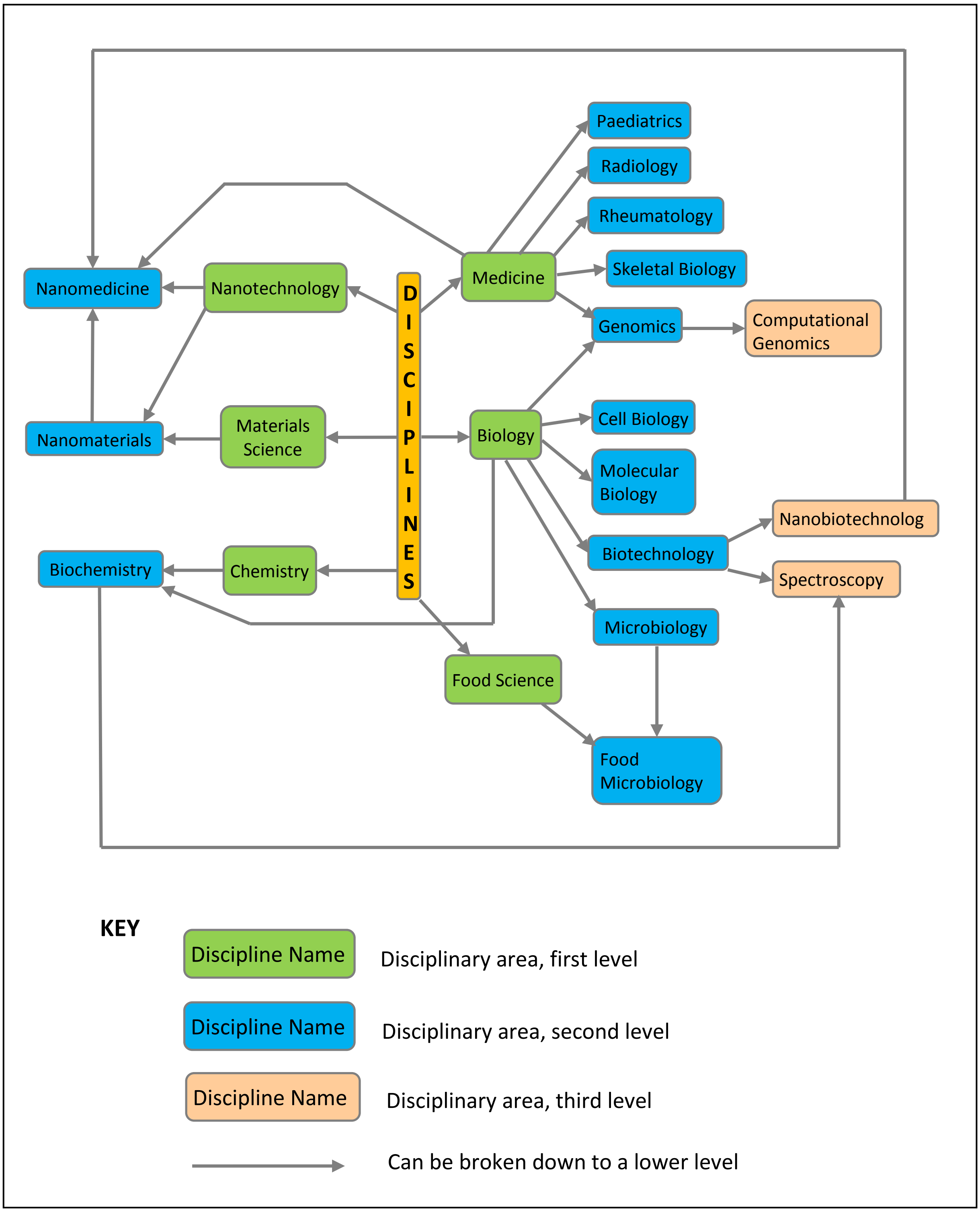


Figure 4.5: Relationship map of the disciplinary areas in the field

To summarise, the first stage of the study undertaken in our research consisted in the shaping, bounding, and mapping the field of enquiry. Three main layers were identified and characterised to construct an overview of the multi-dimensional settings under investigation. The five scientific projects of interest were presented with the organisations that contributed to these projects and from which participants were recruited. All the participants were characterised with respect to their *project titles*, which denote their roles and responsibilities towards the project, and their *work titles* to capture their involvements from a disciplinary expertise perspective. Three interrelated field maps were produced to illustrate the different levels and offer an overall picture of the projects, organisations, and participants involved in our study.

To develop a thorough understanding of how scientific work is conducted within the settings of a large European multi-sited and cross-disciplinary project, 21 of the identified participants were first interviewed in great depth, as explained next.

4.3 Second stage: the interview-based study

The second key stage of our overall empirical consisted of an interview-based study of the ways scientific practioners set up, organise, conduct, manage and monitor co-operative work within the settings of a global multi-sited and cross-disciplinary project. Using an interactionist lens, the aim was to get initial insights into these practitioners' interpretations on the ways they undertake intensely distributed work in large projects to maximise the co-operative potential of such projects. This interview-based study took place from January 2012 to November 2012 and involved 21 participants from the five projects that make up the field. It produced a set of initial findings that should not be considered as the main analytical material of this thesis, but rather as helping to frame our understandings of the main issues under enquiry: the use of information artefacts by distributed scientists to support the co-ordination of their work.

4.3.1 Setup and participants

The details of the 21 participants who took part in our initial interview-based study is shown in table 4.6.

Work title	Project title	Organisation and site	Project
Cell & Microbiologist	Research Scientist & Leading Partner	Cell & micro- biology department *(Stockholm, SE)*	**GastroInt**
Paediatrician	Research Scientist & Leading Partner	Paediatrics department *(Düsseldorf, DE)*	
Biochemist & Molecular Biologist	Research Scientist & Leading Partner	Biochemistry & molecular biology department *(Granada, ES)*	
Gut Microbiologist	Research Scientist & Leading Partner	Microbiology & food institute (*Paris, FR)*	
Food Scientist	Research Scientist & Leading Partner	Food development department *(Cork, IE)*	
Food Science Lecturer	Research Scientist		
Food Technologist	Research Scientist		
R&D Project Manager	Technical Project Manager	Diagnostics equipment firm *(Florence, IT)*	**NanoHPV**
Optical sensor researcher	Research Scientist & Leading Partner	Optical sensors lab *(Dublin, IE)*	
Biochemistry Professor	Research Scientist & Leading Partner	Biochemistry department *(Florence, IT)*	
Biotechnology Researcher	Research Scientist & Leading Partner	Spectroscopy lab *(Florence, IT)*	
Data Scientist	Research Scientist		
Mathematician	Postdoctoral researcher	Biomodelling firm *(Budapest, HU)*	
Statistician & Modeller	Research Scientist & Leading Partner	Computational genomics lab *(Paris, FR)*	
Nanomaterials Officer	EC Research Programme Officer	European Commission	
Nanosafety Adviser	Project Technical Adviser		
Bioprocess Researcher	Research Scientist & Principal Investigator	Bioengineering centre *(Braga, PT)*	**NanoInflam**
Environment Biotechnologist	Research Scientist & Leading Partner	Environment biotechnology lab *(Graz, AT)*	
Molecular Medicine Professor	Research Scientist & Principal Investigator	Nanostructures centre *(Dublin, IE)*	**NanoCancer**
Research Consultant	Scientific Coordinator	Research project management firm *(Greater Lausanne, CH)*	**NanoArth**
Micro-nano-bio Systems Officer	EC Research Programme Officer	European Commission	Other

Table 4.6: Participants in the interview-based study

From this pool of participants:

- 3 participants dealt with the overall management of the project (see table 4.5). 2 participants were Principal Investigators of the NanoInflam and NanoCancer projects respectively, while 1 participant was the Scientific Coordinator of the NanoArth project. Thus, these participants had a good understanding of what it takes to set up and run a large co-operative project to answer a European funding call to resolve a specific scientific problem and of the related issues at *the Project Layer*.
- 11 participants were involved with the management of day-to-day project operations. 1 participant was the Technical Project Manager for the NanoHPV project. In this capacity, he oversaw the participation of the different sites to the project and hence had an insider’s viewpoint on the daily experiences and problems faced by the main actors that interacted across sites to work together. The other 10 participants were Leading Partners and thus had a grasp of what is required to oversee and monitor the local contribution of their site to the overall research effort which gave them a good understanding of the issues in the *Organisation Layer*.
- The remits of 16 of the participants (15 as Research Scientists and 1 as a Postdoctoral Student) was to conduct the actual in-lab scientific and experimental activities. Thus, they played a role in the *Participant Layer* and had clear insights of what was happening locally within the settings of their labs or research units, with respect to the details of the scientific work at their site and the issues encountered.
- 3 participants provided external monitoring and advice; 2 as Research Programme Officer and 1 as Project Technical Adviser. In this capacity, they had knowledge on externally overlooking projects, advising on technical matters and helping to resolve specific problems.

It is to be noted that by January 2012, when this interview-based stage of our overall empirical study began, the GastroInt and the NanoHPV projects has been completed while the NanoInflam, NanoCancer and NanoArth were all roughly halfway through. Thus, it was safe to assume that the participants who took part had a reasonable experience of working at the different levels of a large European multi-sited project that bring together different institutions, not only from these five projects in the field but also from previous involvements in projects of this type.

4.3.2 Interview-based study design and data collection

This second key stage of our study consisted of 21 semi-structured in-depth interviews to explore the activities and challenges of intensively distributed scientific work in a multi-sited cross-disciplinary project. The intent was to get an idea of the nature of the distributed work involved in global cross-disciplinary scientific projects, the management of this work, the interactions between the different actors and groups involved in the co-operative endeavour and the key problems with these interactions. The emphasis was on participants' interpretations of the cross-project interactions they engaged in when setting up and/or participating in a large collaborative scientific project. The focus was on assembling a fitting project consortium, defining interdependent work arrangements, bringing together disparate situated work activities, sharing resources, exchanging results, and producing common outputs to contribute towards the common goal of the project.

In-depth interviewing, also referred to simply as qualitative interviewing, is a well-suited approach for understanding the participants experiences and perceptions of their experiences (Blandford, 2016). It seeks to uncover the deep understandings that are held by the actors in the everyday situations they find themselves in and to learn about the meanings of their actions in these situations and the nature of their experiences (Johnson & Rowlands, 2012). Inspired by the interactionist view promoted by Kotarba (2014) in his own investigation of translational research, our interview-based study can help understand the multi-sited project from the participants' insider viewpoint and uncover the features of cross-disciplinary translational research that they may take for granted. Bearing this in mind, the semi-structured interviews were designed to be wide-ranging and at the same time to be used in a flexible and *conversational* manner (ibid.) so as to encourage talk of a natural and informal nature and allow the participant to take the interview in whatever direction they liked. The interview guide is included in Appendix B. The questions were devised to freely consider the history of the involvement of each participant in each project, from its inception to the reporting on the findings, with an emphasis on intra-consortium interactions. The guide was mainly aimed at participants with a direct involvement in a project, but it was also used loosely for the 3 representatives of the European Commission.

All 21 interviews were conducted remotely between January and November 2012, using a voice-over-IP (voice-over-Internet Protocol) application, and lasted between 42 and 103 minutes. All the interviews were digitally audio-recorded and transcribed in their entirety. Handwritten notes were also taken during the interviews to capture thoughts and ideas 'on-the-fly' or to make connections with other interviews, particularly in the latter stages when more interviews were conducted.

4.3.3 Interview-based study analysis and initial findings

The analytical approach adopted for this interview-based component of our study was inspired by Boyatzis' *thematic analysis* (1998) and Saldaña's *qualitative research coding* (2009). The interview transcripts were read several times with great attention to identify the segments that focused on activities, work practices, exchanges and interactions, as well as the challenges with intensely distributed co-operation and the management of the project interactions. A code was allocated to "symbolically assign a summative, salient, essence-capturing, and/or evocative attribute" (Saladaña, 2013; p. 3) to each section that was deemed to be relevant to the understanding of working within a global scientific project. In a second instance, the segments were further scrutinised to find commonalities and patterns in the ways to handle the identified work activities, interactions and challenges within an intensely distributed project setup. Thus, the data was grouped and re-grouped, but also separated and re-connected, to consolidate meaning, and from this process, coding categories and sub-categories were identifying based on the characteristics they shared (Bernard, 2011; Grbich, 2013). The resulting coding scheme is displayed in figure 4.6 in the form of a *categorisation map* to provide a better visualisation of all the categories, sub-categories and codes on one page.

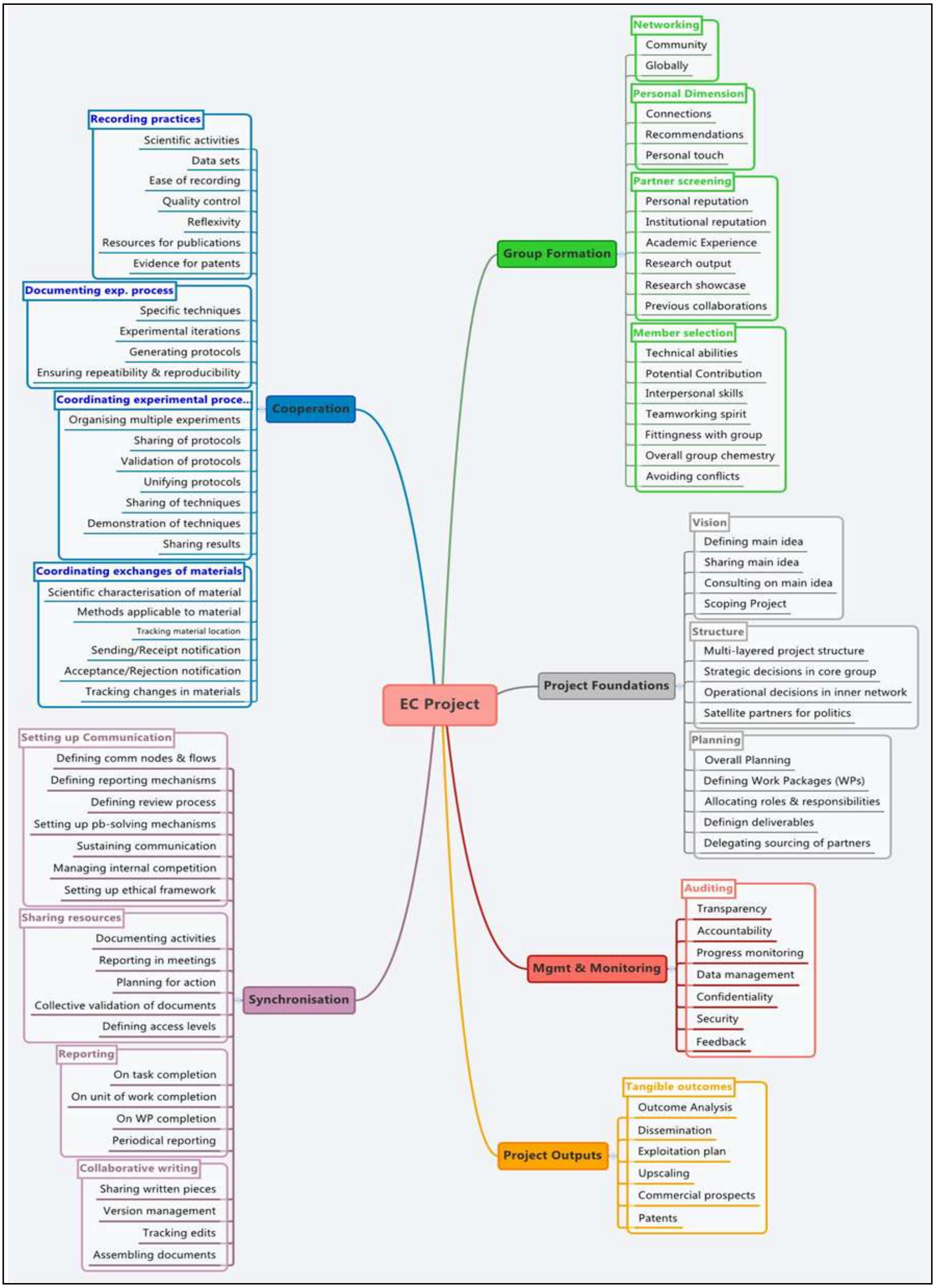


Figure 4.6: Categorisation map for the interview-based study

The following discussion briefly analyses the findings unearthed through conducting these initial in-depth interviews to help understand the ways in which the participants in the field organise their scientific work within the settings of global translational project and manage their interactions around this scientific work. This also helped to subsequently identify one specific project, the NanoArth project, and focus particularly on the co-ordination of scientific activities in the settings of this one project, and on the ways information artefacts help to support it.

Through these interviews, it was first established that the enterprise of forming an adequate global project consortium to answer a funding call for a specific translational research problem relied on a system of established reputations and personal connections (see the *Group Formation* category in figure 4.6). The scientists working in the same academic communities, i.e. the same *social worlds* (Clarke and Star, 2008; Strauss, 1978), essentially created interpersonal links by attending conferences, seminars, and workshops, where they presented their research work to one another. This allowed for them to identify who the key players in their fields of interest were, and to potentially approach them to setup collaborative endeavours. The locating of other possible partners outside their immediate academic disciplinary area to set up a cross-disciplinary co-operative arrangement also tended to be done through personal recommendations, typically via an introduction by a member of the community who has had dealings with them in the past. The credentials of a possible collaborator were checked by carefully examining their research outputs, as well as the publicly available information on the involvements of their research units/laboratories in previous co-operative projects. Ensuring the suitability of an institutional partner to a project of this type was not without its challenges, and there were instances when the participation of a member of the consortium had to be terminated because of differences of opinion.

The second dimension the interviews gave in-depth insights into was the different ways the efforts of all contributors were managed centrally and locally within a project of this type (see the *Project Foundations* and *Management & Monitoring* categories in figure 4.6). A management structure was rapidly put in place as the project consortium took shape, and a management steering group was assembled. It usually included the Principal Investigator, the Scientific Coordinator and the Project Manager (see table 4.5). The steering group was typically responsible for running the project and made the strategic decisions that defined the scope and influenced the overall direction of the project. Very often, a multi-layered managerial structure was implemented, and a second layer of management brought together the management steering group with the Leading Partners for each site. This secondary network translated the strategic decisions of the steering group into operational decisions that directly affected the day-to-day running of the project, and the Project Manager appeared to play a key role in this process. For instance, the overall work to be undertaken in the project was typically broken down, initially by the steering group, into a number of Work Packages, associated to several deliverables. The Leading Partners got involved shortly after to provide high-level details of the planned design of the experimental work to be carried out locally at their respective sites, and thus to help define their site's contributions to each Work Package. This information was shared and discussed with the team operating in the labs to inform the actual experimental design to be implemented *at the bench.*

The other areas explored by the interviews (see the *Cooperation, Synchronisation* and *Project Outputs* categories in figure 4.6) were useful in initially highlighting key issues with actually organising co-operative work on a daily basis in the five projects under consideration and managing the regular interactions between the various distributed partners. The findings of this preliminary quantitative analysis pointed to the challenges of setting up functioning communication channels between partners with very different understandings of the project and the work that needed to be done. These communicating partners could be co-located, i.e. working in the same lab or research unit, or they could work together across multiple sites. They could be operating in the same disciplinary areas or in complete different fields. They could be representatives of the project management with an idea of the overall direction of the project, scientists who manage a team or a lab and who are aware of the contributions of their own group to the project, or doctoral students or lab technicians with a much narrower view of the scientific activities to be performed. If these communications were mainly handled digitally via email, there were also minuted face-to-face exchanges during scheduled meetings, informal exchanges during workshops and other consortium events as well as numerous talks over the phone or VoIP applications. Not only partners with very diverging views needed to continuously exchange verbal and written messages to work together but they also needed to share a considerable amount of resources. This could entail sending each other digital documents, as varied as publications, periodic reports, result spreadsheets, diagrams, images, or files generated by specialised software. These exchanges tended to also be managed by a multitude of emails, which could create a number of problems with having to continuously ensure that the right co-operators had access to the relevant information. Consortium members might also need to share physical materials, as part of their experimental design, which could result in additional difficulties, as some of the substances might be hazardous, and tracking multiple exchanges of these materials added to the complexities of the already complex intra-project communication. Communication needed to also be established with external partners from the EC, such as the Research Programme Officer who monitors the progress of a project, and the Project Technical Advisors who provide different levels of guidance and support.

Beyond highlighting the complexity of the communication mechanisms across a large project, this interview-based component of our study was essential in highlighting many key issues related to the actual conduct of daily scientific work activities *at the bench* within the context of an intensely distributed setup (see *cooperation* category in figure 4.6). After having reviewed the STS and the CSCW literatures and having many discussions during the interviews, a number of questions arose on the ways scientific enquiry work that is experimental in nature can actually be undertaken co-operatively in such global project settings. These included: how is experiment-based scientific enquiry work designed and conducted co-operatively in global cross disciplinary and multi-sited arrangements? Through which practices is this co-design and co-conduct of experimental work co-ordinated and integrated? How is concerted action accomplished when experimenting scientists have only partial access and knowledge of the work of their partners? How do they manage to co-design and co-conduct experimental work when they have different approaches and perspectives and have to deal with their own local situations and contingencies? What are the roles of information artefacts in the co-design and co-conduct of experimental work? How do project partners interact through them? How are scientists' individual activities co-ordinated and integrated using these information artefacts? How do their material characteristics influence co-operative practices? How do their various transformations impact co-operation and concerted action?

These many different questions about the actual design and conduct of experimental activities in intensely distributed work arrangements and the roles of information artefacts in relation to these took central stage in our study subsequently. Endeavouring to answer them is what motivated the design of the third key stage of our overall study which focused on one project in depth and which is explored in the next section.

4.4 Third stage: a multi-method empirical study of the NanoArth project

To develop an in-depth understanding of how scientists operating in intensely distributed settings co-ordinate the design and conduct of their experimental work (and how they use information artefacts to support this co-ordination) the field was narrowed down, and a multi-method study was conducted focused on one specific project: the NanoArth project. The NanoArth-focused empirical study (referred to subsequently as the “study of NanoArth”) lasted from March 2012 to December 2015 (with the greater part conducted between March 2012 and November 2013 and follow up interactions thereafter) and involved participants from 7 different sites (see field map in figure 4.4).

The next sub-section briefly describes the nanomedicine and nanodiagnostics disciplinary areas this project is concerned with and their related challenges. The methodological components that were designed and deployed in our study of NanoArth to probe the ways scientists organised and articulated their experimental activities are then discussed, along with the specific qualitative methods that were used within each of the components.

For greater convenience and clarity, a table describing the components, methods and techniques used in the study of NanoArth is given at the start of this section. Therefore, table 4.7 summarises all the methodological components that were designed in our study of NanoArth to collect multiple types of data through a range of techniques, i.e. interviews, observations, participant observations with verbalisation, situated interviews, participatory learning exercises, and other discussions and interactions with the participants that took part. The labels used to denote every method relied on our study of NanoArth are explained in the following sections, as the methods are discussed.

Component	Label	Method & Description (+ site)	Date
First component: **early interviews**	Interv_SC	Remote interview with NanoArth Scientific Coordinator (Greater Lausanne site).	03/2012
	Interv_PM	Remote interview with NanoArth Project Manager (Greater Lausanne site).	03/2012
	Interv_PM&SC	Face-to-face interview with both Scientific Coordinator and Project Manager (Greater Lausanne site).	04/2012
Second component: **participant observations**	PartObs_ND_1	Participant observations of the synthesis, characterisation and functionalisation of SuperParamagnetic Iron Oxide Nanoparticles (SPIONs) for in-vivo experiments at the Imaging Unit in Geneva (Lausanne site).	05/2012
	PartObs_NRE_1		
	PartObs_ ND&NRE_1		
	PartObs_NCE_1		
	PartObs_ND_2	Participant Observation of the synthesis, characterisation and functionalisation of SPIONs for in-vitro toxicity testing at the Rheumatology Department in Berlin (Lausanne site).	02/2013
	PartObs_NRE_2		
	PartObs_ ND&NRE_2		
	PartObs_NCE_2		
	PartObs_NS	Participant observation of computer-based simulation tests on nanomaterials (Lausanne site).	05/2012
Third component: **situated interviews**	Interv_ND_1	Contextual interview with Nanoparticles Developer after participant observation (Lausanne site).	05/2012
	Interv_NRE_1	Contextual interview with Nanoparticles & Reactor Engineer after participant observation (Lausanne site).	05/2012
	Interv_NCE_1	Contextual interview with Nanoparticles Coating Engineer after participant observation (Lausanne site).	05/2012
	Interv_ND_2	Contextual interview with Nanoparticles Developer after participant observation (Lausanne site).	02/2013
	Interv_NRE_2	Contextual interview with Nanoparticles Coating Engineer after participant observation (Lausanne site).	02/2013
	Interv_NCE_2	Contextual interview with Nanoparticles Developer after participant observation (Lausanne site).	02/2013
	Interv_NS	Contextual interview with Nanoparticles Scientist after participant observation (Lausanne site).	02/2013

Fourth component: **further interviews**	Interv_BB	Face-to-face interview with Bone Biologist (Geneva site)	05/2012
	Interv_MRIP	Face-to-face interview with MRI Physicist (Geneva site)	05/2012
	Interv_RS	Remote interview with Rheumatology Scientist (Berlin site)	03/2013
	Interv_BE	Remote interview with Biomechanics Engineer (Berlin site)	07/2013
	Interv_BR	Remote interview with Biotechnology Researcher (Lund site)	07/2013
	Interv_ME	Remote interview with Microfluidics Engineer (Neuchatel site)	07/2013
Fifth component: **participatory learning exercises**	PLE_1	First participatory learning exercise on nanotoxicity standardisation with Scientific Coordinator, Project Manager and Nanoparticles Developer (in Greater Lausanne)	02/2013
	PLE_2	Second participatory learning exercise on nanotoxicity standardisation with Project Manager and Nanoparticles Developer (in London)	08/2013
	PLE_3	Third participatory learning exercise on nanotoxicity standardisation with Project Manager and Nanoparticles Developer (in Bern)	09/2013
	PLE_4	Fourth participatory learning exercise on nanotoxicity standardisation with Scientific Coordinator, Project Manager, Nanoparticles Developer and Nanomaterial Professor (in Lisbon)	11/2013

Table 4.7: Methods and techniques deployed in the NanoArth-focused study

4.4.1 NanoArth: a nanodiagnostics project

The Nanodiagnostics for Arthitis project (NanoArth project) ran for four years from February 2010 to January 2014 and had an EC budget of €8.9 million. As for the NanoInflam project, it was concerned with the use of nanomaterials to produce a diagnostic tool targeted towards chronic inflammatory diseases. The main objective of the NanoArth project was the development of a novel nanodiagnostics technological platform to detect the molecular processes that may cause the inception and progress of rheumatoid arthritis and osteoarthritis. The main idea behind this diagnostic tool was the synthesis and use of functionalised SuperParamagnetic Iron Oxide Nanoparticles (SPIONs) to image the inflammatory events of arthritis, and thus identify the biomarkers associated with the joint disorders. In brief, the NanoArth project was a nanomedical project particularly concerned with nanodiagnostics, the area of nanomedicine that investigates the use of nanotechnologies to develop innovative detection methods for a range of diseases (see section 4.2.2).

Nanomaterials have been defined by the EC as materials for which more than half of the particles that constitute them have at least one external dimension smaller than 100 nm (Potočnik, 2011). Nanoparticles are defined as individual particles having three external dimensions smaller than 100 nm (ibid.). Nanomaterials and nanoparticles have attracted significant interest in biomedical research (thus leading to the defining of the nanomedical discipline) because their physical, chemical, and biological properties may significantly change in the nanorange, thereby enabling new or improved diagnoses and therapies (Roubert et al., 2016). For instance, SPIONs of key interest to the NanoArth project, may show characteristics that change their magnetic behaviours at sizes below 15 nm (Xu & Sun, 2013) and act as a contrast agent for MRI scans. It is precisely this property that the NanoArth project sought to exploit to develop a nanotechnology-based diagnostic system.

The disciplinary area of nanomedicine, and its sub-discipline of nanodiagnostics are not without their complexities. Nanomaterials and nanoparticles are highly volatile and thus pose major safety challenges to human health and the environment. The European Food Safety Authority (EFSA) suggests that nanomaterials should be assessed for risk, considering exposure, at five different levels as their state evolve in varying conditions (European Food Safety Authority, 2009). The US Food and Drug Administration (FDA) recognises that the challenges presented by nanomaterials may be heightened because their properties change continuously as the size enters the nanoscale range (Food and Drug Administration, 2007). "Nanotechnology entails new toxicological risks which are vaguely defined and difficult to test, a field in which our knowledge about immune defence response – if it is able to react at all in any given situation – is poor" (Reinsborough & Sullivan, 2011; p. 4). Engineered nanoparticles raise particular concerns of their own as they can be highly reactive and mobile within the human body and lead to toxic reaction, even though the evidence is disparate and the mechanisms of uptake are still only partially examined (Toy et al., 2014).

It is in this challenging disciplinary context that the NanoArth project was set up to design and conduct complex experimental-driven scientific work to investigate the development of a SPIONs-based diagnostics platform, and it is this complex scientific work that the components of our study of NanoArth deployed thereafter sought to probe in great depth.

4.4.2 Early interviews

The first component of our study of NanoArth consisted of a set of **three in-depth interviews** with the **Scientific Co-ordinator** and the **Project Manager** of the NanoArth project. The **first two interviews**, respectively with the Scientific Co-ordinator and the Project Manager, took place in March 2012 remotely using a voice-over-IP application and lasted 122 minutes each and 109 minutes respectively. For further reference, these interviews were respectively labelled **Interv_PM** and **Interv_SC** (with Interv standing for interview and the other initials pointing at the role of the interviewee). The **third interview** was face-to-face and was a group interview, as it involved **these two members of the project management team** simultaneously. It was held in April 2012 in the offices of the research project management company where they both work in Greater Lausanne, Switzerland. It was labelled as **Interv_PM&SC** (following the same logic). The three interviews were all audio-recorded and extensive fieldnotes were taken, particularly during the face-to-face encounter with both members of the project management steering group, to record *in situ* some of the key points that were made.

These three in-depth interviews kickstarted our study of NanoArth and sought to develop an initial understanding of the ways the experimental work is organised, managed and monitored across the project from a managerial standpoint and to uncover their views on the challenges and issues faced involved in doing so. The first two interviews (Interv_PM and Interv_SC) were semi-structured and loosely used the interview guide that was produced in the previous key stage of our overall empirical study to probe a range of practices (see Appendix B). Because of her role as Scientific Coordinator but also because of her experience as a scientist in this project and in past project, the interview Interv_SC helped us unpack some of the practices adopted to design and validate experimental work. Because of her standpoint, the Project Manager focused the interview Interv_PM on the recording, sharing and management of project data and on the various reporting mechanisms in place in the project. The third interview Interv_PM&SC with both individuals was less structured and took the form of a directed conversation (albeit being recorded and later transcribed). Insights were offered on the organisation of the scientific work as both participants projected different but complementary views and clarifications were provided on some of the aspects mentioned during the previous two discussions.

4.4.3 Participant Observations

During the interview Interv_PM&SC, access was secured for two field visits at the Material and Powder Lab in Lausanne (see field map in figure 4.4). In her gatekeeper's capacity, the Project Manager enabled contact to be made with the Nanomaterial Professor who runs the lab and who allowed for the two visits to take place. The Nanomaterial Professor is a Leading Partner in the NanoArth project as the research team he manages at this lab contributes to the project in a major way. Essentially, the Material and Powder lab is the site responsible for the investigation, synthesis (i.e. the development), characterisation (i.e. the measurement of size, concentration and surface charge), functionalisation (i.e. the surface coating) and distribution of the nanoparticles of type SPIONs used by the other sites for their own experimental work. The key contribution that this lab makes to the overall project made this a particularly important site to visit and for participant-observations to be conducted there.

The first field visit took place over one day in May 2012. It provided the opportunity to meet the research team and actively observe the experimental work required by the synthesis, characterisation and functionalisation of a batch of SPIONs to be sent to the Imaging Unit site in Geneva and to be used there as part of in-vivo experiments on mice. This visit sought to develop an initial understanding of the current practices in the lab, the different types of interactions between the participants and the use of information artefacts to support their activities and interactions. The second field visit occurred in February 2013 and lasted two days. It focused on the experimental activities undertaken to synthesise, characterise and functionalise a batch of SPIONs to be sent to the Rheumatology Lab in Berlin for in-vitro toxicity testing. The focus of this second visit was more specifically the utilisations of information artefacts in the design and conduct of experimental work and the ways they are used to support various social interactions. Both field visits enabled the collection of multiple types of data through a range of techniques that included straight-forward observations, participant observations with verbalisation, situated interviews and discussions with the participants during team meetings.

The **observations** during the first visit involved different experimental activities by various members of the team i.e. the synthesis of SPIONS by the **Nanoparticles Developer** on her own (labelled PartObs_ND_1); the characterisation of SPIONS she undertook alongside the **Nanoparticles & Reactor Engineer** (labelled **PartObs_ND&NRE_1**); and the functionalisation of SPIONS by the **Nanoparticles Coating Engineer** (labelled **PartObs_NCE_1**). A number of iterations of the characterisation work by the **Nanoparticles & Reactor Engineer** were also observed (labelled **PartObs_NRE_1**). I, as the researcher, was initially a *complete observer* (Gold, 1958) since, to start with, experimenters' activities were looked at with little participation in the culture of the scientists operating in the lab. This changed gradually as the bond with the participants grew stronger but also as my role in relation to the NanoArth project evolved. Progressively, I took a much more active role in the project to help define and formulate standardisation methods in regard to the toxicity of nanomaterials (i.e. nanotoxicity), based on the use of a range of key information artefacts (Hool et al., 2013; Roubert et al.; 2016). This resulted in regular participatory interactions and the running of a number of participatory learning exercises, as discussed in detail in sub-sections 4.4.6 and 4.4.7.

The second visit in February 2013 saw my greater participation in the **observations** that were conducted and that focused on the experimental work of the **Nanoparticles Developer** (observation labelled **PartObs_ND_2**), the **Nanoparticles & Reactor Engineer** (labelled **PartObs_NRE_2**), the **Nanoparticles Coating Engineer** (**PartObs_NCE_2**) and the **Nanomaterial Scientist** (**PartObs_NS**) at the Material and Powder Lab in Lausanne (see field map in figure 4.4). Experimental work on characterisation by both the **Nanoparticles Developer** and the **Nanoparticles & Reactor Engineer together** (labelled **PartObs_ND&NRE_2**) was also observed. A much more probing stance was taken during these observations and the observed participants were asked to verbalise their actions, in line with an active view of a think-aloud approach (Blandford, 2016). Opportunistic questions were asked as various tasks were being performed to enquire about how a particular information artefact was used or about the way specific information was recorded or communicated to other parties. Specific instances of editing an experimental protocol, recording of observations in a lab book, and capturing the details of a characterisation were considered to uncover specific practices and concerns associated with these.

During both sets of participant observations, extensive unstructured fieldnotes were taken, and they were used later to help frame the data analysis. When the opportunity arose to access real-life documentation, such as experimental protocols and material logs, their structure, their format and content was analysed. In the observations during the second visit, the verbalisations made by the participants during the observations were all audio-recorded and transcribed. Several photos of the observed participants operating at the bench *in-situ* were also taken.

4.4.4 Situated interviews

After each observation, a number of *in situ* interviews were conducted with the participant. Regarding the first field visit in May 2012, interviews were conducted with the Nanoparticles Developer, the Nanoparticles & Reactor Engineer and the Nanoparticles Coating Engineer, within the settings of the lab, right after having observed their experimental work on synthesising, characterising and functionalising SPIONs. Questions were asked on the detail of the practices that had just been witnessed and on the ways various items of information were captured in relation to the activities that had taken place. Clarifications were sought about specific issues and challenges faced when carrying out experimental operations *in situ*. This **first set of situated interviews** were labelled respectively **Interv_ND_1**, **Interv_NRE_1** and **Interv_NCE_1**, for further reference, to denote first round of situated interviews with this set of participants.

For the second field visit in February 2013, the interviews were conducted during and after the observations, drawing on (albeit loosely) the *contextual enquiry* approach (Beyer & Holtzblatt, 1998). Not only were the participants asked to verbalise individual tasks carried out at the bench but also probing questions were asked while they were engaged in their work activities, which mainly focused on their use of information artefacts to support these activities. Questions were asked on the authoring, editing and sharing of experimental procedures when designing experimental work; on the recording, sharing and validating of experimental data as the lab work unfolds; and on the logging, shipping and tracking of experimental materials such as batches of synthesised nanoparticles. Additional clarifications were sought after the observations, if needed. The aim of these sets of situated interviews was to incite the participants, who are experts in their work, to reflect on their own actions and intents (Holtzblatt and Beyer, 2013), particularly in relation to the *in situ* use of information artefacts to support the design and conduct of experimental operations. This **second set of situated interviews** involved the **Nanoparticles Developer**, the **Nanoparticles & Reactor Engineer**, the **Nanoparticles Coating Engineer** and the **Nanomaterial Scientist** and consequently were labelled **Interv_ND_2**, **Interv_NRE_2**, **Interv_NCE_2**, **Interv_NS** for further reference.

During both visits at the Material and Powder Lab in Lausanne, I also had the opportunity to attend team meetings. They were chaired by the Nanomaterial Professor and brought together the entire team involved in the synthesis, characterisation and functionalisation of the SPIONs (i.e. the five afore-mentioned Lausanne-based participants), as well as an administrative assistant. These were open discussions on the current experimental work to be undertaken, on the difficulties encountered and on potential solutions to overcome them. Field notes were taken to keep a log of instances of verbal exchanges that occurred during these meetings.

4.4.5 Further interviews

In addition to the field visits in the lab in Lausanne where participant-observations and situated interviews took place, **6 semi-structured in-depth interviews** were conducted with **participants from another 4 sites** that participate in the NanoArth project. **Two interviews** were conducted **face-to-face**, with the **Bone Biologist** and the **MRI Physicist** who both work together in the Imaging Unit in Geneva (see field map in figure 4.4). These are labelled **Interv_BB** and **Interv_MRIP**, respectively, and took place in Lausanne in May 2012, the day after the first set of participant observations. Both the Bone Biologist and the MRI Physicist attended a workshop on nanomaterial toxicity in Lausanne organised by the NanoArth management steering group and intended for all the scientists in the Nanodiagnostics cluster with an interest in the subject and to which I was invited (see section 4.4.7 for more information).

The other **four in-depth interviews** took place remotely using the voice-over-IP application in March 2013 and July 2013. These involved respectively the **Rheumatology Scientist** from the Berlin Rheumatology lab (**Interv_RS**); the **Biomechanics Engineer** from Musculoskeletal Centre also in Berlin (**Interv_BE**); the **Microfluidics Engineer** from the Micro- & Nano-tech R&D company in Neuchatel, Switzerland (**Interv_ME**); and the **Biotechnology Researcher** from Lund in Sweden (**Interv_BR**). The intent of these set of interviews was to 'hear their side of the story' i.e. to uncover the views of the participants who directly co-operate with the main site, the Material and Powder Lab in Lausanne, on the ways the distributed nature of the experimental work is assisted by the use of information artefacts. Unstructured questions were combined with more targeted questions to uncover the ways these set of partners conducted their experimental activities in collaboration with the team at the Material and Powder Lab, and others, and to seek clarifications on a number of aspects that emerged during the visits in Lausanne on the use of information artefacts such as protocols, laboratory books and material logs. These interviews lasted between 52 minutes and 97 minutes. Selected summaries of transcriptions of particularly revealing interviews can be seen in Appendix C.

4.4.6 Participatory learning exercises

As the study of NanoArth progressed, my role as a qualitative researcher gradually evolved and a much greater and more direct contribution to the NanoArth project was made. Right from the early interviews (Interv_SC, Interv_PM and Interv_PM&SC), it emerged that there was a great interest in the NanoArth project, spear-headed by the Scientific Coordinator and Project Manager, in looking in detail at the actual mechanisms of scientific co-ordination (at the centre of our research), in the context of their distributed project, and in the related area of standardisation of scientific practices across the multiple sites that came together in this project. The 5th Work Package (led by the Scientific Coordinator and the Project Manager in Greater Lausanne) was labelled *Scientific Coordination and Data Management* explicitly and focused specifically on the ways in which experimental data was managed and shared between the different partners across sites. This meant that one of the deliverables of the NanoArth project would be a report that would specifically discuss and inform the mechanisms adopted to assist with the co-ordination of experimental work and the sharing of data. Thus, my role would be one of an involved researcher and my findings would also contribute towards the deliverables for this work package.

It also emerged progressively during our study of NanoArth, that the differences in practices across the different sites in the ways nanoparticles were handled was considered as a burning issue. In the field of nanodiagnostics that rely on potentially harmful engineered nanoparticles (see section 4.4.1), the area of nanotoxicity takes top priority and finding ways to minimise the risks to human health and the environment is a key driver for any decisions that are made. Hence, it became clear that there was a continuous interest in identifying ways in which methods for the synthesis, characterisation, functionalisation and sending of the nanomaterials could be standardised across the sites of the consortium (and beyond). Nanotoxicity still being a relatively young field, standardisation methods are still being currently defined. The participants at the Material and Powder Lab (i.e. Nanomaterial Professor, the Nanoparticles Developer, the Nanoparticles & Reactor Engineer, Nanoparticles Coating Engineer and the Nanoparticles Scientist) continuously highlighted how the practices they had put in place to synthesise, characterise, functionalise and ship the SPIONs could contribute to a better standardisation of the methods to produce and share nanomaterials. The participants in charge of the management of the project (i.e. the Scientific Coordinator and the Project Manager) were very keen for this to be a strong contribution of the NanoArth project to the field of nanotoxicity, and nanodiagnostics in general, and strongly encouraged my closer involvement in this endeavour.

Four **participatory learning exercises** (and, later, several participatory interactions) were conducted for these issues of nanotoxicity and standardisation to be considered in greater depth. These took the form of comprehensive group discussions; two involved **the Project Manager and the Nanoparticles Developer** (**PLE_2 and PLE3**); the first one involved them both and **the Scientific Coordinator** (**PLE_1**); and the last one, all three along with **the Nanomaterial Professor** (**PLE_4**). Those discussions sought to co-operatively think of innovative ways to standardise the methods used in the synthesis, characterisation, functionalisation of the SPIONs to improve the quality and the safety of these engineered nanomaterials across the project and to explore how a number of information artefacts could be introduced, configured and potentially digitalised to support these methods. An emphasis was put on the lessons that could be learnt from the NanoArth project and potentially extended to other projects.

These participatory learning exercises took place in Greater Lausanne in February 2013 (PLE_1), in London in August 2013 (PLE_2), in Bern in September 2013 (PLE_3) and in Lisbon in November 2013 (PLE_4), respectively. They lasted between 85 minutes and 172 minutes. They were essentially unstructured to start with but became gradually more focused towards the production of a deliverable i.e. an academic publication (Roubert et al.; 2016). All of them were audio-recorded and transcribed selectively. A summary of the transcription of the first one (PLE_1) can be seen in Appendix D.

4.4.7 Regular participatory interactions

To build on the four the participatory learning exercises described previously, extensive discussions were held very regularly with both the Nanoparticles Developer and the Project Manager jointly (through the voice-over-IP application) from March 2012 all the way to December 2015. These led to multiple exchanges that contributed greatly to the effort of defining more robust and more formal nanotoxicity standardisation methods.

Last but not least, several other opportunities to interact with members of the NanoArth consortium emerged. Several formally organised events were attended by myself: a nanotoxicity workshop in Lausanne in May 2012, a conference and working session on inorganic nanomedicine in Bern in September 2013, and a conference on Nanodiagnostics for inflammatory diseases run jointly by NanoArth and NanoInflam (see table 4.2) in November 2013. These provided a very valuable opportunity to observe and take part in the face-to-face interactions between the members of the NanoArth consortium (and NanoInflam to a certain extent) when exchanging ideas and to take part in some of the discussions. My involvement as a researcher also became gradually more participatory in these exchanges, as my role evolved throughout the study of NanoArth. Moreover, I also attended a number of social events, which allowed for a more informal immersion in the *social worlds* (Strauss, 1978; 1979; Clarke, 20003; 2005) of the researchers under investigation, and provided me with additional valuable insights into the meanings they attribute to the conduct of their scientific practices.

4.5 Chapter conclusion: towards data analysis

This chapter has described in great detail how the overall multi-method multi-sited empirical study was constructed, designed and deployed in practice. Three main stages were defined: the construction of the field, an interview-based study and a multi-method project-focused study. Initial contact with three gatekeepers enabled access to a pool of 34 participants from 5 global cross-disciplinary projects concerned with translational biomedical research. The entire field was mapped out carefully and a Project Layer, an Organisational Layer, and a Participant Layer were identified and characterised with great precision. The project consortia were described meticulously, and the roles, responsibilities and disciplinary expertise of the considered participants were discussed and categorised. An interview-based study was conducted to construct an initial understanding of the main issues in the field and uncover the ways in which scientists organise their scientific work in an intensely distributed co-operative environment and the challenges they encounter in doing so.

The co-ordination of the experimental efforts to enabled concerted action emerged as being an area of key interest with particular challenges because of the complexities of the experimental activities to be conducted and articulated within and across multiple sites. To address some of these issues around co-ordination of experimental operations, and probe the roles played by information artefacts to support it, the field of enquiry was narrowed down to one multi-sited cross-disciplinary project in nanodiagnostics: NanoArth. A number of components in the study of NanoArth were designed and deployed to investigate the details of the design and conduct of experimental work in this specific project and explore how a number of information artefacts are designed and used to assist with integrating this work across this co-operative work arrangement. Table 4.7 summarises the methodological components and techniques designed and used to collect data in the study of NanoArth: interviews, observations, participant observations with verbalisation, situated interviews, participatory learning exercises, participatory interactions, and other discussions.

Analytically, the approach drew from *thematic analysis* and *qualitative research coding* to make sense of the rich data collected. All transcripts were run through multiple times to identify the sections that shed light on the design and conduct of experimental activities, on the ways they were organised and articulated within and across sites, on the interactions and exchanges that occurred around these activities and on the ways information artefacts were used in these practices and interactions. A number of *areas of scientific activities and interactions* were identified as key thematic areas of concerns and are used to frame the analysis presented in the following two chapters. For each of these, work practices, social interactions, utilisations of information artefacts, as well as interpretations and meanings allocated by the NanoArth scientists, and issues and difficulties they highlighted, were uncovered and are discussed in detail in the next two chapters.

Chapter 5 Co-designing distributed scientific work

5.1 Chapter Introduction

As NanoArth is a global cross-disciplinary project, it provided an ideal co-operative work arrangement to develop a detailed empirical understanding of the design and conduct of intensely distributed scientific work and how information artefacts are relied upon to assist with the articulation of scientific activities in multi-sited settings. This chapter (and the following) gives a detailed analytical account of the NanoArth-focused study conducted in this PhD to investigate the ways in which scientists operating in a large distributed project design and organise their scientific work co-operatively and use information artefacts to support the co-ordination of their efforts to achieve concerted action. Thus, in this investigation, the analytical focus was on the practices adopted by the scientists to design, organise, manage, and align their experimental activities, and to design, maintain, and modulate a range of information artefacts to integrate these activities towards the completion of the common goal of the project. In line with the interactionist approach drawn on in our research, a particular attention was put on how the co-operating actors define the situations based on the local meanings they allocate to them and on the way social interactions affect these meanings, particularly in multi-sited settings.

During the conduct of the qualitative analysis of the rich data that was collected, seven significant thematic areas of concern were identified and were used to frame the analysis. They are referred to as key *areas of activities and interactions* in the remainder of this thesis. They are essentially aspects of the scientific enquiry work in which day-to-day scientific activities occurred, around which social interactions between researchers took place and for which information artefacts were designed, configured and used co-operatively to support enquiry work. These *areas of activities and interactions* are:

(1) *Experimental Design*;
(2) *Experimental Validation*;
(3) *Experimental Quality*;

(4) *Experimental Material Supply*;
(5) *Experimental Material Exchanges*;
(6) *Multi-type Exchanges*;
(7) *Experimental Logging*.

The first three, brought together under the broader area of *the co-design of distributed scientific work*, articulate the analytical account presented in this chapter. To start with, this chapter examines the practices involved in designing and maintaining the experimental protocol information artefact to support the design and conduct of co-operative experimental activities. It explores how the experimenters who participated in the study of NanoArth authored, configured, and modified their experimental protocols collaboratively within a site and across multiple sites to drive complex experimental design and the challenges they encountered. Subsequently, the chapter explores the ways in which the co-operative use of the protocol assisted with the validation of the experimental work and the ensuring of experimental quality. Lastly, issues of centralisation and standardisation of protocols and the effects these had on the co-design of experimental activities are considered.

It is to be noted that codes are used after every snippet of data presented in this chapter and the next to link it up each snippet to the specific methodological component, method and data collection technique it originates from, and thus to indicate how the analysis draws on our multi-method methodological approach. The codes refer to those provided in table 4.7 and follow each quote in brackets. The *work title* (see section 4.2.4) of the participant from whom the quote is taken, and the site at which they work, are included in the text and emboldened for greater visibility.

5.2 Co-designing scientific enquiry work

In a large multi-sited project like NanoArth, scientific work is often organised in complex co-operative work arrangements distributed across heterogeneous cross-disciplinary teams. These teams have to define and design experimental activities that need to take place at different locations, where the required expertise or equipment is available, but that are closely interconnected as part of the same unit of investigatory work. In such complex experimental setups, the primary concern for the scientists conducting investigatory work that involves these co-operative groups of geographically dispersed scientists with different perspectives and *modus operandi*, is to find ways to co-design experimental activities that can be integrated to serve the common objective of the unit of work, work package, or entire project. This section first discusses these co-operative scientific enquiry work arrangements and what they mean for the scientists involved in them. It then identifies and probes the experimental protocol as this key artefact that plays a crucial role in supporting the co-design and articulation of the distributed experimental activities.

5.2.1 Distributed scientific enquiry work arrangements

An early understanding of the ways in which the overall scientific work was organised in the NanoArth project emerged during the initial interviews that were conducted with the Scientific Co-ordinator (Interv_SC), the Project Manager (Interv_SC) and both of them together (Interv_PM&SC). When authoring the proposal for the NanoArth project, the work was divided in 9 work packages. “A work package is a building block of the work breakdown structure that allows the project management to define the steps necessary for completion of the work. As such, a work package can be thought of as a sub-project, which, when combined with other work package units, form the completed project” (European Commission, 2012b). The **Scientific Coordinator in Greater Lausanne** gave an overview of the overall project structure and the breaking down in work packages:

> *“We divided the work into 5 research work packages and 4 supporting ones. The research packages were for the actual research, while the other ones were for the dissemination and the valorisation of our work but also to deal with ethical matters and administration issues”* (Interv_SC).

A ‘kick-start’ meeting attended by the management steering group and the Leading Partners took place earlier on in the project to outline the content of each work packages and allocate roles and responsibilities. In addition, at the start of every work package, a meeting would be organised to bring together the different teams involved in that work package to define and plan the different experimental work arrangements to be undertaken in this specific building block. Examples of such distributed co-operative work arrangements were discussed with several participants. For instance, the **Biotechnology Researcher** operating **in Lund** and the **Rheumatologist Scientist** located **in Berlin** discussed distributed experimental setups and the concerns of bringing diverse efforts together in the following terms:

> *"At the start of the work package that involved the Geneva, the Lausanne, the Berlin and the Lund sites, we needed to think carefully about how we were going to design our experiments so that they would work together towards the deliverables of the work package"* (Interv_BR).

> *"In Lausanne, they develop the nanoparticles and in Geneva they use them for their in-vivo experiments on mice. In Berlin, we do the in-vitro tests to evaluate the toxicity of the particles on the immune cells but also the MRI scans on the patients and we take the serum. In Lund, they analyse the serum. We needed to think of ways to get all this working together"* (Interv_RS).

What came across from these early discussions was the need to find ways to co-ordinate different experimental activities at a very fine level of detail so that the respective activities could be aligned in a meaningful manner towards the completion of the deliverables of their common work package. If the meetings at the start of the project and each work package were essential to somehow instigate a space for co-operation (Lee, 2007), they were not sufficient on their own and the necessity to establish continuous and sustained communication to articulate the efforts of the different parties involved in a work package was highlighted on many occasions. An example of such an intervention by the **MRI physicist in Geneva** is given below:

> *"We use any opportunity we have to discuss the things we need to do in the work package and to share ideas about our experiments. We first met with the other guys at the first official meeting, one of those that take place twice a year. That is how we first we got to know them and to lay out the work we were going to have to do together. Then we met a couple more times after that, just us in the work package, to finalise things. After that we exchanged quite a few emails and had Skype talks as well, when we needed to"* (Interv_MRIP).

From this, it could be derived that the initial project meetings and work package meetings played a role in assisting with *articulation with regards to actors* and *articulation with regards to responsibilities* (Schmidt, 1991) as they helped allocate large units of experimental work to multi-sited and cross-disciplinary teams of individuals with the right skills and identify the various individuals who are accountable for these units of experimental work. To a certain extent, the meetings also supported *articulation with regards to activities* (ibid.) as the discussions at those early stages helped define the problem and outline the various activities to be undertaken to resolve it. On the other hand, the continuous interactions within each work package to define and organise the experimental work in detail between the various distributed groups of researchers played a role in supporting both *articulation with regards to activities* and *articulation with regards to tasks* (ibid.). Once the broad units of experimental activities had been defined, these were broken down into smaller activities that in turn were divided in detailed sequence of tasks (i.e. smaller experimental operations that had to be carried out at a site) during the regular exchanges of emails, conversations over the phone or Skype and face-to-face meetings if possible. This way activities were allocated to teams while sequences of more detailed tasks were assigned to specific individuals. In parallel, the roles and contribution of different information artefacts, material resources, and equipment and infrastructures were continuously discussed and defined during these exchanges thus helping support *articulation with regards to conceptual structures* and *articulation with regards to resources* (ibid.). The precise mechanisms of how these dimensions of articulation work are supported in the practice of the scientists involved in the distributed multi-sited enquiry work arrangements in the NanoArth project are explored in great depth in the following sections.

5.2.2 The experimental protocol information artefact

When probing the design of distributed scientific work in detail, it became rapidly apparent that the many discussions and exchanges established by co-operating parties to integrate their efforts when working in the same work package or experimental activities often focused on one artefact used by the scientists to define and set up their investigation work: the experimental protocol. This can be illustrated for instance by the following intervention by the **Bone Biologist in Geneva** who gave a revealing account of some of the early interactions which took place around experimental protocols:

> "*After the first couple of meetings we started to get a rough idea of how we were going to put together our [experimental] protocols at our end, for our bit of the work package. So, when we got back in the lab, we wrote the draft versions of the protocols and just had a go at experimenting with them. Then we emailed them to the other guys, either to check things with them or just because they wanted to have a look at them to see how we were doing things"* (Interv_BB).

This illustrates the wealth of interactions that appear to take place around the design, authoring and use of experimental protocols. This and other interventions of this type highlighted it as an artefact of great interest, as it appeared to play an essential role, not only to stipulate how the experimental work should be designed, but also as a key vehicle to co-ordinate the efforts of co-operating distributed investigators.

In essence, an experimental protocol is a written specification that stipulates a detailed sequence of tasks and operations that need to be undertaken to carry out an experiment. It usually features equipment, reagents, steps to be performed, as well as sometimes additional tips or troubleshooting techniques (Cooper et al., 2015; Giraldo et al., 2014). The experimental protocol came to the fore as a key information artefact in this setting as it carried huge significance for all the members involved in the multi-sited cross-disciplinary project at many different levels. Our empirical study of NanoArth clearly revealed that it goes beyond being just a procedural document and it takes different symbolic meanings for different people depending on their roles within the project.

For the scientist who conducts experiment at the bench, the experimental protocol is indeed the main tool that is relied upon to *do science*. It is a dynamic artefact that is carefully designed, tested on many instances and continuously refined until it reaches a stable content and can be finalised. This point is illustrated in this intervention by the **Nanoparticles Developer in Lausanne**, when queried about how she set up her own experimental work during the first participant observation:

> "*When I need to do an experiment, the first thing I think about is how I am going to write my protocol. Then I try to put one together and when I have a rough version I go and test it in the lab to see if it kind of works. Then I test it many more times until I get something I am really happy with. Sometimes, it can take a while and I carry on testing it and modifying it until I get there*" (PartObs_ND_1).

This exemplified how, for many experimenters in the NanoArth project, like this nanoparticles developer, the design of an experimental protocol was seen as the key starting point of the conduct of scientific enquiry. Also, the protocol did not take the shape of a fixed monolithic repository of procedural information, but it was seen rather as a constantly changing information artefact that was continuously developed and tinkered with, until it reached a somehow permanent state that could help capture the scientist most up-to-date understanding of the experimental work to be performed.

For the scientists who work in co-operation with others, the protocol was viewed as the artefact that managed to encapsulate their counterparts' experimental practices, and that could be used to shed light on their partners' work, the methods they used and the type of results they obtained. The **Biomechanics Engineer in Berlin** explained how accessing her co-operating partners' protocols helped her get an understanding of the enquiry work they were undertaking so that she could align her own investigation with her remote partners':

> "*I wanted to find out how they did the imaging with their mice [that had been injected with the SPIONs particles] in Geneva, like which sequence they used. So, I asked them to send me their protocols so that I could get a feel of how they were imaging with rodents. Even though it is very different, it helped me with developing my own MRI sequences for the scanning of patients' joints*" (Interv_BE).

This is one of the many instances in which the experimental protocol was used as a resource to get a snapshot of a partner's scientific enquiry practices and draw inspiration from it. Thus, referring to co-operators' protocols allowed scientists to develop an overall understanding of the various methods and techniques deployed in the co-design of experimental work and helped them to adjust their own investigation work accordingly. This can be viewed as an example of the use of the protocol to create a collective understanding of the experimental design, and thus to support *activity awareness* and *process awareness* (See section 3.4.2 and Kusunoki et al., 2014).

For the members of staff involved in the management of the project, as well as for the scientists who did the lab work, the protocol in its more finalised and stable form could be seen as a key research output in itself, as illustrated by the **NanoArth Project Manager**:

> "*At different points in the projects we ask the researchers to give us their periodic reports that explain what they have done and their experimental protocols too. The protocols are a big part of the deliverables of the project; they have a lot of value for the project*" (Interv_PM).

The protocol could have a significant commercial value if it is patentable and if there was an interest from an industrial partner to upscale it to a pre-clinical level or clinical-level with a view to then produce a marketable product in the health sector. Thus, the protocol also had an intrinsic value for those partners concerned with the industrial exploitation of the experimental activities conducted in the NanoArth project and their results.

The multiple meanings ascribed by the various scientists involved in the distributed multi-sited NanoArth project to the experimental protocol and the ways to which it appeared to be permeating a large number of interactions between the researchers to support the accomplishment of scientific enquiry work, made it naturally an information artefact worthy of investigation in our research. What our empirical study of NanoArth sought to probe is finding how precisely the protocol was co-designed by the co-operating actors in a distributed work arrangement, and the exact role the co-design and operational use of this artefact played in supporting the co-ordination of complex scientific enquiries activities.

The following sections explore how experimental protocols were developed iteratively to support the design and implementation of experimental activities individually and co-operatively in the NanoArth project, how they were evaluated and tested to ensure the validity of the experimental work, and how they were shaped by the issues of quality control and standardisation. Thereafter, how the experimental protocols were co-designed in multi-sited co-operative arrangements and how they helped articulate the distributed scientific enquiry activities is discussed.

5.3 Setting up experimental protocols for experimental design

When probing the co-design of experimental activities and the processes of authoring and developing experimental protocols as part of the study of NanoArth, different stages in the elaboration of a protocol were identified. The **Bone Biologist in Geneva** gave a detailed account of how she developed her experimental protocols and shed light on an incremental development process:

> *"You first start by writing your draft protocol; you put a few ideas down on how you are going to set up your experiment. Then you try things in the lab to see if it works, to see if your protocol is OK. And then you keep working on it and improving it, it is very much like a trial-and-error thing. Once you are reasonably happy with it, you have to test it properly to make sure it is valid. Later when you know it is stable and you validated it properly, you can finalise it, send it to the coordinator, archive it or whatever"* (Interv_BB).

This incremental protocol development process was also highlighted by the **NanoArth Project Manager**, who was reflecting on the ways protocols were created and handled:

> "*Whatever experimental work they do, [the scientists] will go through a similar step-by-step approach. They come up with a rough idea, they draft a protocol, they test it, they discuss it with others, they work on it to improve it, they test it again and then eventually they write it all up properly and pass it onto me for me to archive it*" (Interv_PM).

From discussions with a number of the participants in the empirical study of NanoArth who were actively engaged with experimental work at the bench and with members of the project management team, it was inferred that the protocol development process could be broken down into a number of phases. These can be described broadly as (1) initialising the protocol and drafting; (2) experimenting with the protocol and refining; (3) testing the protocol and validating; (4) collaboratively editing the protocol; and (5) finalising the protocol and archiving. The following sections explore these processes and several of these phases in greater detail.

5.3.1 The experimental protocol development process

It is essential to mention that the incremental process of the protocol design and development was in no way presented as a one-dimensional linear approach, by which the identified stages are performed in a strict sequential manner. Instead, the design of the experimental activities, and the development of the experimental protocol it entails, was often depicted as a somehow dynamic and messy process which involved numerous iterations and interchanges between the various protocol developmental stages identified above. An illustration was provided by the **Nanoparticles Developer in Lausanne** when discussing how she designs and conduct her experiments during the first participant observation:

> "*It is very much a trial-and-error process… you try things in the lab, you talk to people, you test the protocol, you try to experiment with that new [piece of] equipment the lab has just received, you change your protocol… you would think that science is very structured, very organised, but in fact the practice of it is very messy and quite creative*" (PartObs_ND_1).

The tinkering or bricolage nature of the design and performing of experimental activities she is referring to came to the fore very clearly during our study of NanoArth and many participants emphasised it. It has been contended in the STS literature that laboratory experimental work requires a substantial amount of *tinkering* (Knorr Cetina, 1981a) or *bricolage* (Lynch & Woolgar, 1988) to deal with situated nature of scientific work and continuously arising contingencies (see section 2.4.2). The prevalence of a bricolage culture specifically in the field of nanoscience has also been highlighted in other scholarly work (e.g. Jouvenet, 2007) and this was certainly an aspect that the participants in our empirical study underscored frequently.

In addition to the protocol development process being non-linear and convoluted, it was mentioned that its end goal could also move. Many instances were reported of changes in the focus of the experimental design, and thus in the designing of the protocol, as here by the **Biomechanics Engineer in Berlin**:

> *"The design of the protocol for the analysis of the serum [collected from patients] was affected by the changes of directions in the project. We had to rethink how we were going to do that work after they told us about the new direction"* (Interv_BE).

Translational projects in nanomedicine like NanoArth, NanoHPV, NanoInflam and NanoCancer were very much exploratory in nature, and hence subject to being modified regularly, which could influence the experimental design and thus how the protocols were being developed. This means that the experimental design, and thus the protocol stipulating this experimental work, could change frequently, depending on the local circumstances and contingencies.

The extent of the intricacy of the development of the protocol from an early draft form to a more crystallised version was highlighted as being dependent on the scientific field and the nature of the experimental work. The **MRI Physicist in Geneva** compares the stability of her protocols with the ones of co-operators in different disciplines:

> *"Because they are based on well-defined sequences of magnetic resonance imaging, our protocols became stable quite quickly. It is not quite the same with the biologists… particularly if they do their experiments in-vivo; you cannot never quite predict how things are going to go when you deal with animals"* (Interv_MRIP).

It transpired that certain experimental activities were subject to more variations than others and that this would impact on the protocol development process. For instance, the analysis in Berlin of a range of biomarkers in rodents after injection of the SPIONs required more testing and tinkering than the imaging, thereafter in Geneva, of the same rodents using MRI techniques, which followed a well-determined sequence. Thus, co-operating parties working in different *epistemic cultures* (Knorr Cetina, 1999; 2007) (see section 3.5.2) had to interrelate their activities with each other, and this influenced the way they designed their experimental protocols and made the articulation of their respective practices even more challenging.

The following subsections explore in more depth the different ways in which the various groups of scientists involved in the intensely distributed settings of the NanoArth project defined and configured their experimental protocols, and thus articulated the design and implementation of their experimental practices. This part of the analysis probes how the protocols were created, named, structured, fleshed out, and then developed further individually and collectively on an ad-hoc basis but also more systematically as part of the organisation of the distributed research design in the project.

5.3.2 Naming protocols

When exploring how experimental protocols get initiated, the empirical study unveiled that previous experience and ways of operating, which are somehow embedded within the existing scientific practice of an experimenter or a group of scientists, could influence things as simple as naming and versioning protocols. In this regard, the **Nanoparticles Developer in Lausanne** made a strong case for a meticulous approach for naming protocols:

> "*I have my own very specific way of naming my experimental protocols. I use one word that indicates in which category this protocol is, then the letters PR to indicate that it is a protocol, then the protocol number followed by the version number. Then I have a couple of words to indicate what the protocol is about. It is my own way to do it… not everyone does it like this… but I got it from when I was working in a pharma*" (Interv_ND_1).

She explained that having previously worked in a pharmaceutical company (pharma) in which the process of authoring and managing protocols was "*much stricter*", she had brought in with her a certain way of organising her experimental protocols which worked for her and helped her find her way through the large volumes of protocols she handled as part of her work.

Despite the naming of the experimental protocols being an individual choice for the researcher's own convenience, it was acknowledged that the selected naming system could not be totally opaque. Rather it needed to encapsulate in a few terms what the protocol consisted of so that both the experimenters themselves and others could rapidly understand what the experimental work that it referenced entailed. The **Biotechnology Researcher in Lund** explained how the name of a protocol can be referred to:

> *"When you work on an experiment, you write down the name of the protocol in your lab book... so it has to be kind of meaningful, so you know what experiment the protocol is referring to... because often you work on more than one experiment at the time... and then it can get really messy"* (Interv_BR).

Several instances were indeed reported when multiple experiments could be worked on quasi-simultaneously or in close succession between each other. This could be due to the simple fact that an experimenter was working on several projects at the same time, or on several work packages simultaneously within one single project. The importance of *"naming your protocol properly"* (Bone Biologist, Interv_BB) was underscored here as well as *"it really helps you keep a track of the different types of experiments that you are working on and not getting mixed up"* (Bone Biologist, Interv_BB). This appeared particularly significant when the scientists used a traditional paper-based lab book organised chronologically to log their activities (explored further in chapter 6), as illustrated in this intervention by the **Rheumatology Scientist in Berlin** who highlighted the difficulty of documenting the workings of several experiments taking place within a short time lapse:

> *"The lab book we use is very rigid... you have to date and time everything you do... so when I am working on more than one experiment or on a more complex block of experiments that rely on more than one protocol, I need to make sure I use the right protocol names and link up the entry in my lab book to the right protocols... otherwise it is a nightmare to find my way around"* (Interv_RS).

This highlighted an even greater necessity to use a very clear naming convention for experimental protocols so that specific experiments could be referred to when actually logging lab work operations, particularly in complex experimental arrangements.

Beyond concerns with naming protocols adequately, there are issues with maintaining a sound versioning system for protocols over time, people, and projects. These are considered in the following section.

5.3.3 Versioning protocols

Scientists involved in the design of experimental protocols as part of their experimental work were not only concerned with meticulously naming and managing their different protocols, but also with thinking of ways to maintain several versions of the same protocol. It was both observed and reported that, particularly at the early stage when a protocol was being trialled, frequent adjustments could be made to a protocol to reflect the various attempts to improve an experiment. The **Nanoparticles Developer in Lausanne** gave an account of how she creates various versions of a protocol:

> *"When I start experimenting with my very first draft protocol, I try things around, just to see if the protocol is sort of working… then I progressively refine it, like improve it… I tend to create a new version every time I make quite significant changes… I like to keep a track of the various things I have done… so that I can get back to previous versions if I need to… maybe try something else later"* (Interv_ND_1).

A number of scientists felt the need to track quite closely the early trial-and-error attempts of the authoring of protocols by relying on a fairly tight versioning system that helped them monitor the early design of their protocols, for their own benefits and the ones of others. The **Nanoparticles and Reactor Engineer in Lausanne** explained how he handled various versions of a protocol:

> *"I tend to create a new version of a protocol if I introduce something really new in my experiment… it helps me to keep a record of the various attempts I made… but also when [the Nanomaterial professor who runs the materials and power lab] comes in to*

> *see how I am getting on, it helps me to explain him what I have been up to and the various things I have tried…I can have a look at my notes and the various versions of the protocols I have written and it is all there”* (Interv_NRE_1).

This suggested that the necessity expressed by a number of experimenters to maintain some sort of a protocol versioning system was not only for their own personal progress monitoring, but it was also driven by the need to provide some sort of accountability to management staff or anyone else who may enquire about the progress made.

The importance of clearly organising and maintaining various protocols used as part of the experimental work was highlighted even more in the case where the experimental design was particularly complex and required several experiments to be run together or quasi-simultaneously. Indeed, sometimes when scientists needed to work on multiple experiments concurrently, as part of the same work package or unit of experimental work, as illustrated in this statement by the **Nanoparticles and Reactor Engineer** during the observation:

> *“Sometimes you have to do three or four different experiments within a short time… because for example you want the nanoparticles to be in the same or very similar state… and they [the experiments] are sort of connected… because taken together they might give you interesting results… so you deal with three or four protocols and you have to be really well organised”* (PartObs_NRE_1).

Such a research design did require the authoring and trialling of multiple research protocols practically at once and thus it highlighted the challenges of having to carefully manage and control all the various versions of these numerous protocols. This was even more problematic when experimental work was specifically designed to take place at different locations, and separate activities that generated different versions of protocols needed to be co-ordinated across multiple sites. In complex experimental setups of this type with a high level of interdependence, maintaining a sound versioning system that was meaningful for everyone involved was seen as even more crucial. The specific issues of the distributed co-design of experimental activities across sites are discussed in section 5.4.

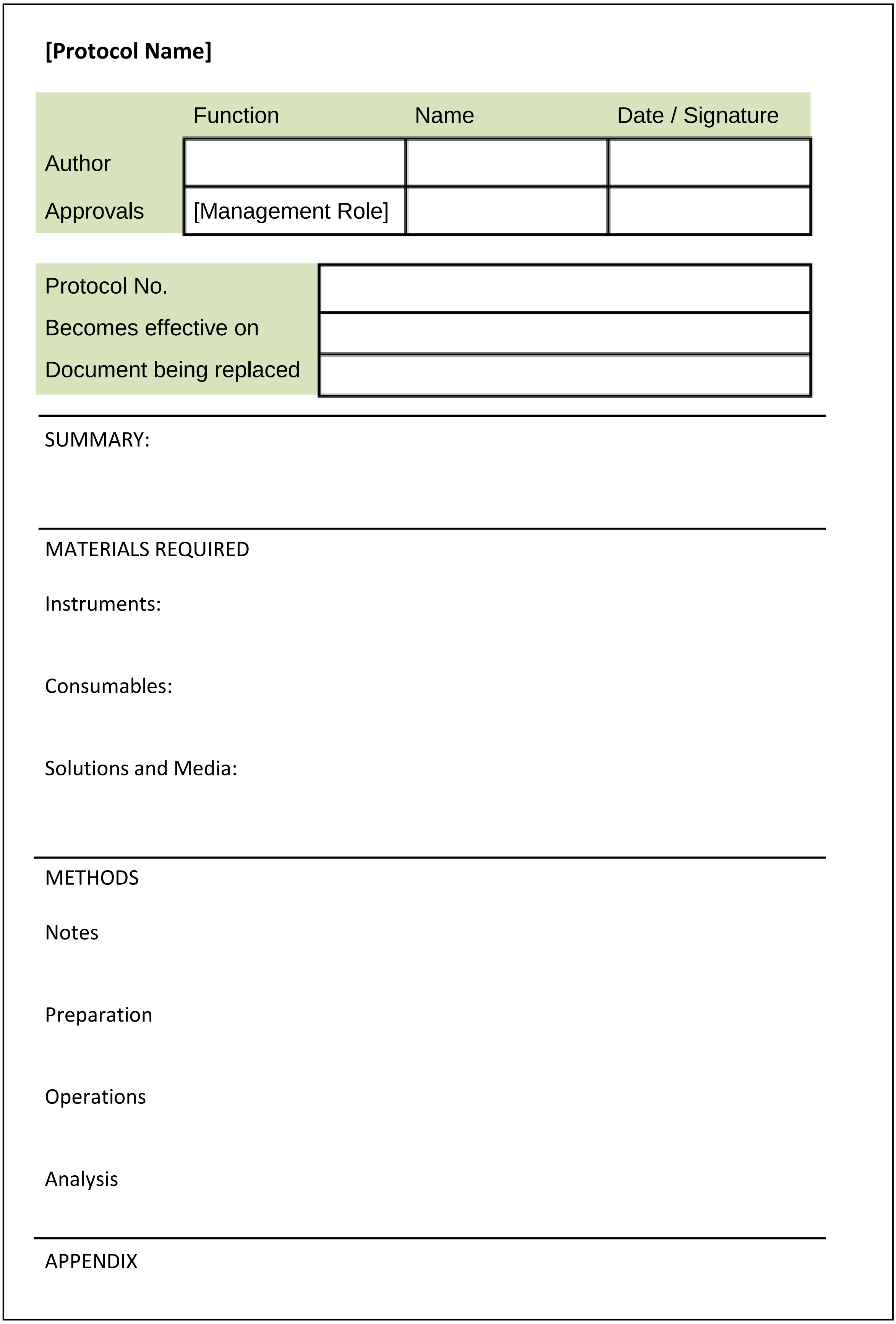
Before even examining the complex design of co-operative scientific activities at multiple locations, it is crucial to consider the practices used to define the structure of the protocols.

5.3.4 Structuring protocols

A prevailing issue, which emerged in relation to the creation and development of the protocol to drive the experimental work, was how to organise and structure the actual content of the protocol. The common understanding in science is that an experimental protocol should include items such as equipment and reagents used as part of the experiment, the steps to be performed and possibly additional tips and troubleshooting techniques (Cooper et al., 2015; Giraldo et al., 2014). However, the **NanoArth Project Manager** explained that a recommended structure for protocols specific to the NanoArth project was suggested to all members of the project consortium to ensure consistency across the various teams operating at different sites:

> *"In the early stages of the project, but maybe not sufficiently early, we introduced a protocol template for everyone to use. It would have all the essential sections that you want to have in a protocol… stuff like who is authoring the document, who is approving it, the starting date, a summary, a list of materials used and a description of the experimental methods… the idea was that everyone would use the same template so that it would be so much easier for us to find out what everyone is doing"* (Project Manager, PLE_1).

The recommended protocol template for the NanoArth project is reproduced in figure 5.1.



[Protocol Name]

	Function	Name	Date / Signature
Author			
Approvals	[Management Role]		

Protocol No.	
Becomes effective on	
Document being replaced	

SUMMARY:

MATERIALS REQUIRED

Instruments:

Consumables:

Solutions and Media:

METHODS

Notes

Preparation

Operations

Analysis

APPENDIX

Figure 5.1: Recommended template for protocols in NanoArth project

It was suggested by the NanoArth Project Manager and the Scientific Coordinator (PLE_1) that this structural format was selected for all protocols, as it offered the right balance between providing highly structured experimental specifications and offering the flexibility for the scientists to customise it to satisfy their own needs. This way the structural properties of the experimental protocol appeared to embrace the idea of *under-specification* (Schmidt & Simone, 1996) that allows for a range of potential co-operative utilisations: in this format, the protocol could cover a spectrum of utilisations ranging from playing the role of a very prescriptive script putting forward very rigid stipulations to being used as a map permitting the scientists to tailor it to their own needs and help decision-making. Also, the NanoArth Scientific Coordinator acknowledged that having all the protocols formatted in the exact same way, all with the same suggested components, made it easier for her to review them and to ensure the scientific coherence and consistency of the work produced, as this was her direct remit in the project.

The introduction of a common template was not always seen as helpful by the researchers on the project. A number of scientists thought it was not suitable for all the different types of experimental activities that take place at the various project locations. For example, the **Nanomaterial Scientist in Lausanne** whose experimental work consisted of the running of computer-based simulation tests on nanomaterials explained during her observation:

> *"In my protocols, I need to have the summary of the simulation input files, the actual input data, the computer code used for the simulation and the output files. The template they gave us doesn't really have any of that"* (PartObs_NS).

Other scientists also expressed their concerns with the inability of the template to accommodate disciplinary and localised ways of doing things. This point was made by the **MRI physicist in Geneva** when comparing her protocols with her co-operator's in Berlin:

> *"The protocols I wrote to describe the various sequences of magnetic resonance imaging we used with the mice are very different from the ones that [the Rheumatologist Scientist in Berlin] uses to do his in-vitro experiments to study the*

> *toxicity levels in the cells after they have been injected with the [nano]particles. If I am going to use the template, then I need to be able to make some changes to it so that it works for me*" (Interv_MRIP).

The latter two examples clearly illustrate the difficulties of introducing an identical structuring format for all procedural information artefacts that describe the experimental process: it was felt that the recommended format did not work for all experimental practices. The Nanomaterial Scientist performing computer-based simulations, the MRI Physicist developing imaging sequences of rodents and the Rheumatologist Scientists conducting in-vitro toxicity tests on cells did not organise their experimental work in the same way and did not have the same requirements for authoring their protocols. If the common template was convenient the management team, the scientists at the bench expressed the need for adjustments to be made to the structuring and formatting of the protocol to suit their own practices. Further issues of standardisation of protocols, in relation to experimental quality, are discussed specifically in section 5.6.3

5.3.5 Summary of findings

The findings in relation to defining and configuring experimental protocols for experimental design are summarised in table 5.1.

Section 5.3: Setting up Experimental protocols for experimental design		***Area: Experimental Design***
	Work practices and associated meanings	**Issues, difficulties and challenges**
Protocol development process	Generally, development of protocol had stages: (1) Initialising & drafting (2) Experimenting & refining (3) Testing & validating (4) Collaboratively editing (5) Finalising & archiving	• Protocol design often a non-linear and convoluted process that required high levels of tinkering.
Complexity of designing scientific enquiry work	• Inherent nature of scientific enquiry work as highly localised and contingent work that often requires tinkering. • Design of scientific enquiry work affected by exploratory character of the project and frequent changes in directions. • Complexity of scientific work design process influenced by diverging disciplinary modes of operating.	• Protocol design could be subject to frequent changes as experimental work is continuously re-defined. • Protocol design needed to be made adaptable to take into account frequent changes of directions.
Naming of protocols	• Strict naming system was perceived as essential to identify experimental work and distinguish between various protocols. • Name identified uniquely protocol and associated version. • Protocol name cross-referenced in lab book. • Protocol name referenced to by partners when working co-operatively.	• Difficulty in keeping a track of multiple iterations of multiple protocols. • Different naming conventions could lead to cross-referencing problems.
Versioning of protocols	• Strict versioning seen as essential to identify iterations of experimental work particularly in heavily distributed setups with high degree of interdependency. • Strict versioning provided accountability & traceability for management. • Strict versioning key when co-designing experiments with others.	• Use of different versioning systems by different scientists. • Difficulty in keeping track of multiple versions of protocols, particularly if experimental work highly distributed and interdependence between experimental activities was significant.
Structuring protocols	• Effort made to design and deploy structural format of protocol as a template that is both prescriptive and sufficiently underspecified. • Design of a template mainly driven by management's convenience.	• Use of template for protocols can be perceived as not always adapted to local scientific practice. • Structure of protocol can vary depending on type of activities undertaken by scientists locally.

Table 5.1: Summary of findings on setting up protocols for experimental design

The practices around the co-design of protocols in the intensely distributed settings of the NanoArth project are explored next.

5.4 Co-designing experimental protocols

In a cross-disciplinary and multi-sited project, like the NanoArth project under study in this PhD, which is driven by different specialisms and disciplinary knowledge, the experimental design is very much based on *interdependent work arrangements* that are both *situated* and *distributed* (Schmidt, 2011) (see section 2.2.1). As explored in section 5.2.1, these work arrangements are first defined at the start of the project, and at the start of each work package, when the experimental work is broken down into a number of planned units of experimental work and associated deliverables that are allocated to one or more teams involved in the project. This means that to complete these distributed experimental working units and achieve these deliverables, the laboratories or research centres working together needed to plan and design their experimental activities and smaller experimental tasks in co-operation, and thus co-design and co-develop their experimental protocols collaboratively. The following sections explore how the distributed co-design and co-development of protocols was carried out in practice to drive this process, the different approaches adopted, the issues that were encountered, and how the interactions between the different scientists around this protocol co-design influenced the design of experimental activities. Situations where the co-design occurred mainly locally are considered first, these are then extended to distributed cases where the design was flexibly co-ordinated, and finally instances which required tightly co-ordinated collective design across sites are explored.

5.4.1 Local co-design of protocols

Several instances were reported in which experimental protocols were developed mainly at one site within a co-located team but using a range of external inputs. For example, the **MRI Physicist** and the **Bone Biologist** who work as part of the same team in the Imaging Unit **in Geneva** described in great detail how a number of protocols were produced co-operatively by the team to use imaging techniques on rodent to create models of arthritis to determine the levels of inflammation and joint damage, and how this co-operative process gained from various internal and external contributions:

> *"The protocols were mainly designed internally with a small team made of a radiologist who had knowledge of the clinical techniques, a PhD student in medical studies who had started developing biological models and a biologist who helped develop the biological models at cellular level"* (Interv_MRIP).

> *"We got the initial idea for the protocols from the guys in Berlin… but we also used our previous experience with using nanoparticles for different diseases and our experience of MRI imaging to make it work for us… also looking at similar work published in journals was useful"* (Interv_BB).

These statements illustrate that, if the initial design of the protocol benefited from the contribution of a partner at one of the other project sites, it needed to be adapted to the local settings and *"made to work"* using the team member's prior experiences and previous understandings of similar work put together, and the adoption of an explorative tinkering approach. This point was further illustrated by the same **MRI Physicist in Geneva**:

> *"The aim was to set up a set of protocols that would result in a working and predictable model... but there was a level of randomness because we did not know whether the imaging sequences were going to work with the mice injected with the nanoparticles. So, we initially tested the animal models without the added complexities of the nanoparticles and then we refined the protocols to make it work with the nanoparticles"* (Interv_MRIP).

This co-operative protocol development and refining process was achieved through a number of meetings in which the various members of the team contributed using their previous experience and practical understanding of the field. This *cross-fertilisation* of ideas was key to the design of robust workable protocols, as noted by the **Bone Biologist in Geneva**:

> *"We needed to discuss with the team all the various elements of the experimental setup to get the protocols right… the concern was that some things that work with the animal model may not necessarily translate on the images… but everyone came up with some pretty good ideas on how to resolve the various issues"* (Interv_BB).

Not only were these interactions crucial for all the scientists to help design and improved the experimental protocols, but also to help articulate finer components of the experimental setup, as emphasised by the same **Bone Biologist**:

> *"We spent a lot of time discussing how we could align all the timings of the various experiments… and that was the really tricky bit… because we use rodents there is an issue of expiry date for the experiment… so we needed to get our timings right"* (Interv_BB).

Hence, it was essential for the co-design of the protocol to carefully consider the local circumstances and the constraints attached to the particular experimental work under enquiry to allow for the experimental activities to be articulated at a fine level of details.

This example of the imaging protocol development illustrates a typical case where the protocol co-design and development process took place among a team of co-located scientists but used a range of external sources as inspiration. The actual protocol co-design and development process consisted here of the adaptation of these external ideas to the conditions and constraints defined by the local settings, and by the nature of the actual experimental work under consideration. This tailoring process appeared to take the form of negotiations between the different experimenters involved in this scientific enquiry work. Ultimately, these negotiations resulted in the production of a protocol that provided sufficiently detailed stipulations to allow the various members of the team to align and interconnect their various experimental work practices to work collectively in the local settings. At the same time, it led to the development of a protocol that also gave the co-operators sufficient flexibility to modify their practices if the local conditions were to vary. Indeed, in Simone and Schmidt's view (1994), for the protocol to play the role of a *coordination mechanism* (see section 2.3.2) that can enable the meticulous articulation of distributed activities, it should be specified explicitly only to the extent that it is directly relevant to the purpose for which it has been designed. It is only when it is well adapted to the local conditions in which it is used and can handle the local contingencies that it can become a vehicle of social interaction and take a role in mediating the articulation of distributed activities. The following sections explore this mediation role in situations that require the co-design of distributed activities within and across multiple sites.

5.4.2 Flexibly co-ordinated co-design of protocols across sites

The other ways in which experimental protocols were co-operatively designed and developed to define experimental enquiry work involved multiple partners from different sites in a more direct manner. A few examples of these highly interdependent multi-sited experimental work arrangements were investigated in great detail in this study of NanoArth to probe the ways in which the scientists working together as part of these arrangements articulated their efforts to fulfil their objectives and produce the required deliverables. The development of scientific operations, and thus the design of experimental protocols in these co-operative work arrangements, naturally required the establishing of cross-site formal and informal interactions to align the respective practices, and these were the subject of this part of the investigation in order to get a clear understanding of the collective protocol development process.

A number of these instances of collective design of experimental work appeared to require what can be qualified as *flexible co-ordination* between the various parties involved, in the sense that the circumstances of these co-operative endeavours did not apply excessive time-related constraints on the completion of the activities by the respective sides and on their interdependence and need for articulation. If the experimental operations conducted by the various members involved in this type of co-operative work ensemble were clearly interconnected and interdependent, the need for timely alignment of the various respective tasks to be completed was not overly constraining. This type of co-operative work arrangement would come under the category “loose coupling” conceptualised by Perrow (1984, p. 96) to describe work setups in which the sequence of tasks can be changed, a range of alternative methods are available, and delays in processing are possible.

A revealing instantiation of such flexibly co-ordinated multi-sited co-design of experimental activities in the NanoArth project involved *in-vitro* experimentation work in the rheumatology department **in Berlin,** under the direction of the **Rheumatology Scientist** who leads that department and who is a Leading Partner for the NanoArth project. He explained that this enquiry work consisted of *"conducting in-vitro toxicity tests to assess the impact of the nanoparticles on immune cells. We were particularly interested in finding out about their impact on the immune cell survival functions and on cell differentiation"* (Interv_RS). This experimental work, therefore, mainly took place in a laboratory at one site but required materials from other sites and an experimental design that brought together the knowledge and inputs from scientists located on different sites and with different specialisms. As the nanoparticles needed for this particular work made use were engineered on site in Lausanne, it was made clear, right at the start, that the design of the experimental activities for this particular toxicity enquiry work needed to be done in close partnership with the scientists producing the particles there. This was corroborated by the **Nanoparticles and Reactor Engineer in Lausanne** who was charge of the synthesis of these nanoparticles:

> *"We knew right from the start that in this work package the guys in Berlin were going to need these particles with a specific coating to do their in-vitro tox[icity] tests on immune cells and that therefore we were going to have to work closely with them"* (Interv_NRE_2).

The design of this experimental work called for regular communication to be established between the experimenting site in Germany and the site producing the nanoparticles in Switzerland. These exchanges were crucial to align the expectations of the scientists who were going to perform the actual toxicity tests in Berlin with what was actually technically feasible by the particle developers in Lausanne, in regard to the production and coating of the requested particles. The protocols on both sites (i.e. the protocol to synthesise the nanoparticles in Lausanne and the protocol designed for the toxicity tests in Berlin) played a key role, as highlighted by these 2 statements, respectively from the **Rheumatology Scientist in Berlin** and from **the Nanoparticles Developer in Lausanne**:

> *"We had many exchanges with the [nanoparticles and reactor engineer] and [nanoparticles developer] in Lausanne right at the start of the work package to discuss the particles we needed for our toxicity tests on the immune cells. We put together some very early protocols and from these we could define our requirements for a particular type of particles, with a particular characterisation, that we were going to use in our toxicity tests"* (Interv_RS).

> *"Once we had a good idea of the specific tox[icity] tests they wanted to do [in Berlin] and how they wanted their particles to do their tests, we wrote our initial production protocols and sent it to them [in Berlin] so that they could see how we were going to synthesise the particles to fit in with their work"* (Interv_ND_2).

This does show again that the experimental protocol was used as the primary information artefact used to drive the experimental co-design. Not only was it used as an essential resource to stipulate what was required by the experimental work, but it also helped mediate the negotiations between the scientists in order to define the common ground between what could be expected by the leading experimenters in this enquiry work and what could be provided by those synthesising the particles. In this sense, a parallel can be drawn with the role of a *boundary object* (see section 2.5.1) as sharing the protocol helped reach out across sites and *epistemic cultures* (see section 3.5.2) to define that common ground. This was described in detail by the **Nanoparticles Developer in Lausanne** during the participant observation:

> "*I asked [the rheumatology scientist] to send me his early protocols, even if they were just drafts, so that I could get a feel of how he was going to do his tox tests and how he wanted his particles. I have a background in biology so I could make sense of their work but it was not so easy for [nanoparticles and reactor engineer] as he is a physicist. I find that understanding their work in depth really helps me with mine. It helps me think how I can develop exactly the particles they want, characterised as they want it… but it was not always possible to do exactly what they wanted, and we needed to discuss more how we could develop the particles in a way that we could both be happy with*" (PartObs_ND_2).

This provided a revealing illustration of the manner with which the experimental protocol was used in practice by a scientist whose activities were interdependent with those of her counterpart at another site. Accessing the protocols authored by the rheumatologist in Berlin (and his team) to conduct the toxicity tests, helped the Nanoparticles Developer and the Nanoparticles and Reactor Engineer in Lausanne construct a detailed understanding of the methods and techniques designed in Berlin so that they could align their experimental design with the one of their ‘Berlin partner’. Thus, the protocol acted as the information artefact relied upon to convey all the information needed for this alignment to occur, i.e. the material to be used including the nanoparticles, the equipment involved, and the actual descriptions of the procedures to be performed. Subsequently, the protocol was used as the basis for all ensuing interactions. A number of verbal and written exchanges regarding the properties of the required nanomaterials would be held so that to negotiate a precise understanding of the materials to be synthesized at one hand and utilised in experimental work at the other. The protocol would assist with this negotiation process and would also be continuously modified to accommodate the changes required by both parties as confirmed by the same **Nanoparticles Developer in Lausanne**:

> *“From the moment we sort of knew how they were going to use our particles in their toxicity tests [in Berlin], we had lots of conversations to make adjustments and to make sure we delivered particles that they could work with. They were some limitations, mainly because of the polymers we used for the particles, so we had to agree on what could work for both sides and change our protocols to reflect that.”* (Interv_ND_2).

The entire negotiation process around this interdependent experimental design thus appeared to both shape and to be shaped by the continuous co-development of protocols. The protocols provided each site with useful information on the partner’s experimental design so that to allow each party to understand the expectations of their counterparts and adjust their experimental activities to align them properly with those on the other side.

In brief, both teams of experimenters in Lausanne and Berlin first designed and sent early versions of protocols to their partners across the other site to provide them with a point of reference that could help them get a sense of each other’s experimental work. Having an initial understanding of the experimental activities designed by their co-operators at the other site, each site further refined their experimental procedures to both take into account their partners' visions and their own specific circumstances. This improvement process was assisted by numerous discussions based on both sets of protocols so as to allow for a common ground to be established and for both parties to agree on how the respective experimental designs could be further aligned, despite the local constraints (e.g. the type of polymer supplied to the Nanoparticles Developer in Lausanne, as mentioned in her previous quote). The protocols at each site were modified on many instances to reflect the changes made to the experimental procedures to fit in with each other's experimental work. These negotiations and protocol co-design continued until both parties agreed on the outcome of the experimental work, i.e. on the specific properties of the nanomaterials to be synthesised in Lausanne so that they could be used in the toxicity tests in Berlin.

A parallel can be drawn with the concept of *coordination mechanism* (see section 2.3.2) to better unpack the use of the experimental protocol in this instance of flexibly co-ordinated distributed experimental design. The experimental protocol consists of a set of rules (in this case an operating procedure which helps temporally organise experimental activities and a range of guiding principles on how these activities should be conducted) and it is instantiated by a tangible representational artefact (in this case an experimental protocol document). This pair protocol / artefact can be thought of as a *coordination mechanism,* i.e. a dyad *coordinative protocol / coordinative artefact*, insofar as it helps propagates the state of completion of the experimental activity being undertaken and reduce the space of possibilities to enable co-operators to interconnect their own activities with the one under consideration.

When closely examining the interplays between the use of protocols across teams of scientists involved in the co-design of experimental work between the sites in Lausanne and Berlin, another parallel can be drawn, with *boundary negotiating objects* and *boundary specifying objects* (see section 2.5.3). In its early versions, the protocol was at the centre of the negotiations between the various members of the distributed work arrangement, and it helped define the space for co-operation and alignment of the experimental activities between teams that are not necessarily familiar with each other's work. Thus, this kind of utilisation can be linked to the use of a *boundary negotiating object*. As the protocol got refined and became more stable, it could be likened to a *boundary specifying object* inasmuch as it provided a way for the partners to work in synergy, yet independently, with their counterparts (Pennington, 2010). This double role of the experimental protocol (*boundary negotiating* and *boundary specifying*) is illustrated further by the **Rheumatology Scientist in Berlin**:

> *"We needed to make our toxicity test protocols work with the particles we received from Lausanne and that was tricky, at least at first, when we were not familiar with the properties of the nanomaterials. Their synthesis protocols really helped. Little by little, we got to understand the properties of the particles better, and we kept on improving our own protocols until they got much better, much more stable, and we could really get going with our toxicity tests and get stuff done"* (Interv_RS).

What also came through is that, as both parties became more familiar with each other and worked closer together, the roles of the protocol as a coordination mechanism on the one hand, and as boundary specifying/negotiating object on the other, became even more prominent. As the co-operation became stronger, the particle developers and engineers in Lausanne sent their production protocols with increasing frequency to provide their partners in Berlin with a continuously up-to-date view of the latest development process. This was explained by the **Nanoparticles Coating Engineer in Lausanne** during the participant observation:

> *"Once we got to know them better [in Berlin] and after we talked about it, we started sending them the updated protocols all the time, on top of the particles characterisation documents. We kind of figured out together that it helps them always knowing everything about how we synthetise and coat the SPIONs, and anything we change along the way, so that they know immediately what they are dealing with"* (PartObs_NCE_2).

In this sense, the protocol for the development of the particles took the meaning of a *technical diary*, which not only informed the experimenters of the properties of the materials to be used, but also of the steps that were taken to create them. The scientists in Berlin receiving the materials had thus access to a detailed account of increasingly stable methods used to produce materials with specific properties they required. This helped them develop a continuously improving understanding of the materials they manipulated as part of their own experimental work to optimise their utilisation in their own experimental work.

The analysis of the interactions and negotiations that took place as part of the design of distributed enquiry work in the context of loosely couple experimental activities have shed light on the key role that the experimental play as part of these interactions. It has shown that the protocol acts both a point of reference, as well as a point of alignment in the distributed experimental design. The next section provides an analytical account of the ways with which the experimental protocol was used as part of *tightly co-ordinated* scientific enquiry work arrangements.

5.4.3 Tightly co-ordinated co-design of protocols across sites

Other instances were reported of cross-sited experimental work arrangements that required a much tighter coordination. In these arrangements, the interdependence of the experimental activities strongly hinged on the timely alignment of the various efforts by the different parties involved. This type of arrangements can be qualified as requiring "tight coupling", according to Perrow's characterisations of co-operative work ensembles (1984, p.96), as the sequence of activities tended to be well determined and delay in the processing of these activities could be seriously problematic.

An enlightening case of this type of *tight coupling* co-operative experimental design was discussed in depth with the **Biomechanics Engineer**, who worked in the Musculoskeletal Centre **in Berlin**, and with the Biotechnology Researcher operating at the Rheumatology and Skeletal Biology Lab in Lund, Sweden.

> *"This work involves the measurement of cartilage degradation among two cohorts of volleyball athletes, a younger cohort and an older cohort. These are people who train intensively, very frequently and who are therefore at higher risk of experiencing cartilage ruptures or to have arthritis. It is a longitudinal work which takes place over a period of two years and which involves a direct co-operation between [the sites in] Berlin, Salzburg and Lund"* (Interv_BE).

The purpose of this experimental work was to develop a new way to evaluate the level of degradation of cartilage by making three different types of measurements and correlating them *"in order to get an overview of the clinical processes related to cartilage degradation"* (Interv_BR). The first set (function measurements) consisted of the measurement of the functions within the knee using magnetic resonance imaging techniques in Berlin. The second set also relied on MRI, and it sought to analyse the development of the cartilage volume in the knees of the patients over time, and was led by the radiology and imaging experts in Salzburg, Austria. The third set consisted of the measurement, in Lund, of the development of biomarkers over time in blood, serum and urine samples to establish whether there was a correlation with the degradation of the cartilage. *"Our hypothesis is that there are higher levels of biomarkers in these fluids when the cartilage is damaged"* (Interv_BR). The ultimate goal of this study was to evaluate whether a correlation could be established between these three types of measurements so that to develop an advanced model of the degradation of knee cartilage.

To organise the details of the distributed experimental work arrangement across the three sites (Berlin, Salzburg and Lund), a number of discussions took place at an early stage of the experimental co-design between a number of researchers from the different sites as recorded by **Biomechanics Engineer in Berlin:**

> *"Right at the start, during the kick-start meeting, we had lots of discussions to decide how we were going to proceed. They involved a radiologist, two biomechanics engineers, including myself, a physicist and a clinical doctor, if I recall. I felt that they were quite open and very useful to set out the different steps of what we were going to do together"* (Interv_BE).

These initial exchanges were essential to define the interdependences between the activities taking place at each respective team, i.e. to define an overall sequence of procedural operations to be put in place to conduct the distributed scientific enquiry work with a view to develop the cartilage degradation model, as explained by the biotech researcher in Lund:

> *"The patients would be recruited in Berlin as we have access to athletes there. We would first test our initial protocols of MRI sequences on a sample of subjects, we would then improve them and deploy them to the rest of the patients. At the same time, we would take the samples of urine, serum and bloods from the patients. The analysis of the imaging would be done in Berlin and Salzburg while the analysis of the biomarkers would be taking place in Lund where we have the right expertise"* (Interv_BR).

Furthermore, it transpired that beyond the overall sequential operations that defined this cross-sited experimental work unit, researchers at the Musculoskeletal Centre in Berlin had to work very closely with their partners at the Musculoskeletal Institute in Salzburg as their respective work both involved MRI techniques to make measurements on the knee and their expertise was complementary. Hence, several visits of the Salzburg team were organised to take place in the German capital so that initial measurements could be discussed and protocols of MRI sequences could be initiated, respectively for the knee function measurements in Berlin and for the cartilage volume measurements in Salzburg. These face-to-face encounters were essential as they brought various specialisms together, and they enabled the fruitful exchange of ideas to make key practical decisions on experimental details and come up with implementable solutions. Thereafter, multiple exchanges between the two groups of scientists took place to align their respective visions and improve both sets of protocols. These discussions generally took place remotely via emails or using voice over IP (VoIP) applications, while others were face-to-face during the global project meetings, additional intra-consortium seminars, or other summer schools. The **Biomechanics Engineer in Berlin** emphasised the benefits of these multiple interactions.

> "*The input from the clinical partners in Salzburg was decisive because they had already conducted similar research work with patients and that really helped us with our protocols. We on our side had a few ideas based on what we read and stuff we tried before"* (Interv_BE).

Previous research was relied upon, as well as knowledge inspired from their understanding of the field to set out initial protocols separately, which were subsequently discussed collectively. These discussions generally took place remotely via emails or using voice over

IP (VoIP) applications while others were face-to-face during the global project meetings or additional intra-consortium seminars and other summer schools.

Further negotiations were needed to evaluate and further improve the experimental procedures with the experimental protocol being used as a mediator in these negotiations as well as being a deliverable in its own right. The first stable drafts of the experimental protocols describing the sequences of images to be taken, to both represent the functions of the knee and to measure the volume of cartilage, were subsequently trialled with a sample of subjects to evaluate their validity:

> "*We needed to make sure that the sequence of [MRI] scans we came up with really worked live with patients. So, we got to test them with a small group of patients both for the knee function and the cartilage volume. We then did some basic analysis. That really helped us to find out whether we were on the right track. We then went back to the drawing board, had more discussions and improved our protocols"* (Interv_BE).

This testing of the protocol in a real-life situation allowed the experts to learn a great deal from initial measurements and thus fed into the re-design of the protocol and, following a number of interactions, the protocol was *"stabilised"* and made operational for the actual experimental measurements to be made. This provided another illustration, that for these experts, this process of defining, shaping, refining and improving the experimental protocol was at the heart of what it means to *do science,* and that in this scientific practice the protocol could be seen as playing the role of a key *coordination mechanisms,* as it was both used as a point of reference to *stipulate* the activities to be undertaken, and as a point of alignment to *mediate* the articulation of these activities.

In parallel to the first two sets of measurements using MRI techniques, the team in Lund was seeking to analyse biomarkers from the fluids taken from patients to develop a third way to assess cartilage degradation, which they hoped to correlate to the first two techniques. The initial protocols for these biological measurements were produced by the researchers based at the Lund site separately, as they had the expertise in-house. At first then, few interactions occurred with the teams at the other two sites to develop the draft protocols to analyse the biomarkers in the blood, urine and serum. However, a number of discussions took place subsequently, both synchronously and asynchronously, to agree and finalise the practicalities of the experimental setup, as relayed by the **Biomechanics Engineer in Berlin**:

> *"Once they shared their initial ideas with us and let us have their draft protocols there were quite a lot of emails sent back and forth to discuss practical stuff, like basically how we were going to do this together. We also had a few Skype calls as talking directly tend to help for these practical things. For example, we decided that we were going to take the samples from the patients on the days when they were going to be in for their MRI scans. So, we had to work out some specific timelines and properly divide the work between us"* (Interv_BE).

The initial protocols, which were rather imprecise in the way that they only gave an overview of the experimental process were expanded, so that to introduce technical and practical stipulations and some were broken down into "*smaller technical protocols*" (Interv_BR). Separate protocols were designed to deal with particular technical aspects, when deemed necessary, so that specific techniques could be explored independently without interfering with the main experimental work. The authoring of separate supporting "*technical protocols"* was also reported in other instances, like by the **Nanoparticles and Reactor Engineer in Lausanne**, to carry out specific activities:

> *"We tend to have a protocol for pretty much everything... for using a particular piece of equipment, for calibrating a specific machine, for storing a batch of particles, for sending tissues or organs to a partner… anything that is kind of tricky and a bit technical… we write a protocol"* (PartObs_NRE_1).

The **Nanoparticles Developer**, also in the Material and Powder Lab **in Lausanne**, also commented on the development of cluster of interrelated protocols to assist with numerous activities:

> *"There are a whole series of protocols about how to synthesise nanoparticles, how to store them, how to send them to another site, how to test them after you have received*

> *them to make sure they are OK, how to manipulate them… the whole cycle of manufacturing, storing, shipping and experimenting with nanoparticles is there"* (PartObs_ND_1).

However, for other partners in the project, the excessive proliferation of protocols was not seen as particularly helpful. In their view, it led to difficulties in locating protocols, finding the correct ones associated to a specific activity and ultimately using them to set up experimental work or carry out supporting activities. This was reported by the **Bone Biologist in Geneva**.

> "*I feel it is a bit too much, like you have a protocol for everything… one for using this machine, one for handling this material, one for sending the material… even one for writing your monthly report… it kind of defies the point in the end…it sort of feels like it is a thing management wants to push through so that everything is written down properly… but you end up not being able to find anything or taking ages to find stuff that you really need*" (Interv_BB).

What emerged in this analysis of the co-design of complex distributed experimental work was a strong reliance on the use of the protocol, not only to *stipulate* and *articulate* activities, but also to *off-load* certain *technical* aspects of scientific work, in the sense referred to by Salomon (1993). This off-loading could be directed towards the scientists that author the protocol themselves and their co-located, for further reference, or could be aimed at partners across other sites to assist them with tasks they may not be familiar with. At the same time, it appears that there needs to be an agreement on the appropriateness of these protocols as their proliferation appeared to cause friction in relation to the co-ordination of experimental activities.

5.4.4 Summary of findings

The findings in relation to the co-design of experimental protocols are summarised in table 5.2.

Section 5.4: Co-designing experimental protocols		***Area: Experimental Design***
	Work practices and associated meanings	**Issues, difficulties and challenges**
Co-located co-design of protocols	• Use of in-house knowledge to set up experimental work and protocols. • Use of external sources of inspirations. • Engaging in co-located interactions to assist co-operative protocol design. • Adapting ideas to local settings to take into account constraints. • Handling local contingencies to *make protocol work* in local conditions.	• Challenge of designing a protocol that provides appropriate stipulations to take into account local situations and help resolve situated contingencies.
Flexibly co-ordinated co-design	• Exchange of protocols to develop overall understanding of partners' experimental work. • Engaging in continuous synchronous and asynchronous interactions. • Spontaneous sending of protocols to inform partners of technical details. • Protocol used to facilitate negotiations and define common ground and continuously modified as a result. • Protocol used as a *coordination mechanism* to *stipulate* the activities to be undertaken and as a point of alignment to *mediate* the articulation of these activities. • Protocol used as *boundary negotiating artefact* during negotiation process and as it gets more stable as *boundary specifying object*.	• Difficulty in understanding partners' experimental work because of scientific disciplinary differences. • Familiarisation with partners' ways of operating can take time. • Challenge of interconnecting with partners' experimental design to align it to one's own experimental work. • Challenge of having to continuously modify one's experimental design so that it is align with partner's.
Tightly co-ordinated co-design	• Setting up of early discussions to work out sequence of operations and alignment. • Engaging in continuous synchronous and asynchronous interactions. • Holding inter-site discussions and negotiations to improve and stabilise protocol. • Parallel development of protocols for co-design of experimental activities. • Use of protocol as a *coordination mechanism* to *stipulate* the activities to be undertaken and as a point of alignment to *mediate* the articulation of these activities. • Breaking down of main protocols into smaller technical protocols to off-load aspects of enquiry work. • Developing a network of interconnected protocols.	• Challenge of having to continuously modify experimental designs to fit within complex networks of experimental practices stipulated by set of inter-related and continuously evolving protocols. • Issue of excessive proliferation of protocols and versions of protocols. • Difficulty in locating and using the required versions of protocols.

Table 5.2: Summary of findings on the co-designing experimental protocols

The next section examines the practices involved in the validation of distributed experimental work, and thus of the experimental protocols in the NanoArth project.

5.5 Validating experimental protocols

What transpired when investigating the distributed scientific work arrangements as part of the empirical study of NanoArth is that *Experimental Validation* played an essential role in experimental design and, thus, in the development of the supporting protocols. It was completely embedded within the protocol design and appeared at various stages of the collective experimental design. We established that the testing for experimental validity was performed and organized around two well recognised concepts in the empirical sciences – *repeatability* and *reproducibility*. As a starting point, the research methods literature in the medical and biological sciences indicates that repeatability is the extent to which the same results are obtained when repeating a given experiment under identical experimental conditions while reproducibility is the degree to which the same results are seen when the study conditions change (Benestad & Laake, 2007). In practice, for the scientists who participated in our study of NanoArth, repeatability meant the ability for an individual to conduct a specific experiment on several occasions in their lab conditions and to obtain similar results every time it would be run. Reproducibility pushed this further and, for the NanoArth participants, denoted the capacity for experiments to still achieve analogous results when conducted at a different location and thus under different lab conditions. When further probing the ways in which the scientists worked towards achieving a reasonable level of experimental validity, it was identified that a differentiation was sometimes operated (more or less explicitly) between four levels of repeatability/reproducibility. The four levels of experimental validity unearthed in our empirical study that apply to distributed experimental work (*local repeatability*, *local reproducibility*, *distributed repeatability* and *distributed reproducibility*) are presented in table 5.3, along with a brief description of the work arrangements that were typically identified in our study for them to be ensured. These four levels are discussed in greater depth in the following sections.

Level of experimental validation	**Typical work arrangement**
LOCAL REPEATABILITY	• Same lab & same scientist • Same material & same apparatus
LOCAL REPRODUCIBILITY	• Same lab & different scientist • Same material & same apparatus
DISTRIBUTED REPEATABILITY	• Different lab & same scientist • Same material & different apparatus
DISTRIBUTED REPRODUCIBILITY	• Different lab & different scientist • Same material & different apparatus

Table 5.3: Four levels of validation of distributed experimental work

5.5.1 Local repeatability and reproducibility

It was commonly observed that once an initial protocol had been established at one site, the scientist leading the experimental work locally usually repeated the experiment several times, in the same lab conditions, to evaluate whether the results could be replicated and improved, as reported by the **Nanoparticles and Reactor Engineer in Lausanne**:

> *"Once you have your initial protocol, you tend to do the experiment again and again to see if you can get the same results and to see what adjustments you need to make to get better results"* (PartObs_NRE_1).

Thus, the scientist typically engaged in a typical experimental cycle based on trial and error to evaluate and improve the quality of the defined procedure, which was widely seen as an inherent part of the experimental process. This was corroborated by the **Nanoparticles Developer in Lausanne** during her participant observation:

> *"The first thing you want to do when you have a rough protocol is to do the experiment again just to see if it is repeatable in the same lab conditions. That is just part of scientific experimenting, you do it several times yourself in the lab just to see if your results are OK and if your protocol is reasonable"* (PartObs_ND_1).

This first level is labelled *local repeatability* in our study, as it involved the same experimenter iterating through the same experiment in identical lab conditions, i.e. using the same material and apparatus.

The protocol validation process often did not stop at this stage. It was reported that it was common for scientists to consult their colleagues and ask them, more or less spontaneously, if they could follow the protocol and undertake the experimental operations themselves in the same lab conditions and using the same equipment to see if they could obtain similar results. In this case, the aim was to ensure the reproducibility of the experiment, and thus verify the quality of the written protocol, based on an identical experimental setup but undertaken by a different individual. This is illustrated in this intervention by the same **Nanoparticles Developer in Lausanne**:

> *"Once you have an experiment that you are pretty confident with and that seems to produce similar results every time you do it yourself, you ask someone else, like one of your colleagues or something, if they can have a go and follow the protocol. It is so that you sort of remove the personal element from it, like to make sure that everyone can do it and not just you. It helps you make sure that your experiment is on the right track"* (Interv_ND_1).

This validation step, which expanded on the repeatability validation, thus sought to ensure that the experimental procedure was not dependent on the actual experimenter conducting it but could be undertaken by anyone else (and this was checked locally by asking a co-located partner). This was highlighted by several participants in our study of NanoArth as an important step in the scientific methods towards the production of more robust experimental work and was referred to simply as *reproducibility.* It is labelled as *local reproducibility* in this thesis as it denotes that this validation step takes place locally, at the same site, generally in the same lab, although performed by another person. It was underscored that, despite this validation being seen as a key step of the experimental design process by most scientists in NanoArth, the arrangements to ensure it often seemed to be made on an-hoc basis, depending on the expertise and willingness of co-located colleagues. This was illustrated by the **Nanoparticles Developer in Lausanne**:

> *"It depends who you work with, your working relationship with them and if they do similar work to yours. I started giving my protocols to [Nanoparticles and Engineer Reactor], more and more as we got closer, so that he could have a go and check them out after me, just to see if he could get similar results, to see if they were reproducible"* (Interv_ND_1).

Interestingly, it was also pointed out that reproducibility was not a validation step that was always sought after, depending on the discipline or the specific experimental work that was being undertaken. The **MRI Scientist in Geneva** made this point:

> *"In biology, you test your own experimental work continuously, but it tends to be the same person testing their own protocols for consistency… because different people would manipulate things differently… for example the way you inject nanoparticles in a mouse may have a certain influence on the experimental results so you want the same person to inject every time"* (Interv_MRIP).

This meant that reproducibility could take a different meaning depending on the type of experimental work considered and the *epistemic culture* (see section 3.5.2) in which a scientist operated. For most participants in our study of NanoArth, reproducibility was an essential dimension, because it sought to remove the human variable from experimentation work. On the other hand, for other researchers, involving another experimenter in an experiment was not encouraged as it could hinder the consistency of the of specific manipulations that highly relied on it. This could possibly be a source of friction between co-operators working together but operating in different scientific cultures, particularly with regard to experimental validation. Distributed validation is explored next.

5.5.2 Distributed repeatability and reproducibility

Instances were reported in which a NanoArth scientist visited the site of distributed partners, particularly when they co-operated closely together as part of an experimental work arrangement. This was mostly the case when the degree of interdependence between the experimental activities on the respective sites was high and the practical conditions allowed for such visits to be organised. For instance, when referring to experimental work in Lausanne of importance to the team working in Geneva, the **Nanoparticles Developer** stated:

> *"The assay we did on the iron oxide particles was going to be of direct use to the guys in Geneva… so pretty early, once I had a pretty decent protocol we arranged for me to go out there so that I could show them the experiment and also see if it worked in their labs"* (Interv_ND_1).

Beyond the demonstration purposes of such a visit, it provided the opportunity for this experimenter to test her experimental procedure in different settings, with different materials and apparatus, and potentially to edit the protocol and adjust it to refine the results. This validation step, which can be referred to as *distributed repeatability,* was not reported as being done in a systematic manner, at least initially. It was explained that exchanges of these types became more frequent as the project unfolded and the partners became more familiar with each other across sites. As the socialisation around scientific work led to closer interpersonal links, and if practical conditions allowed so, *distributed repeatability* became better embedded within the experimental process, as these links grew stronger

Other situations were described where similar experiments had to be conducted in parallel at various sites, so that the results could then be compared or correlated, like for instance with regard to the imaging work in Lund, Berlin and Salzburg (see section 5.4.3). These situations offered the opportunity for additional validation of experimental protocols by ensuring what is labelled *distributed reproducibility* in this thesis, i.e. the verification of a protocol by another researcher, in different lab conditions. Another example was given by the **Bone Biologist** working **in Geneva**, referring to exchanges with the rheumatology team in Berlin.

> *"There were a few instances where [the Berlin team] were doing experimental work that was very similar to ours so they asked for our protocols. We sent them the protocols and we asked them to have a go and do the experiment themselves, just to see if they got something similar. Then we discussed the differences and that was quite useful"* (Interv_BB).

If this type of validation was not perhaps entirely systematic (since it required the right experimental setup to be in place), again it became more frequent as the various members of the consortium got to interact more regularly and more freely, on their own initiative. Interestingly, the variations between the results obtained by the two sets of experimental results (respectively in Geneva and Berlin) then led to discussions between the two parties on the authored protocols, i.e. not only on the actual data like it might have been in co-located environments, but on the differences in the methods used to conduct and validate the experimental work.

What emerged from this analysis of the ways with which experimental validity was ensured, is the fact that the two concepts of *repeatability* and *reproducibility,* considered by the scientists as inherent to scientific enquiry work, were adapted to and made to fit to the multi-sited and cross-disciplinary settings of a project like the NanoArth project. This tailoring to a distributed project of this type takes the form of the four different levels of repeatability/reproducibility considered here which are adhered to various degrees, depending on the discipline, the type of scientific activities, and on the local circumstances.

5.5.3 Summary of findings

The findings in relation to the co-validation of experimental protocols are summarised in table 5.4.

Section 5.5: Validating experimental protocols		***Area: Experimental Validation***
	Work practices and associated meanings	**Issues, difficulties and challenges**
Local repeatability and reproducibility	• Ensuring local repeatability: experimental work iterations by main experimenter in same lab conditions. • Ensuring local reproducibility: experimental work iterations by co-located co-operator in same lab conditions. • Local reproducibility not required when human variability needs to be eliminated, depending on scientific cultures and experimental activities.	• Arrangements for ensuring reproducibility can be ad-hoc • Differences in ensuring reproducibility because of scientific cultures may create frictions
Distributed repeatability and reproducibility	• Ensuring distributed repeatability: experimental work iterations by main experimenter in different lab conditions. • Ensuring distributed reproducibility: experimental work iterations by co-operator on different site in different lab conditions.	• Great variations in distributed validation practices depending on interpersonal connections and practical conditions. • Discussions on validation methods used in experimental protocols.

Table 5.4: Summary of findings on local and distributed experimental validation

To further extend this analysis of validation practices, issues of centralisation and standardisation (in relation to quality control) are considered next.

5.6 Centralising and standardising experimental protocols

When probing distributed scientific enquiry work arrangements as part of the NanoArth project and the practices put in place by the various scientists to organise and co-ordinate their experimental activities, concerns were often reported with regards to the quality control of scientific work, despite the validation processes examined in the previous section. These concerns led to the use of two approach to control scientific activity (centralisation and standardisation) both of which required co-ordination and which themselves introduced their own work practices.

5.6.1 Quality control of experimental work

A number of experimenters highlighted that there were variations in the mechanisms put in place to scrutinise the finer details of their experimental work by others (through ensuring *local* and/or *distributed reproducibility* or through checks by leading partners or members of the project management team) to verify the results that they obtained.

> *"Sometimes, it feels that the actual details of your experimental work could be given more attention, particularly if you work on your own on something tricky or on something separate that you don't get to discuss with others too much… yes, [the NanoArth Scientific Coordinator] will have look at the overall results but no one is really going to go and have a look at your protocol, at your lab book or at the details of your spreadsheet with the results"* (Interv_ND_2).

The level of scrutiny of the actual details of the experimental processes appeared to depend, to a certain extent, on the level of interdependence of the scientific work with the work of potential partners. If the experimental design was very localised and self-contained, some scientists felt that, at times, no sufficient interest was given to quality control, beyond the personal one (unaccountable to the project management team) that was in-built as part of basic *repeatability* check. Conversely, if the experimental design was much more distributed and if the interdependence with the work of others was higher, more efforts were made to verify the small details of the experimental operations designed and undertaken by oneself and those of others. A revealing example was given by the **Nanoparticles and Reactor Engineer in Lausanne**:

> *"When you synthesize particles that are going to be used by people at another site, everyone tends to check your protocol design with a lot more care and attention… because you know and they know that if you mess up it is going to lead to problems for everybody… and you also know that they are going to check things carefully at their end when they get them"* (PartObs_ND&NRE_1).

It therefore transpired that quality control of the experimental protocol design was heightened by other partners' expectations, and the higher these expectations were, the stronger the experimental validation by the experimenter (*repeatability*) and by others (*reproducibility*) was. These issues around enforcing quality control, and the lack of a systematic approach to the validation of experimental design, methods, and outputs, was seen as a great source of concern for the management team of the NanoArth project. This was commented on by the NanoArth Scientific Coordinator:

> *"I think we had some issues at project level regarding quality control, particularly at the start… We felt that everyone was doing their own thing… and that it was always very difficult to find out exactly what people were doing exactly… you would only see the positive results, the things that worked, that were presented in a particular way to show that everything is fine… but how about those attempts that did not work out? How do you know whether the small details of their experimental work are actually valid?*" (Interv_PM&SC).

These concerns over the lack of consistency in the approaches adopted to scrutinise the scientists' own work and the work of others is what justified the centralisation and standardisation of experimental protocols at project level.

5.6.2 Centralisation of protocols

A key measure introduced by management to increase the visibility of experimental work across the project was the centralisation of various products used and generated when conducting scientific work, essentially experimental protocols and intermediate experimental results. Initially, all partners were required to send electronic copies of these documents periodically to the NanoArth Project Manager in Greater Lausanne, via email, so that she could make them accessible to the entire project consortium. Subsequently, the researchers were asked to upload those experimental products directly onto a central repository, on an internal Web space, so that to make them available to all members instantaneously, without the need for the intervention of member of the management team.

It transpired that the push for centrally storing the various information artefacts used and/or produced as part of experimental work, was received with various degrees of (dis)approval. For some researchers, it was perceived as a show of excessive control and monitoring by management, and thus as evidence of lack of trust from management towards the experimenters at the bench, and, in this respect, was quite problematic. This point was made by the **Bone Biologist in Geneva**:

> *"It feels like we are being checked on all the time and honestly I find that it's a bit too much… I can appreciate that [the members of the management team] want to find out what we do and how we are getting on with it… fine… but asking us to upload absolutely everything feels like we are being overly monitored"* (Interv_BB).

For others, this call for continuously sharing the products of the scientific work globally was seen as a hindrance as it was deemed to interfere with the actual work and to create unnecessary overheads. The **Biomechanics Engineer in Berlin** made this explicit:

> *"When you have done a couple of experiments and obtained a number of MRI scans, you want to go and analyse them so that you can then go back and experiment more if you need to… you don't want to have to think 'oh now I have to compile them somehow to then upload them on the system'… it feels like that's getting in the way"* (Interv_BE).

Other scientists expressed their concerns about having to make available experimental products that they considered as "work-in-progress" (Interv_NRE_1), i.e. only partially complete and in a not sufficiently stable state. In their views, this could lead to what could become serious version management issues, as commented on by the **Rheumatology Scientist in Berlin**:

> *"As requested [by management], I upload a protocol and a result file for an experiment that I have performed onto the Web space… but then the following day you have another go and get slightly different results and then you are meant to be uploading that again.... but then it becomes a nightmare because you have all these versions and some*

> *of them are not that different and it is very hard to find your way around them a few days later when you are looking for the really meaningful ones"* (Interv_RS).

The issue of excessive proliferation of recorded versions of information artefacts was seen as problematic, specifically with regards to the authoring and maintaining of experimental protocols (see section 5.3.3) and particularly if they were used to drive and co-ordinate complex distributed experimental arrangements (see section 5.4). Therefore, what might have been promoted as a means to strengthen quality control, might instead have had the opposite effect.

5.6.3 Standardisation of protocols

NanoArth being a project in the area of nanodiagnostics, for which nanotoxicity is a key issue, there was a strong interest in identifying how methods for the synthesis, characterisation, functionalisation and sharing of the nanomaterials could be standardised across the sites of the consortium (see section 4.4.6). Beyond the standardisation of the production of nanomaterials to make them safer, there was a push to standardise experimental practices, and the ways to document and capture these practices. As part of this effort, the standardisation of protocols was a key measure brought in by the management team to increase the transparency in the experimental work and its reusability among and across sites. The **NanoArth Project Manager in Greater Lausanne** explained the motivations behind increasing the standardisation of the ways the partners recorded their experimental design through the authoring of protocols:

> *"Everyone in the project was using different protocols… and these were very different depending on the site, on the institution, on the discipline or on whether they were an industrial partner or an academic researcher… everyone has different ways of operating and of designing their experiments… but it made it very difficult not only for us but for everyone to understand what was going on with anyone else's work and for people to work together"* (PLE_1).

Not only were there differences between the ways in which scientists set up their experimental work and design their procedures that emanated from disciplinary, institutional and geographical variations, but there were also notable differences between the scientific cultures of partners working in the industry and those working in academic institutions with regards to standardisation:

> *"In the industry, they are used to working with very clearly defined standardised procedures… for them standardisation is de-facto, it is a way of life… for academic researchers, it is very different, they do not like to be too constrained, they think it is going to restrict their creativity"* (Scientific Coordinator, PLE_1).

The challenge was thus for management to introduce standardisation levels across the project that could improve visibility and foster the sharing of experimental work without overly interfering with the respective practices. An attempt to rise to this challenge in the NanoArth project was of the introduction of Standard Operating Procedures (SOPs), which are widely used in clinical research and pharmaceutical processing (Gough & Hamrell, 2009; Hattemer-Apostel, 2001).

The International Conference on Harmonisation of Technical Requirements for Registration of Pharmaceuticals for Human Use (ICH), a project that brings together leading regulatory authorities and pharmaceutical industry experts, define SOPs as "detailed, written instructions to achieve uniformity of the performance of a specific function" (ICH, 2015). In scientific research, SOPs are often related to the development of pharmaceutical products as they are used to describe procedures policies and processes that assist the manufacturing of a given product and include elements such as the monitoring of the environment, the cleaning of facilities and policies for storing products and keeping records (Lindgren, 2009). In fact, it is partly because of the previous experience of the **Nanoparticles Developer** with using SOPs in the pharmaceutical industry that they were introduced in NanoArth:

> *"I used to work in a big pharma[ceutical company] and there we had to use very structured, very rigid SOPs… and that had definitely an influence on the way I organise my protocols but also the way I like other people to do their protocols… I know it is not the same in a project like [the NanoArth project] where it is about exploring and not*

> *just about manufacturing… but I have incorporated some of these ideas to the way I design my experiments"* (PLE_1).

The Nanoparticles Developer's way of designing and structuring her experimental work and of organising her protocols in a standardised manner (see figure 5.1) was picked up by members of the management team, namely the Project Manager and Scientific Coordinator, who decided to take this to the whole project.

The standardisation of protocols in NanoArth did not occur without creating a number of frictions. Not only did a number of scientists found this requirement for formatting protocol in a standardised manner overly constraining, and not always suited to their own individual practices (see section 5.3.4), but questions were raised by a number of researchers more generally about the idea of standardising the design and development of experimental protocols across the project consortium.

Some, like the **Bone Biologist in Geneva**, deplored that this initiative was purely driven by the management team perhaps to the detriment of the experimenters.

> *"I can see why [the management team] introduced the SOPs but I felt like it was more to make them happy than to help us with our work"* (Interv_BB).

Along the same lines, others, like the **MRI Physicist**, also **in Geneva**, complained about the increased workload resulting from such standardisation approaches.

> *"I felt that the SOPs were kind of useful to make everyone sing from the same song sheet but, at the same time, that was yet another thing we had to do… on top of the reports and everything else… just to keep a track on what we do"* (Interv_MRIP).

Finally, researchers like the **Biomechanics Engineer in Berlin**, criticised the disruption of this standardisation on existing experimental design practices.

> *"The main problem with the SOPs was when they were introduced… by then we already have quite a few of our protocols well in place… not all of them were stable but they were usable… and having to then move on to SOPs felt like a huge task, something major that would have to be done on top of everything else and that would take so much time… so much valuable time away from the actual experimental work"* (Interv_BE)

The last point raised by the Biomechanics Engineer was critical as there was a perception that the adoption of SOPs, albeit making sense to enhance alignment, unsettled practices that had required time, effort and better familiarisation between co-operating partners. The **Nanoparticles and Reactor Engineer** concurred that the timing of the introduction of standardised experimental design and protocols was crucial:

> *"I think the introduction of SOPs is a great idea, if you do it right at the start of the project… then everyone knows that it is the way you write your SOPs and fine, it works… but if you try to introduce them a year or two into the project, then it is going to create a right mess, there is no way it is going to work"* (PartObs_ND&NRE_2).

In brief, these participants were concerned that this route to protocol standardisation was imposed by management without much regard for the experimenters' established practices, that it was overly constraining and time-consuming, that it led to a greater workload, and that it interfered with the scientific practices already in place. A number of scientists thought that these issues could potentially be avoided, if the standardisation approach was implemented very early, right from the start. Then standardisation could be seen as a useful practice, that could help with co-operative exchanges and aligning work better, as opposed to being seen as overly constraining and disruptive

5.6.4 Summary of findings

The findings in relation to the centralisation and standardisation of experimental protocols to enhance experimental quality control are summarised in table 5.5.

Section 5.6: Centralisation and standardisation of experimental protocols		***Area: Experimental Quality***
	Work practices and associated meanings	Issues, difficulties and challenges
Quality control	• Level of scrutiny of experimental work depends on interdependence level with others' work. • Scrutiny of localised and self-contained work appears limited. • Scrutiny of distributed and highly interdependent work is higher. • Management push to harmonise practices and encourage improved experimental validation and verifications.	• Disparities in levels of scrutiny depending of interdependence of experimental designs and activities, source of great concern for management.
Centralisation of protocols	• Push by management to centralise protocol to make them accessible to all partners to enable greater visibility and transparency.	• Concerns over excessive control from management. • Concerns over unjustified increased workload and interference with experimental work. • Challenges related to proliferation of protocols and version management.
Standardisation of protocols	• Push by management to standardise protocols for increased consistency and better alignment. • Introduction of SOPs inspired from practice in the pharma industry. • Introduction of a template to structure and organise protocol design better.	• Variations in experimental design and in documenting experimental procedures due to disciplinary, institutional and geographical differences. • Concerns over standardisation and harmonisation of practices as being overly constraining. • Perception of overly rigid approach not suitable to all practices. • Concerns over excessive from management. • Concerns over increased workload and interference with experimental work. • Concerns over the ill-timed and disruptive impact of introduction of SOPs on existing scientific practices.

Table 5.5: Summary of findings on centralisation and standardisation of protocols

5.7 Chapter conclusion: key role of the protocol

So far, this analytical account has shed light on some of the practices put in place by the NanoArth scientists and their management to co-design intensely distributed experimental activities and has underscored the central role of the experimental protocol as an information artefact in this co-design. Because of the inherent nature of exploratory scientific work in these global settings (distributed across interdependent work arrangements while also heavily localised and contingent), the experimental protocol was subject to multiple changes and continuously modified to take into account the many changes of directions of the scientific enquiry.

As part of distributed experimental work arrangements (flexibly or tightly co-ordinated), the protocol was used and took multiple meanings such as a technical diary, a map or a plan. Essentially it was used as a key point of reference for the stipulation of the experimental activities and the meditation of the articulation of these activities. In this sense, it played the key role as a co-ordination mechanism (by being used to propagate the state of completion of one's own work) but also as a boundary negotiating object (to mediate the negotiations around a space of co-operation and alignment) and as a boundary specifying object (to provides a way for the partner to work in synergy, yet independently) across multiple sites.

Experimental co-design was also tightly linked with thorough experimental validation practices which differed depending on the nature and interdependence of the distributed activities and the levels of familiarity between co-operating partners. If *repeatability* was very often enforced (mostly locally and sometimes in a distributed manner), there were greater variations on ensuring *reproducibility* mostly depending interpersonal connections and practical conditions. Management pressed for the adoption of a more systematic approach to experimental validation and generally to the control of experimental quality. To this effect, several measures were introduced ranging from defining clearer naming and versioning guidelines to support protocol authoring to the centralisation and standardisation of all protocols across the consortium. These measures were adopted with varying levels of approval by the NanoArth experimenters as they were often deemed as overly constraining and disruptive of existing practices. Introducing them at a very early stage in the project was highlighted as critical towards the success of their adoption.

The next chapter uncovers the practices around the actual co-conduct of distributed experimental work, and the supporting activities necessary for this experimental co-conduct to be operational. It highlights the roles of another two key information artefacts in this process: the material log and the lab book.

Chapter 6 Co-managing distributed scientific work

6.1 Chapter Introduction

This second analytical chapter provides a detailed account of the ways in which scientists in the NanoArth project organise, manage, and support their scientific work co-operatively. It is concerned with how they use information artefacts to support the co-ordination of the activities that assist the actual conduct of their distributed scientific activities: the supply of nanomaterials, the exchanges of physical and digital experimental materials, and the logging of scientific activity. The focus of this chapter is thus on these activities that support the co-design, co-validation and co-conduct of experimental work: distribution and exchanges of experimental materials, and logging and reporting on experimental work. Analytically, this analytical account is articulated around the last five thematic areas identified in the previous chapter as *areas of activities and interactions* (see section 5.1): (4) *Experimental Material Supply*; (5) *Experimental Material Exchanges*; (6) *Multi-type Exchanges*; and (7) *Experimental Logging.*

The overall setup for NanoArth required for nanomaterials to be engineered at a specific site and distributed to the other teams, as well as for a range of other materials to be sent between the various labs where experiments were being performed (using the produced nanomaterials and the other materials). When probing these processes, a complex network of exchanges of samples of experimental materials between the various sites emerged, as illustrated in figure 6.1, which provides a diagrammatic illustration of the flows of experimental materials sent between the different sites of the consortium. This diagram was inspired by, and refined from, a schematic representation that was produced by the NanoArth Project Manager and presented at the nanotoxicity workshop in Lausanne in May 2012 (see section 4.4.7) to give an overview of the various exchanges of samples between the different partners (Roubert et al., 2016).

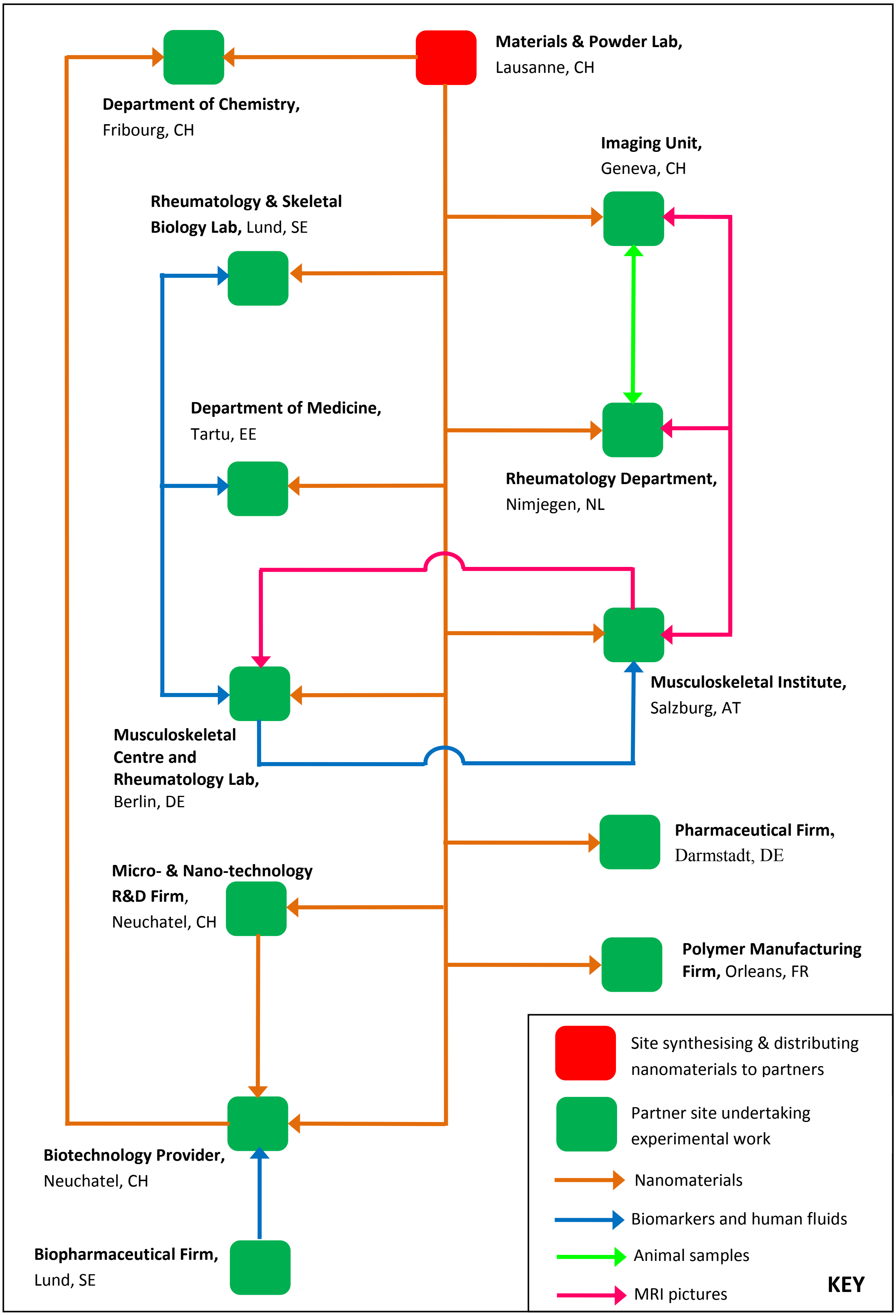


Figure 6.1: Exchanges of experimental materials in the NanoArth project consortium

The chapter first concentrates on the production of the nanomaterials at the Material and Powder Lab in Lausanne and the distribution of these nanomaterials to the other sites (in light brown colour in figure 6.1). The section probes the nanoparticles synthesis process and the artefact-mediated practices adopted by the nanomaterial developers to manage the supply to their partners across sites.

The following section (section 6.3) explores how the exchanges of experimental materials were organised and co-managed between the various sites to support the design and performing of their experimental activities. Multiple interchanges of various samples occurred between the other members of the consortium, as an integral part of the multi-sited experimental co-design, as follows:

- Biomarkers and human fluids were exchanged (in blue in figure 6.1) between the Rheumatology and Skeletal Biology Lab in Lund, their counterparts in Berlin and the Medicine Department in Tartu, Estonia.
- Biomarkers and human fluids were sent from the site in Berlin to the Musculoskeletal Institute in Salzburg and from the Biopharmaceutical Firm in Lund to the biotechnology provider in Neuchatel. Exchanges of animal samples took place (in light green in figure 6.1) between the Imaging Unit in Geneva and the Rheumatology Department in Nimjegen.
- MRI scans were exchanged (in pink in figure 6.1) between the sites in Geneva, Nimjegen and Salzburg was well as being sent from Salzburg to Berlin.

This section 6.3 examines how these exchanges are captured and reported, probes the role of the material log to stipulate and mediate these exchanges, and looks at how attempts were made to centrally record all exchanges in a standardised manner.

In the subsequent section 6.4, the focus is on the practices used by the various partners to establish means of communications to support and manage the exchange of materials, and the duality of exchanges of physical and digital materials, will be explored.

The final section of the chapter explores the practices related to the logging and collating of experimental data as experimental work is being conducted and considers the different utilisations and values held by the lab book to support these practices.

6.2 Co-managing the synthesis and supply of nanomaterials

The synthesis and supply of nanomaterials emerged as one significant area to be investigated in its own right, as it appeared to be the subject of a great deal of interpersonal and interorganisational interactions between the various practitioners conducting cross-sited experimental work. As a brief reminder, the primary objective of the NanoArth project was the investigation of the behaviour of the imaging properties of a specific nanoparticles (SPIONs) with a view to design a nanodiagnostics model to detect and possibly treat various forms of joint disorders. In this project, the SPIONs were produced at the Material and Powder Lab in Lausanne and supplied to all partners requiring them for their own experiments (exchanges represented in light brown in figure 6.1). The following sub-sections provides an in-depth analysis of how the synthesis and supply of nanomaterials was organised, and the roles of range of standardised information artefacts to support the co-ordination of this production and distribution process.

6.2.1 Managing nanosynthesis: reference samples and acceptance ranges

When probing the practices adopted by the scientists working in the Material and Powder Lab in Lausanne (the NanoParticles Developer, the NanoParticles and Reactor Engineer and the Nanoparticles Coating Engineer) during the various visits at that site, it emerged that the primary concern for the team was to ensure a consistently high quality in the production and supply of the SPIONs to be used by their NanoArth partners. Hence, so as to ensure this high quality, it was made clear right from the first participant observation, that a strict standardised procedural approach was in place to support the nanosynthesis.

The development process of the SPIONs started with the authoring of a synthesis protocol to produce a "*master batch*" (PartObs_ND_1) of nanoparticles that complied with the precise requirements agreed with one or more partners, specified as part of a Work Package. For instance, the team in Lausanne were asked to synthesise SPIONs that would be used by the experimenters in the Rheumatology Lab in Berlin to conduct in-vitro toxicity tests to assess the impact of the nanoparticles on immune cells (see section 5.4.2). The experimental design to synthesise the master batch in Lausanne was supported by the continuous development of the experimental protocol, which was used to mediate the negotiations with the partners in Berlin, and progressively improve the engineering of the SPIONs, as explained in section 5.4.2. The synthesis of the *master batch* of SPIONs was key, as it would subsequently be used as a reference for all further batches developed subsequently. The produced particles in the reference batch were physically and chemically characterised immediately after their synthesis, i.e. measured to determine their structure and properties with great accuracy and accurately define their sizes and electrochemical charges. A process of functionalisation of the SPIONs occurred afterwards, by which the surface of the particles was coated, and the coated particles were then fully characterised as well.

A number of related batches of SPIONs, referred to as "*initial batches*" (PartObs_ND&NRE_1), was produced shortly after based on the *master batch*. These were also fully characterised and compared to the master batch. The aim of the synthesis of these *initial batches* and the comparison to the first *master batch* was explicitly to define a "*Range of Acceptance*" (PartObs_ND&NRE_1) values. This Range of Acceptance (RoA) values determined the "*boundary values for accepting and using the SPIONS that are synthesised*" (PartObs_ND&NRE_1), in the sense that these values were referred to as a standard against which all subsequent batches of synthesized particles would be measured and used to accept or reject them.

For every batch of new particles that were produced and characterised, the RoA values (from the *master batch* and *initial batches*) were recorded on a sheet, alongside the results of the characterisation. Thus, the experimenters who used them in their experimental work could rapidly and precisely determine how the particles compared with respect to the *master batch* and the *initial batches*. However, an additional challenge emerged with this experimental engineering of SPIONs: it was possible for the properties of a batch of particles to vary over time. Therefore, multiple characterisations of a particular batch had to be performed at different points in time, as explained by the **Nanoparticles Developer in Lausanne**:

> *"We keep the characterisation of the initial production separate from later characterisations… just to see how our particles evolve with time… we can then compare the new characterisations to the initial one to see how our particles change… it is important for us to keep a track of all that"* (PartObs_ND&NRE_1).

The initial characterisation was thus guaranteed for a period of time, providing that the particles were stored following specific conditions mentioned in the initial protocol used to produce the *master batch*. New characterisations needed to be conducted after that time to determine whether the particles had evolved, and the RoA values helped identify whether the quality had been compromised.

In this synthesis process, the mediating role of the experimental protocol is underscored as being used as a key point of reference, not only for stipulating the initial development of nanoparticles but, also for capturing essential information that is used at later stages to support the synthesis of further batches of nanomaterials. It is used in parallel with a sheet that contains characterisation information, RoA values and toxicity data. Issues of toxicity during the synthesis stage are considered next.

6.2.2 Managing toxicity tests

It was reported that if a batch of nanoparticles were to be sent to members of the project consortium who intended to use them as part of *in vivo* experiments, it was essential for that batch of particles to be thoroughly tested for toxicity. A series of "*Preliminary Toxicity Tests*" (PartObs_ND1) were introduced so that they would be conducted in the lab in Lausanne at different points in time, before the particles would be sent to the other sites to guarantee their safety. These *Preliminary Toxicity Tests* (PTTs) consisted of cell viability tests, as explained by the **Nanoparticles Developer in Lausanne**:

> *"You cultivate [commonly used in scientific research] HeLa cells, and when they have grown, you add the nanoparticles to your cells. You leave them for a certain time for interactions and then, after a certain time of incubation, you carry out the test and see how the cells react"* (PartObs_ND1).

Again, reference tests with the same type of cells and a master batch of particles were used as a standard against which subsequent toxicity tests would be compared:

> *"Because all the previous tests were done with the HeLa cells, we always keep the HeLa cells and our master batch as the control"* (PartObs_ND1).

What became clear is that the relatively complex initial testing led to an early decision point which helped determine whether the development of a given material could be continued. If the batch of new particles were considered non-toxic, and the decision was taken to go ahead with sending it out to partners, further tests were conducted to ensure maximum safety. Subsequent PTTs were conducted at different time points and under conditions that were as close as possible to the conditions under which the particles were to be used as part of the partner's experimental work, as underscored by the **Nanoparticles and Reactor Engineer in Lausanne**:

> *"If the experiment that is going to be performed is done in blood, then you need to test your particles in blood to try to have a medium as similar as possible to theirs"* (PartObs_NRE_1).

To sum up, if a new batch was produced for direct experimental use at another site, a series of PTTs were conducted, and the results carefully recorded, before the particles were shipped across. If a batch of particles had been produced previously and stored for a certain period of time, a new toxicity test would be conducted to guarantee that the particles were still in a stable state and had not become toxic. On certain instances and if they had the required facilities to do so, the partners receiving the particles conducted their own toxicity tests to ensure that the toxicity levels were still within the acceptable range and thus that the particles were safe to use.

Notwithstanding the introduction of these measures, it was decided that increased artefact-mediated standardisation was required.

6.2.3 Increasing standardisation: Certificates of Analysis

Despite the standardised procedural process described in the two previous sections to produce and supply high-quality SPIONs, it was reported that there were still issues with the produced nanomaterials. A key problem was highlighted by the NanoArth **Scientific Coordinator in Greater Lausanne** and related to the difficulty in synthesising batches of nanoparticles that were absolutely identical. After multiple enquiries, it was established that these variations came from differences in the materials sent by the industrial partners for their coating:

> *"We realised at some point that different lots of the polymer that [the industrial partner] sent us for us to coat the particles had small but significant differences and that as a result what were apparently identical nanoparticles behaved differently in-vivo"* (PLE_1).

This underscored, for the team in the Material and Powder Lab in Lausanne, the need to find ways to accurately and consistently identify and record all the details of the materials used in the synthesis of nanoparticles, as was highlighted by the **Nanoparticles Developer**, also during the first participatory learning exercise:

> *"After we realised there were differences with the polymer, we decided that we needed to be a lot stricter with the way we were keeping track of all the materials used in the synthesis otherwise it is a right mess"* (PLE_1).

In practice, it was decided that all materials used in the nanosynthesis process were to be recorded in a *"material log"* (Project Manager, Interv_PM), initially an electronic spreadsheet, and that the nanoparticles development protocols were to cross-reference specific entries in this log. It was also decided that this material log needed to be centralised and made accessible to all project partners so that they could refer to it when using the SPIONs in their experimental work, if they needed to find out more about the materials used in their production and how they were likely to behave. The management team made the decision to go even further and to make the nanosynthesis process even more transparent for the benefit of the other sites using the particles. Standard *"Certificates of Analysis" (*Project Manager, Interv_PM) were introduced to accompany every batch of produced nanoparticles:

> *"We [the management team] just felt that the guys in Lausanne needed to give out much more information on the particles they sent out, on how they were synthesised, on their toxicity levels, on how they compared to the original batch… so we decided that the best way would be for them to attach a CofA [Certificates of Analysis] with every batch that it would provide an easy-to-use overview of the particles they sent out"* (Interv_PM).

Certificates of Analysis (CofAs) tend to be used for the manufacturing of pharmaceutical products and, in simple terms, are documents that attest that a particular product has undergone specific tests and that summarises the results (The International Pharmaceutical Excipients Council Europe, 2013). In summary, a CofA is a document that verifies the compliance of a product to certain specifications with a view to certify the quality of that product. An example of a CofA for a batch of SPIONs synthesised at the powder and material lab in Lausanne in June 2012 can be seen in Appendix E.

In the NanoArth project, the concept of CofA was adapted from the large-scale industrial production of materials to the targeted synthesis of the SPIONs. From this point onwards, every new batch of generated nanoparticles were given a CofA that provided a visual summary of the characteristics of these particles in a tabular format. This included the results of the physicochemical and colloidal characterisation for this particular batch alongside the RoA values to show how this particular batch compared to the original one. It could also include the results of the PTTs, particularly if the particles were destined to be used *in vivo* in humans or animals. Typically, this CofA was physically sent alongside the batch of particles to the receiving laboratories. Subsequently, as the practice of producing CofAs became more systematised, scientists were required to upload an electronic copy onto a web-based central repository (the same one used to upload the protocols, see section 5.6.2), for everyone to access, with a view to enable any scientists with an interest in a specific batch to find out more about it. The Nanoparticles Developer explained that, as far as the supply process was concerned, not only this approach provided greater transparency, but also it helped logging any changes that might have occurred in the state of the particles, and hence in their characterisation or in their toxicity levels, so that to ensure that the most up-to-date information was always available.

6.2.4 Summary of findings

The Material and Powder lab plays an important role in NanoArth as the site that synthesises and supplies the other sites with tailored nanomaterials for their work. Standardised methods have been introduced progressively to ensure greater consistency in the quality of the production. These ultimately were supported by two key standardised information artefacts: (1) an initial material log, to keep a track of all materials used in the synthesis, and (2) CofAs to guarantee the quality of the synthesised materials and provide partners with the latest available information on these materials, their characterisations, and their toxicity. These findings are summarised in table 6.1. For further illustrative purposes, an example of a CofA is included in appendix E, while the photo in figure 6.2 shows the Nanoparticles Developer at the bench in Lausanne working on the nanosynthesis of SPIONs destined for in-vitro toxicity testing at the Rheumatology Department in Berlin (during the participant observation coded PartObs_ND_2 which took place in February 2013).

Figure 6.2: Nanoparticles Developer synthesising SPIONs at the bench in Lausanne

Section 6.2: Synthesising and supplying experimental materials		***Area: Experimental Material Supply***
	Work practices and associated meanings	**Issues, difficulties and challenges**
Producing reference samples and defining acceptance ranges	• Synthesis and characterisation of a master batch and initial batches of nanomaterials. • Definition of RoA values based on initial batches. • Characterisations and use of RoA values to accept any subsequent batch. • Characterisations at different time points and use of RoA values to ensure batch still valid.	• Primary concern: ensuring consistency of quality of produced nanomaterials. • Issue of change of state of materials over time. • Challenge of having to characterise frequently nanomaterials to detect changes in states and toxicity.
Managing toxicity tests	• Conducting PTTs and reference tests on master batch. • Use of reference tests for new batches or for batch which has been stored for some time. • Outcome of early tests leads to decision point for subsequent testing.	• Complex initial testing leads to decision point. • Challenge of making the right decision whether to proceed with development of nanomaterial.
Increasing standardisation through CofAs	• Push by management for increased transparency and traceability in nanosynthesis process. • Introduction of an initial material log of all materials used in synthesis of nanomaterials. • Introduction of CofAs to guarantee quality of synthesized materials. • Sending CofAs with RoA values and PTT data. • Centralisation of CofAs to make materials used in nanosynthesis available to all.	• Concerns over differences in nanoparticles produced because of variations of materials used in nanosynthesis.

Table 6.1: Summary of findings on experimental material supply

The managing and tracking of exchanges of other experimental materials are considered next.

6.3 Co-managing the sharing of experimental materials

The following sub-sections provide an analytical account of the other exchanges of experimental materials between the NanoArth sites. They consider how the sharing of *physical experimental items* were organised (essentially exchanges represented in blue and green in figure 6.1), how those exchanges were logged centrally and monitored, and the attempts made to standardise these processes to support the conduct of enquiry work using several information artefacts. The in-depth investigation of the practices involved in supporting the sharing of experimental materials between different sites revealed that there were two different types of exchanges: ad hoc exchanges and structured exchanges.

6.3.1 Organising ad hoc exchanges

Exchanges under the first type were organised on an ad hoc basis, motivated by the experimental needs of the moment, and did not require any particular pre-planning, as illustrated by the **Rheumatology Scientist in Berlin**:

> *"Sometimes as part of my experiment I want to try something and for that I need them to send me a sample. So, I just send them an email explaining what I am after and ask if they can send it to me, just like that"* (Interv_RS).

Another example was given by the **Bone Biologist in Lausanne** when discussing the experimental design and protocol development process which involved the imaging of rodents after injection of the SPIONs (see section 5.3.1):

> *"We made a lot of different attempts to develop that protocol, there was a lot of experimenting… so we needed to be sent nanoparticles quite a few times… so we contacted the guys in Lausanne and asked them to send us new samples when we needed them… the fact that we are in good terms with them made it really easy"* (Interv_BB).

The informality of these exchanges appears to justify why the initiating, logging and monitoring of these exchanges was done in a rather unstructured manner, using traditional communication means such as emails and telephone. The researcher in need of the sample for designing an experiment typically referred to their lab book (the typically paper-based bound notebook on which the details of experimental are usually recorded, see section 6.5) and to the experimental protocol to produce a list of requirements for specific materials. The researcher receiving the request usually recorded the details of the samples to be sent into their own lab book, before organising the shipment, as corroborated by the **Nanoparticles Developer in Lausanne**:

> *"Before sending a sample I write down in my lab book the description of the sample, the description of the condition that the sample is in and any observations that may be useful"* (PartObs_ND_2).

The required materials were subsequently posted and, typically, a confirmation email was sent back to the requesting scientist. Sometimes a physical document was enclosed in the package alongside the samples to provide additional information such as the characterisation of the sample, the conditions of storage and use, RoA values or PTTs data (see section 6.2). On occasion, this would be more sophisticated, and where the sample required a special treatment regime during transit, a digital probe might be included in shipments, such as a digital USB-powered thermos-hygrometer (a combined thermometer and hygrometer) to keep a track of the temperature and moisture levels of the contained material.

6.3.2 Organising structured exchanges

The second type of exchanges that emerged in our study of NanoArth referred to those exchanges of materials which were a lot more constrained by the interdependent and structured nature of the experimental work. The issue of locating and assembling heterogeneous physical materials and resources caused particular problems when experiments needed to be performed under closely controlled conditions. Time constraints sometimes came into consideration (see section 5.4.3), particularly if the exchanged materials had a short lifespan or if they were at risk of changing state. Such issues of exactness are critical in controlled experimental design to ensure experimental validity, and a complex networked exchange of samples usually had to be methodically synchronised in order for the distributed experimental work to be successful, a point that was made by the **Rheumatologist Scientist in Berlin**:

> *"We have this in-vitro testing plan that we have agreed in the work package. By this date we need to do this experiment. For this we need a certain type of particles with a certain type of coating. So, we send them a reminder and the exact descriptions of the particles we need. Or if we are late, we let them know that we will need them later. Then they send them to us and to the other partners who are doing similar work. We do our tests separately and then we talk"* (Interv_RS).

In order to ensure that the exchanges were carried out as planned, documentation usually had to be disseminated between the various partners involved to provide them with the information required for them to set up their experiments. These could take many forms, such as emails, written notes or even, sometimes, verbal data transmitted over the telephone or voice-over-IP. This mix of materials was supported by the use of the lab book artefact to provide the required information (by the sender) and to record this information as part of the experimental set-up (by the receiver). The experimental protocol still played a key role as the information artefact used to drive the experimental design and development process and, in this respect, as the artefact continuously referred to (alongside the lab book) to support the specification and negotiation around the required samples between the sender and the receiver.

It became apparent that these multiple complex exchanges of physical materials and associated physical and digital artefacts were not always organised in a structured manner, and the dispersion of information over different physical and digital platforms could lead to some confusion and the potential for errors because of the distributed project participants. The **NanoArth Project Manager** made this point:

> *"It got very difficult to monitor all the exchanges of materials that were sent around the consortium and keep a track of what was going on… with tons of emails flying back and forth… and sometimes there were problems like for examples the material that was desperately needed by a partner to do their experiment would not get there on time or it would not be exactly what the team was expecting… so that would then generate a whole lot of new emails and make it even more complicated"* (PLE_1).

The managing of multiple communications and the sharing of multi-type materials is explicitly discussed in section 6.4.

This lack of transparency and traceability led the project management team to consider formalising and standardising the logging of exchanges of materials.

6.3.3 Standardising the exchange of materials: the material log

As for the issues previously considered of the lack of consistency between the practices of the various partners to arrange their protocol co-design (see section 5.6), the variations between the ways exchanges of materials were being organised was identified as a source of concern by the management team. The measures already taken to systematise and standardise the production and supply of nanomaterials were extended to all physical experimental materials exchanged between sites. The introduction of an initial log book and the uploading of CofAs onto a single location laid the foundations for the setting up of a global centralised and standardised *material log* platform to record and track the movements of all materials for the entire project. The **Project Manager in Greater Lausanne** justified why management was keen to roll out this practice to the entire consortium:

> *"We thought: why not go further and, not only upload CofAs, but also record every single postage or exchange of materials for everyone to see? Why not ask the scientists to log whatever they are sending each other so that we can keep a track of what is going on?"* (PLE_1).

The scientists were thus required to systematically fill an electronic form specifying information such as the details if the content of the postage, as well as the date and time and the destination of the postage. The researchers receiving the postage were asked to log details such as the arrival date and time, and the condition of the materials received. The data was then stored on a centralised database. As for the centralisation and standardisation of the protocol co-design process (see section 5.6), the motivation for centrally logging all exchanges of materials in a uniform manner was very much justified by the management in terms of increased transparency and ability to monitor and track all movements of physical materials. The NanoArth **Scientific Coordinator in Greater Lausanne** made it explicit:

> *"We thought it would really help having easy instant access to the most up-to-date data about which samples are sent and where… no more hundreds of emails asking: 'what happened to this batch?' Or 'when can you send us the cells?' Keeping an eye on all exchanges would help us make sure we know what is going on"* (PLE_1).

The eagerness of management to keep a track of all material movements was motivated by their interest in monitoring activities, changes in practices, and the repercussions these changes may have on the alignment of activities in the project to promote greater accountability (Redaelli & Carassa, 2015).

As for the standardisation of protocols, the scientists conducting the experimental activities *at the bench* in their respective labs did not always concur on the usefulness of such an approach for a number of reasons. The issue of the additional workload resulting from the introduction of this centralised material logging process (also underlined for the centralisation of protocols, in section 5.6) was mentioned by the **Bone Biologist in Geneva**:

> *"Having to log lots of information every time you send or receive stuff can be really tedious and time consuming. It is just that you have to make this extra effort on top of all the experimental work you already have to do, and it can feel a bit too much at times"* (Interv_BB).

A lack of semantic understanding of what the *experimental materials* to be uploaded on the system included was also highlighted as a prominent problem by the same **Bone Biologist**:

> *"The main issue for me is the fact that we are meant to be logging details of the samples we send. But what is the definition of a sample? Is it a physical object or can it be an electronic piece of information? Is an animal or part of an animal a sample?"* (Interv_BB).

The rigidity of the logging mechanism, in terms of handling of complex cross-sited material exchanges, was mentioned as a limitation by the **MRI Physicist in Geneva**:

> *"One problem for me is that it is quite difficult to combine several postings into one. Say for example you receive particles from Lausanne, you inject them in mice, take your scans and then send the animals or part of the animals to Berlin for them to do their in-vivo stuff. The system does not seem to handle this very well."* (MRI physicist)

For other researchers, like the **Biomechanics Engineer in Berlin**, it was the inability of the logging mechanism to accommodate associated files alongside the recording of the materials to be sent across that was problematic:

> *"Sometimes with the details of a sample you need to also upload a file, like an image or a number of images, because they provide important information on the sample you are sending… I find it difficult to upload extra stuff with the sample. If there are too many files or if the files are too big, it makes it really difficult."* (Interv_BE)

In addition, the timing of the introduction of this web-based material log was mentioned by the **Rheumatology Scientist in Berlin** as an issue because, as for the centralising of protocols, its late introduction was deemed to be disruptive of already established practices:

> *"As for the SOPs, the main problem is that the central log was introduced far too late and then it made it really tricky to use. We were recording the materials we sent each other locally in the lab and then, all of a sudden, we needed to log everything centrally by filling in a form… I don't know, it just felt like we were used to do things in certain ways and then we had to change our ways"* (Interv_RS)

This range of views appears to point out to the difficulty of applying such a standardised approach, which was designed in the first place with a view to provide more transparency and visibility, to fit with the practices of the scientist operating at the bench, to take into account the specificities of the local setting, and to manage the constraints imposed by this local setting. Thus, there was a clear tension between the deployment of a standardised material log that can help facilitate the co-ordination of scientific activities by providing *asynchronous change awareness* (see section 2.2.4 and Tam & Greenberg, 2006; Schumann et al., 2013) and the actual adoption of the log by experimenters who identified a number of challenges with its use.

6.3.4 Summary of findings

The key role of the *material log* was highlighted in this section as an artefact that was introduced to standardise and help co-ordinate the numerous exchanges of physical experimental materials across the NanoArth project. Its adoption *at the bench* was not entirely straightforward and several challenges were highlighted. These findings are summarised in table 6.2.

Section 6.3: Co-managing the sharing of experimental materials		*Area: Experimental Material Exchanges*
	Work practices and associated meanings	**Issues, difficulties and challenges**
Ad-hoc sharing of materials	• Exchanges of materials is an integral part of trial-and-error practices of experimental design. • Requesting researcher uses protocol and lab book to produce requirements list for materials. • Sending researcher logs details of sent samples in lab book, organises shipping and sends confirmation. • Exchange of physical materials typically supported by exchange of heterogeneous digital information	• Initiating, logging and monitoring of these exchanges done in an unstructured manner. • Challenge of using a range of heterogeneous communication channels to manage exchanges. • Challenge of managing unstructured exchanges of both physical and digital data.
Structured sharing of materials	• Exchanges of materials critical to successful interdependent experimental design. • Exchange of physical and heterogeneous information i.e. emails, written notes, verbal data.	• Issue of locating and assembling heterogeneous physical materials and resources when experimental work performed under closely controlled conditions. • Challenge of strictly handling tight time constraints during which nanomaterial may evolve. • Challenge of handling complex multi-directional exchanges of physical and digital materials. • Issue of confusion and errors due to multi-modal exchange of heterogeneous materials.
Standardising exchanges of materials	• Push by management for increased transparency and traceability in exchange of materials. • Introduction of electronic centralised material tracking log to keep a record of all exchanges.	• Issue of lack of consistency between sites in ways of logging materials exchanges. • Concern over rigidity and difficulty to take into account local specificities. • Concerns over the increased workload resulting from constraining logging practices. • Concerns over developing a common conceptual understanding of information to be logged. • Concerns over heterogeneity of data to be logged. • Disruption to existing practices

Table 6.2: Summary of findings on experimental material exchanges

In addition to exchanging physical experimental data, a great variety of digital materials were also shared between the consortium partners. The handling of multiple forms of communications and the interchanges of different types of physical and digital materials are considered next.

6.4 Co-managing multiple communication and multi-material exchanges

A whole range of documents were shared across the NanoArth consortium to assist with the exchanges of physical items, using a variety of communication channels. Nanosynthesis protocols and characterisations were sent electronically, spontaneously or upon request, to explain how the nanoparticles were produced, describe their properties, or discuss how they needed to be stored and manipulated (see section 5.4). CofAs were typically added inside a package of nanoparticles to provide the recipients with added documentary information on the nanomaterials they received such as RoA values and PTT data (see section 6.2). A researcher organising a shipment could also send any additional information on a posted sample, typically in an email, particularly if it was felt that it was key to the experimental work conducted at its remote site of use. Furthermore, a variety of files were exchanged spontaneously between partners, typically when the experimental work was under way, for instance to discuss early results of the experiments. An example was provided by the **Biomechanics Engineer in Berlin**:

> *"We were working closely with the guys in Salzburg on the analysis of our MRI sequences [for the knee] so we felt the need to compare our results… so yes, we sent each other a lot of scans, generally by email because it is nice and easy… but we also set up a [cloud-based synchronised storage solution] Dropbox particularly if the files were too big for emails or if there were too many"* (Interv_BE).

This quote illustrates the complexity, across the project, of the exchanges of both physical products and digital information, with, in certain instances, a required coupling of a digital representation with the physical resource being sent across, while at other times the sharing of electronic data on its own. Beyond the challenges imposed by the exchanges of physical materials highlighted earlier (see section 6.3), there were also a great number of constraints on the sharing of digital information that related to the experimental conditions of particular enquiry work, such as the difficulty to access specific technologies in certain lab conditions, or to the types and properties of the electronic files which could make it difficult for them to be sent across (e.g. large sizes or high volumes of files).

The co-managing of multiple intricate communications is probed next.

6.4.1 Handling multi-directional digital communications

It was made clear that emails remained the primary means of communication between the different partners and were perceived as the most direct and efficient way to address problems or exchange documentation. This was particularly prominent in the case of one-to-one communications between two different sites to address particular technical aspects, as illustrated here by the **MRI Physicist in Geneva**:

> *"We had regular exchanges of emails with Lausanne, as the work was proceeding… maybe once a week, perhaps more often when deadlines were getting closer. Sometimes more… I remember that at some point we were working under quite a lot of pressure and we had some technical issues as a batch of particles we received from Lausanne had different properties than expected… so there were quite a lot of emails between us and them to try to find out what the problem was…like we sent them our results of some of our tests to show them that something was not quite normal… so, they conducted more tests at their end to try to find out what it was… and then quickly they could sent us more data so that we could compare and try to find what the problem was*" (Interv_MRIP).

In a situation like the one described here, where regular interactions needed to occur to resolve specific problems, the exchange of emails appeared to be the *go-to solution* of choice. It is possibly because it is a well-established communication device that, in this situation, allowed the provision of rapid feedback from the team who was using the material to the site who produced it, and a swift response back from the partner who engineered the material. Not only did it enable both sides to react promptly but it also allowed them to send each other documents that were meaningful to both sides with regards to the specific problematic situation they found each other in and they tried to co-solve.

Other circumstances were reported in which emails did not appear to be such a useful communication channel but rather to be too overly cumbersome or invading. The issue of having to deal with an excessive number of emails was commented upon many times by a number of scientists, but it was explained that it was particularly problematic when a large number of documents were exchanged. The following two quotes, respectively from the **Bone Biologist in Geneva** and the **Biomechanics Engineer in Berlin**, illustrate these points.

> *"In a project of this size, you always get huge amount of emails and it makes it difficult to find you way around them. When they are emails between your lab and the two or three other labs with whom you are working closely on your experimental work that is fine. But when they are emails sent to the whole consortium or in which you have been copied for information then it gets tricky because you can't figure out which are relevant to you and which are not and you end up wasting lots of time"* (Interv_BB).

> *"The problem with emails is when people start sending each other lots of documents with multiple versions. Then it becomes a nightmare to find out which one is the latest versions or which changes have been made to a previous version. There is also when two slightly different versions are sent by two different people pretty much at the same time and you don't know which one to go for"* (Interv_BE)

If these comments point out issues of communication overload (rather typical with emails) and version control, these problems appeared to be amplified by the multi-sited nature of a project like NanoArth, as it was the stage for a complex mesh of unstructured multi-directional exchanges of both physical materials and digital documents. The **Scientific Coordinator** acknowledged these issues and the difficulty for the management team to address them:

> *"We have discussed many times in meetings the fact that the number of emails sent out is too high and the fact that it gets confusing for everyone… we have also talked about*

> *problems with document versions, particularly when we are close to a deadline and we are collectively putting together a report for our external partners… and the fact that not always the right people get the right documents… and that some people get too many documents that are not relevant to them… we are aware of these issues… but there doesn't seem to be an easy ready-made solution to address these"* (Interv_SC).

When probing these issues further, the need for a more targeted intra-site and inter-site communication approach was recognized. Ideas were formulated in the participatory learning exercise for a targeted way to exchange materials and supporting documentation. A number of these ideas are considered in chapter 7. Beyond the issues of ever proliferating electronic communications, the co-managing of exchanges of multi-types material is also explored.

6.4.2 Handling exchanges of combined physical and digital materials

It appeared that in certain cases, the dissemination of heterogeneous digital information directly associated with the exchange of physical goods was also quite problematic. As mentioned earlier, the posting of physical experimental materials tended to be supplemented by the electronic sending of digital documents to provide additional data on these materials, such as specific properties or behaviours (see previous section 6.4.1). Additional protocols to give instructions on storage conditions or manipulation methods were typically transmitted by email in parallel to the actual posting of the goods. There were also instances in which the hard copy of a document (e.g. a CofA, see section 6.2.3) might be included as part of the package containing the physical materials. At times, both a soft copy and a hard copy of a document were sent in parallel to the shipped items, the hard copy as part of the postage, the soft copy by email shortly afterwards. In other situations, if a digital probe was added as part of the package (see section 6.3.1), additional data from these was generated, such as temperature and moisture levels, and had to be downloaded and processed by the receiver. These multiple parallel exchanges of information (both digital and physical) were sometimes perceived as difficult to manage, as mentioned here by the **Bone Biologist in Geneva** who organised on many instances for some samples of nanoparticles to be sent to her from Lausanne:

> *"Sometimes it gets all a bit messy. I have to check the email I sent explaining what I was after, the sheet they posted with the sample and the email they sent me as well. And sometimes it is not the same. Particularly if the sample is not exactly what I wanted, and I have to ask for another one. Then more documents are sent and it all gets a bit confusing*" (Interv_BB).

This relationship between physical and electronic information about the samples gives an additional insight into the nature of the distributed experimental process. It is not simply that these experimental materials are things that can be used in the laboratory, but that they carry additional invisible layers of meaning that impact on their use – layers that will determine their use and the interpretations that can be made from their use in experimental conditions. Cross-referencing information on these samples is understandably complex, and recording mixed media content over digital records and across various peoples' lab books can prove practically difficult to co-ordinate and reassemble in the production of scientifically legitimate empirical work.

6.4.3 Summary of findings

The section has highlighted the practices and challenges around the exchanges of both digital and physical materials that are an integral part of the distributed experimental process. The results are summarised in table 6.3.

Section 6.4: Multiple communications & multi-material exchanges		*Area: Multi-type Exchanges*
	Work practices and associated meanings	Issues, difficulties and challenges
Multi-directional digital communications	• Predominant use of emails for rapid feedback on materials sent and problem-solving. • Need for more targeted communication approach.	• Issue of excessive complexity of email-supported digital exchanges. • Issue of email overload and resulting interferences. • Issue of excessive proliferation of docs & perceived lack of relevance.
Exchanges of combined physical and digital materials	• Complex exchanges of both physical and digital products with coupling on certain instances. • Experimental materials carry additional invisible layers of meaning.	• Difficulty to manage duality of physical and digital information can lead to data inconsistencies. • Issue of excessive proliferation of multi-material exchanges.

Table 6.3: Summary of findings on multi-type material exchanges

The logging of scientific data as experimental work is being undertaken *at the bench* in distributed settings, and the role of the lab book information artefact to support the logging and the co-conduct of distributed operations, are considered next.

6.5 Logging scientific work *in situ*

An essential aspect of scientific enquiry work for any scientist involved in conducting experimental activities is the capturing of precious information *on the fly* about what is actually happening as the experiment is unfolding. This is often seen as crucial by the scientific practitioner, whether the work they are undertaking is taking place in a lab, at a computer terminal, or in a hospital ward with patients. The following sections explore the practices of logging scientific work in the settings of the NanoArth project, the different media used for, or in place of, the lab book artefact, and a number of issues that emerged in relation to these utilisations.

6.5.1 Recording scientific data in the lab book

To log the details of scientific enquiries, a laboratory book tends to be used. In essence, the lab book, which is traditionally in paper format, is used by experimenters to keep a record of a wide range of specifics relevant to the experimental work that is being undertaken. These can include events that occur during the experiment, intermediate experimental results, preliminary analysis, thoughts for future experimental trials, issues and errors, or reflections on experimental validity (Klokmose & Zander, 2010).

During our empirical study, it was observed directly, and discussed with many of the participants from the NanoArth project, that a wide variety of practices were relied upon to keep a record of the elements of the experimental work which were significant to them as the experimental operations were being performed. It appeared that the form the lab book took and the way it was actively used in the field varied greatly depending on the scientists, the experimental tasks to be undertaken, the experimental setup and the ways in which this experimental work connected with others' work.

A number of recommendations exist, (e.g. Ebel et al., 2004), that call for lab books to be highly-structured paper-based repositories of a scientist's activities which should be used *in-situ* to make a permanent and meticulous record of the experimental procedures. These cover a wide variety of heterogeneous information, as mentioned above, such as practical experimental techniques, raw thoughts and observations, research hypotheses or initial findings. With regards to the NanoArth project, such an expectation of use appeared to be an especial concern for senior researchers and members of the project management team, as reported here by the **Project Manager**:

> *"All the partners involved should use the same lab notebook with the same format to record everything they do. It is a requirement for our project."* (Interv_PM).

However, it was established in our study of NanoArth that the use of lab books, and the values that they hold, appear in part to contradict this, and in many instances the lab book was not restricted to this one-dimensional, highly-structured physical medium. Lab books clearly encompassed different meanings for different people and different contexts, as their use varied greatly across laboratories and sites. In some ways, the term *lab book* would appear to be more like a metaphor for the sum of recorded experimental documentation, rather than the unique, personal, structured record of a researcher's activities that is alluded to in the research methods literature.

The sections that follow examine how the researchers describe the ways in which they log their scientific activities, the manner in which they create, maintain, utilise, value, and find problems with the lab books or the related media they use, and how these logging practices are embedded within the design and conduct of scientific enquiry work.

6.5.2 Immediacy and media availability

Many of the scientists and technicians reported capturing raw information relevant to the operations they were performing on a range of different media. These were typically paper-based and consisted of rough papers, sticky notes and labels, printouts (often annotated), scrapbooks, notepads, or a variety of combinations of these, as illustrated by the **Nanoparticles and Reactor Engineer in Lausanne**:

> *"As I am doing an experiment, I tend to write things down to keep a record of what is happening… it can be an observation, a quick sketch, calibration levels on a machine, preliminary results or the fact that something is not quite right… Personally, I tend to write stuff on whatever I have on the bench at the time where I am doing my experiment… it can be the lab book but I feel that this is a bit permanent… so I prefer writing on a loose sheet or scrap notebook… sometimes I type stuff down on a document or on the spreadsheet on the computer attached to the machine I am using"* (PartObs_NRE_2).

The commonly used media for *in-situ* documentation of the experimental procedures tended to be those that were 'to hand' at the time of use, in an environment that was often poorly populated with recording materials to select from. The use of such physical media can be easily justified by the constraints of the environment in which the experimental work often took place. For instance, conditions in a wet laboratory, where volatile chemicals, materials or biological matters are handled, or laboratory requirements to avoid contamination (Li et al., 2012) can impact on the types of media that might be used. On the other hand, if a machine was connected to a computer system, the scientists found it easier to log enquiry data on the terminal immediately available there, as part of the experimental setup. They typically entered snippets or data on a Word processing file or a spreadsheet, to rapidly capture what was going on. In many instances, the value that these unstructured media held for the experimenters was not always immediately apparent to them, yet at the same time they recognised that they *might* have potential value. Often, this cost-benefit dilemma was not possible to immediately resolve, and as a consequence, the information on these media failed to make the transition to a more formally recorded format.

> *"It makes it a bit difficult to formally report on the work that I do in the official lab book, I have to admit. I have bits of information in lots of different places and putting it all together can be a bit tricky… sometimes I forget some of the stuff because I cannot quite remember on which bit of paper or file or where I wrote it or whether I saved it somewhere"* (Part_Obs_NRE2).

Nevertheless, these data items were generally considered by respondents to require archiving, often with some further limited annotation to contextualise and make sense of the circumstances of their collection, as related by the **Bone Biologist in Geneva**:

> *"I tend to take notes on loose sheets and sticky notes and then I insert them in the lab book to help me remember the exact circumstances of the observation I am making or what exactly I was doing when I made that comment. I write down the name of the experiment and the date and time when it was taking place on the sheet or sticky notes so that when I stick it inside the lab book, I know what it is referring to"* (Interv_BB).

To aid recall and reuse, snippets of data needed to be stored with other content collected at the same time, some of which might be in a different medium. This fragmented data often stored on mixed media could lead to difficulties in indexing and cataloguing content, not all of which could easily be formed into the common format of lab notebook promoted by the NanoArth project manager quoted above. Working on different experimental units simultaneously could create further confusion. Experimenters sometimes retrieved data from a range of sources where they had stored it previously, but they found it difficult to relate it to the particular unit of experimental work or experiment. The organisational structure of the lab book is discussed next.

6.5.3 Structure and utility

Despite these difficulties in recording and collating experimental information, the structure of recorded material would appear to carry a great importance with many of the researchers interviewed. The project management team tried to promote a specific uniform format for the lab book for greater consistency (see section 6.5.1), based on a paper-based lab book in which the scientists could date and time their experimental attempts. Some researchers explained that they did not adopt it because they preferred using their own personalised looser approach to logging. On the other hand, some experimenters chose to use the recommended highly-structured permanently bound notebook with numbered pages and the possibility to enter dates and times. This is an approach adopted by the **Nanoparticles Developer in Lausanne**:

> *"I use the recommended lab book in which I record everything that is happening. For every assay or test I create a new entry and I write down the date and time. Then I take a note of all the things that I do, of the problems that I have and the thoughts that come to me as I am doing the work; everything that I think may be useful later*" (PartObs_ND_2).

What is interesting in this structured approach is that the lab book can be referenced like a *scientific diary* in which the activities that are performed are systematically entered as the experiment is progressing. This thus provides a chronological and quasi-permanent record of the immediate observations and insights made by the researcher in action, but one that can accommodate different types of observations or content. However, the constraints of such a direct approach to structuring content can also be perceived as too difficult to manage by other researchers or too impractical. This is a viewpoint expressed by the **Bone Biologist in Geneva** who decided to move away from using a hard notebook:

> "*I used to keep one main structured lab book but things became too complicated as I am doing too many things for too many people. It is impossible to have one lab book to record everything when you are involved in so many different projects. So now I try to keep separated lab books for separated projects but even that makes it difficult to maintain"* (Interv_BB).

Such a comment about the practical problems in recording lab notes for activities carried out quasi-concurrently across multiple research projects is revealing about the difficulties faced in making a single lab record. Scientists that carry out many different activities or are accountable to different funders may find it restricting to adopt a rigid time-based organisational strategy to document their activities. This was particularly the case for researchers involved in one or more scientific projects running in parallel and for which they had to perform unrelated experimental tasks, like for the Bone Biologist just quoted above, and for her direct collaborator **in Geneva**, the **MRI Physicist**:

> *"I want to keep together the things that are relevant to each other. So, I write things on sheets of paper and then I file them together for everything concerning a specific part of the project"* (Interv_MRIP).

For these two participants, a form of categorisation of the data logged was considered. However, a single record of their lab-based activities carries little relevance for their work, and organising their observations and activities in a project-based or thematic manner allowed for a more practically useful approach.

For those who decided not to adopt the format recommended by the management team, the selection of the approach adopted to log and organise the description of the researcher's scientific activity appeared to be very personal. It depended on the actual experimental activities *at the bench* and the conditions in which these activities were undertaken, as illustrated by the **Nanomaterial Scientist in Lausanne**:

> *"The experiments I conduct are simulations of nanomaterials based on a series of tests on the computer that require a huge amount of data. I have set up my own wiki-based lab book to record the parameters I use as I am running these tests"* (Interv_NS).

The fact that the experimental activities carried out by this nanomaterial scientist consisted of a series of computer-based simulation tests justified her choice to record digitally the required data on a web-based platform on the same computer system as the one used for the simulation tests, for immediacy and convenience. An online system based on a wiki was selected by this experimenter primarily because of the ease-of-use, flexibility and portability that this platform allows. The ability for her to tailor it to her needs and the ways she could smoothly integrate it in her scientific practice made it a very attractive solution:

> "*I created my own wiki lab book because I could get something up-and-running in no time that would be pretty easy for me to use. And I can add bits to it when I need to. The other thing is that I can access it from pretty much anywhere I want. Sometimes I need to use the other computer to do some of the simulations. I can open my wiki lab book there and record what I need*" (Interv_NS).

In contrast to this way of operating dictated by very particular circumstances (i.e. the running of computer simulations), a very different experimental setup led to the selection of a very different medium to capture the data *on the fly*. In co-operation with her partners in Lund and Salzburg, the **Biomechanics Engineer in Berlin** ran a series of nine pre-designed identical MRI measurement sequences on a number of patients with knee disorders to scan their knee cartilages and ligaments in order to get an overview of the clinical processes related to cartilage degradation (see section 5.4.3). This would have to be done at two different time points, approximately two years apart, to compare the results. Samples of blood, serum and urine were also taken from the subjects in an attempt to correlate subsequently the levels of biomarkers with the damage of the cartilage:

> *"When we get the patients in to do the measurements, we use patient lists and we record data against each patient. We write down things like the times of the different scans and also that the samples have been taken from them. Sometimes we write additional comments like things that we want to remember about a particular patient, things that come up while we are doing the measurements"* (Interv_BE).

In this case, the nature of an experimental setup that required for a large number of measurements to be taken with real patients in a short amount of time called for a pre-designed information artefact (the patient list) to be used alongside a more traditional lab book, as the latter participant explained:

> *"I also use my lab book to write things on the day when the measurements are taking place about the actual experiment as a whole, like the date and time and the settings we used"* (Interv_BE).

This illustrates another instance of the somehow fragmented nature of the experimental data being collected as the experimental activities were being conducted, where part of the data could be recorded in a location while other information was logged somewhere else.

Whatever the experimental setup was and whatever different ways to capture raw experimental data were used *in situ*, the logging of experimental activities as they unfolded was generally followed and completed by a stage during which the captured data was transcribed, structured, and organised in a meaningful way. This record would then take a different sense, allowing for a reflective practice, over a different timescale and for a different audience: the project funders and the corporations that might be interested in upscaling the work from pre-clinical to clinical stages, possibly towards commercialisation.

6.5.4 Summary of findings

The practices in relation to the logging of scientific work *at the bench* has been explored. The lab book took artefact multiple shapes, formats and structures in the settings of the NanoArth project and the values ascribed to it by the experimenters greatly varied. The results are summarised in table 6.4. For further illustrative purposes, the photo in figure 6.3 shows the hard-bound lab book used by the Nanoparticles Developer on her lab bench in Lausanne, during the participant observation coded PartObs_ND_2 in February 2013.

Figure 6.3: Nanoparticles Developer's lab book on her bench in Lausanne

Section 6.5: Logging the conduct of scientific work		***Area: Experimental Logging***
	Work practices and associated meanings	**Issues, difficulties and challenges**
Recording scientific data	• Essential to capture details of enquiry work as they happen. • Traditionally, use of a structured lab book. • Uniform, hard, bounded lab book with page numbers and entries for date and times recommended by management.	• Approach recommended by management not always adopted.
Immediacy & media availability	• In practice, scientists often use of resources at-hand when conducting experimental work. • Lab book metaphor for different ways to collect information. • Use of annotations to contextualise information.	• Diversity in practices to record significant elements of experimental work. • Constraints of the research environment restrict types of media that can be used to log experimental data. • Issue of the fragmentation of experimental data collected on a range of heterogeneous media. • Difficulties in indexing and cataloguing due to fragmented use of media.
Structure & utility	• Deliberate selection of a structured lab book approach by a number of researchers to provide chronological and semi-permanent record, generalizable across topics and media • Approach selected to log experimental data depends on type of activities conducted. • Use of different information artefacts simultaneously to log data.	• Difficulties in complying with formal format of traditional lab book for a number of researchers. • Issue of rigidity of one given structural format for the lab book i.e. chronological vs. thematic particularly with regards to multiple concurrent activities. • Issue of fragmented nature of collected experimental data which makes scientific interpretation difficult.

Table 6.4: Summary of findings on the logging of scientific work

6.6 Chapter conclusion: a cluster of information artefacts for supporting activities

The analytical account in this chapter has identified and examined the practices and challenges involved in the organisation, conduct and support of scientific work in the

NanoArth project, particularly in regard to the managing of complex exchanges of physical and digital experimental materials and the logging and collating of experimental data. It has shed light on the roles of key information artefacts to support these practices (the material log for managing the exchanges and the lab book for logging data) and explored the ways additional practices and standardised artefacts (RoA values, PTTs and CofAs) are used and integrated together, with varying levels of acceptance.

The process of synthesising nanomaterials at one site and supplying it to others was thoroughly examined. A methodical process was put in place to ensure consistency and quality, based on the production of reference batches and secondary batches to derive RoA values. Characterisations and toxicity tests were conducted at different stages and documented systematically. Standardised CofAs were sent along nanosynthesis protocols to guarantee the quality of the nanomaterials supplied and provide them with additional awareness on the production process.

A standardised and centralised material log was introduced to record and track all exchanges of physical experimental materials with a view to enhance transparency and traceability. Its adoption by scientists was sometimes seen as a challenge and issues were raised in regard to its perceived lack of flexibility, increased workload and disruptive effect on already existing practices.

The experimental data logging practices in place across NanoArth were diverse and relied on a range of approaches and media. The uniform lab book recommended by management was accepted by some researchers, who used it as a *scientific diary*, but not adopted by all partners, as issues were raised in relation to its perceived rigidity, in terms of structure and the difficulty to integrate its use in existing practices. The values held by the lab book depended on the experimental design and this in turn influenced the approach and media selected by the scientists to log their data *in situ.*

Chapter 7 Synthesis and implications

7.1 Chapter introduction

The purpose of this chapter is to bring together the various findings that have emerged from the multi-method multi-sited empirical study and to unpack insights from the rich descriptions presented in the analytical account in the two previous chapters of the interactions, exchanges, co-ordinative practices, and utilisations of information artefacts to support these practices. Thus, the aim of this chapter is to provide a meaningful synthesis to the empirical work: it seeks to construct a better theoretical understanding of the mediating roles played by the web of interconnected practices and information artefacts in intensely distributed scientific work and, from this, to inform the design of a range of digital co-ordinative technologies to support the mediating roles of these artefacts.

Initially, this synthesis chapter develops a theoretical explanation of how the interactions between the co-operating scientists involved in intensely distributed experimental work can be supported by the co-ordinated design and interlinked utilisations of three key information artefacts: the *experimental protocol*, the *lab book* and the *material log*. It constructs an understanding of the meanings (from an interactionist perspective) ascribed to these artefacts by the scientists who co-design and use them collectively. It also aims produces a number of abstracted representations to explain how their joint utilisations assist with the sharing of scientific content and mediate interactions between scientist to ultimately support the co-ordination of their actions.

Subsequently, this section presents a theoretical framework that draws and extends the symbolic interactionist notion of *sensitising concept*. The framework identifies several *sensitising tensions* as salient features of intensely distributed work and key interactional strategies that the scientists in global cross-disciplinary settings need to manage. These tensions are then used to suggest practical approaches for the design of interactive technologies to support the co-ordination of intensely distributed scientific activities. Several implications for design and practice are discussed developing from this framework.

7.2 Supporting experimental design & validation

This section focuses on the interactions enabled by the use of the experimental protocol (EP) in conjunction with the lab book (LB) and shows how these interactions steer the experimental design and validation process. We contend that the experimental protocol and the lab book forms an *EP/LB co-ordinative unit* insofar as their joint utilisations enable key social interactions between distributed scientists to support the co-design and co-validation of experimental work locally and across sites.

7.2.1 The co-ordinative role of the experimental protocol

The analytical account in chapters 5 and 6 has highlighted that designing, developing and maintaining the experimental protocol was a dynamic process that both shaped and was shaped by the co-ordinative practices involved in the design and conduct of experimental work. The nature of the nanoscientific work in NanoArth was highly exploratory and relied on interdependent scientific work arrangements (Schmidt, 1991) that were both localised and distributed, prone to frequent changes of directions and frequent *tinkering* (Knorr Cetina, 1981a) or *bricolage* (Jouvenet, 2007; Lynch & Woolgar, 1988), and influenced by diverging organisational setups (Jirotka et al., 2006), *epistemic cultures* (Knorr-Cetina, 1999; 2007) and disciplinary modes of operating. These characteristics appear to have a direct effect on the ways the experimental protocol is dynamically planned, designed, structured, formatted, named and standardised; all things that have themselves an effect on the way intensely distributed nanoscience is done.

The analysis of our empirical study has shown that a draft protocol was first produced, then tested, in conjunction with the use of the lab book, then adjusted, then shared so that it is tested by another scientist and/or in a different experimental setup, then improved, and eventually sent to another part of the project to inform their experimental design (see section 5.4). Thus, the analysis shows that the meaning given to the protocol by the experimenter is not one of a permanent repository of procedural information and experimental stipulations.

Rather, it takes the meaning of a dynamic artefact that is co-designed, co-operatively tested on multiple instances and in many different conditions, subsequently adapted and refined, and eventually finalised and archived. It is seen by experimenters as an ever-evolving artefact that gets continually and collectively developed until it reaches a somehow permanent state. Therefore, a parallel can be drawn between the experimental protocol as an information artefact that needs to be continuously (re)developed to accommodate the local circumstances and handle contingencies (i.e. *to make it work*) and a *plan* of work that needs to be constantly rethought and redesigned (Redaelli & Carassa, 2015), through a process of continuous adjustment (Bardram & Hansen, 2010 a; 2010b). In this sense, the experimental protocol can be viewed as a *dynamic plan* that is used to stipulate experimental activities in ever changing environments (Redaelli & Carassa, 2015).

We further contend that the experimental protocol in global cross-disciplinary settings, like in the NanoArth project, plays the role of a *coordination mechanism* (Schmidt & Simone, 1996). Whatever the complexity of the distributed and interdependent experimental work setup is, the protocol encapsulates standard procedures and working arrangements that can be used to disseminate continuously updated experimental information across space, time and co-operating partners to enable the co-ordination of their actions (Bossen & Markussen, 2010). The analytical descriptions show that its structural features (through its naming, versioning and structuring using a template, see section 5.3) can help provide a precomputation of task interdependencies that can be used by all to reduce the complexity of the articulation required by these distributed activities (ibid.). This applies to whether the experimental arrangement is co-located, or whether it is distributed and requires either flexible or tight co-ordination (see section 5.4). However, owing to the distributed, cross-disciplinary and yet contingent nature of the nanoscientific work under consideration, it is not possible to have a *one-size-fits all* format and structure of the experimental protocol, where the protocol is simply a rigid script that stipulates a sequence of tasks to be completed in a prescriptive manner (Bardram & Bossen, 2005; Bossen & Markussen, 2010). Rather the meaning collectively given to the protocol, in an interactionist sense, is more one of a *map* that is used to orient the scientific work for others by displaying various instantiations of an experimental procedure and thus providing an overview of the state of execution of the procedure so that partners can interconnect their own work with these instantiations across space and time (Bossen & Foss, 2016).

7.2.2 The multiple forms of the lab book

The analytical account has also shown that the lab book can take different forms for different researchers as the ways it is utilised vary greatly across teams, laboratories, and sites (see section 6.5). A number of researchers tended to favour a highly structured physical medium to capture relevant experimental information *on the fly*, as they highly valued the chronological recording and semi-permanence that this type of approach affords. The management of the project was very much inclined to promote this particular line, as reported in the analytical account, as they saw the use of a uniform and highly structured laboratory notebook across the consortium as providing greater transparency. Some experimenters followed these recommendations, while others adopted their own personal combination of loose papers, notepads, sticky labels or digital documents on whatever personal computer was available in the settings in which the experiments took place. Selecting their own approach to log scientific data provided them with a required flexibility to fit with the nature of their experimental work and structure the capturing of experimental details in the way that suited them best. Thus, the lab book can be viewed as the best suited user-centred representation of the different ways of logging experimental information (documenting manipulations, observations and results), when designing and conducting experimental work at the bench.

Looking at the lab book from an interactionist perspective, we suggest that the value held by this artefact for the scientists emanates from its utilisation in co-operative work endeavours with others and that this value is continuously modified based on the social interactions that they engage in with others. When used individually or in a co-located setting, the lab book essentially takes the value of a repository that assists with the *offloading* (Salomon, 1993) of thoughts and ideas as experiments are being conducted. As the researcher is testing their experimental design at the bench (as stipulated by an experimental protocol), the lab book is relied upon to capture meaningful details of the experimental procedure *on the fly*, so that they can *offload* immediately the key observations, results, intuitions, or interpretations that come to them as they are manipulating experimental materials. Subsequently, it can also be used to support a process of *reflection* after the experiment, away from the bench, to allow the experimenter to review their work and add reflective comments (Roubert & Perry, 2013). Furthermore, we contend that when it is used as part of a co-operative experimental work arrangement, in conjunction with the experimental protocol artefact, the lab book is also ascribed a co-ordinative value and plays a key role in supporting the social distribution and articulation of experimental activities. It is the latter use that the next section explores.

7.2.3 Interactional practices supported by the EP/LB dyad

We contend in this research that that it is the combined use of the protocol with the lab book artefact that enables several key social interactions within an intensely distributed setting that are essential to the co-ordination of the design, conduct and validation of scientific work. The analysis has shown that the protocol is used to both stipulate and orient the experimental design for others, while the lab book is relied upon to capture and interpret *in situ* relevant information about the conduct of the scientific operations specified in the experimental protocol. When used in conjunction, we maintain that they form an *EP/LB dyad* (i.e. an Experimental Protocol / Lab Book two-component unit) that supports a system of *interactional practices* (Welsh et al., 2006) to help the co-ordination of action for experimental design and experimental validation.

Figure 7.1 provides an abstracted representation of these interactional practices around the design and validation of experimental work in a distributed setup as afforded by the combined utilisations of the protocol and the lab book. It is an abstraction of the various exchanges of information (capturing, sending, retrieving and monitoring) enabled by the joint use of these two information artefacts (Star, 2003) that emerged from the empirical study of the scientists' activities and the scientific practices they facilitate in relation to experimental design and validation. It intends to be a simple rendering of what we make out to be typical utilisations of different instances of lab books when designing and validating protocol-led experimental design in distributed settings.

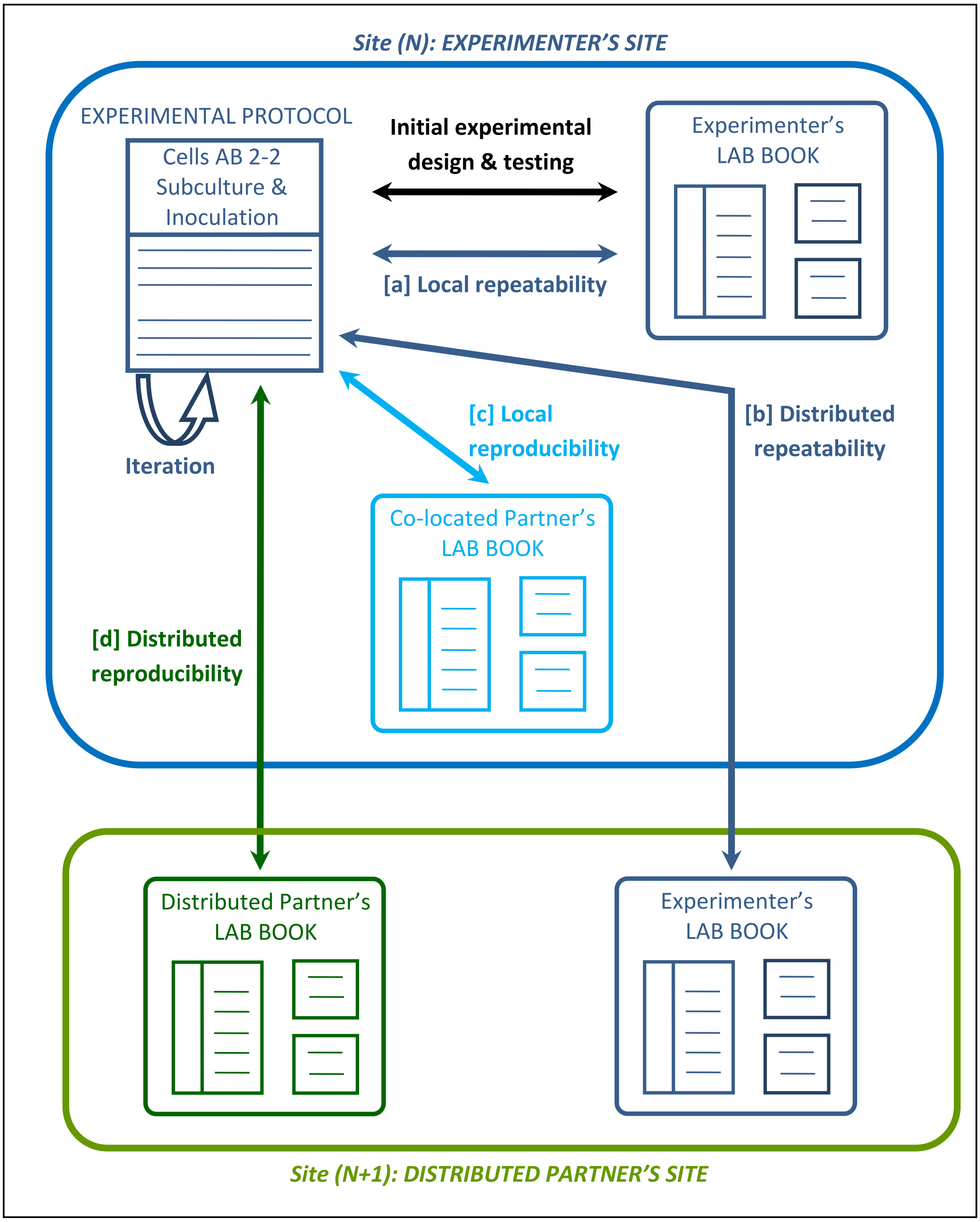


Figure 7.1: Abstraction of interactional practices supported by the EP/LB dyad

Figure 7.1 illustrates various interconnected utilisations of a protocol iteratively designed by an experimenter with several instances of a laboratory book:

- the lab book of a scientist who creates and develops a protocol (top right-hand corner and bottom right hand corner) at a site (N);
- the lab book of one of their co-located partners, who works at the same site (N) (centre);
- the lab book of one of their distributed partners, who operates at a different site (N+1) (bottom left-hand corner)

The lab books are shown as a collection of heterogeneous media to illustrate the fact that they can be instantiated by different types of artefacts (e.g. notebook, sticky notes, loose sheets, digital spreadsheets on a computer) to allow the scientists to capture experimental information at the bench *on the fly* as the experiment is being carried out.

The analytical account has shown that the protocol-driven experimental design is highly iterative (represented on the diagram with a circular iteration arrow right under the protocol), and tightly integrated with experimental validation (see section 5.5). An experimental procedure is continuously modified, re-thought, and re-defined until it achieves a certain level of stability, and thus until the protocol that instantiates this procedure is stable (Bossen & Foss, 2016). This continuous experimental re-design process is the result of constant experimental validation at the heart of the scientific method (Betz, 2011). We suggest in our study that in intensely distributed settings, the multiple interconnections (in the sense of the interchange of information that their usage support) between the use of the lab books from different experimenters and the experimental protocol enables experimental validation that goes further than in purely co-located conditions. We contend that the combined use of the protocol and different instances of the lab book support the conduct of four different types of experimental validation (as represented by the double arrows in figure 7.1): [a] *local repeatability*, [b] *distributed repeatability*, [c] *local reproducibility* and [d] *distributed reproducibility*. These in turn result in the continuous change of state of the protocol and thus drive the iterative re-design of an experimental activity until the state of the protocol, is sufficiently stable. We examine these four different types of validation in greater detail below.

[a] Local repeatability

Initially, the scientist operating at a site (N) comes up with a draft protocol that gives an initial overview of the experimental work to be conducted (top left-hand corner of figure 7.1). The protocol specifies the necessary resources to be used and the experimental operations to be undertaken. The experimenter then tests their experimental procedure by running the experiment in the conditions of the lab available to them at site (N), at the time of the experiment. They use the lab book (or some material available at hand) to make notes and thoroughly document the actual process of running the experiment and thus testing the protocol (top right-hand corner of figure 7.1). The scientists may rely on different *lab book media* (of their own choice) to capture a wide range of information, such as details of the actual tasks they carry out, observations they make, preliminary results, things that work and aspects that do not work., etc. Their lab book plays a key role here in assisting with that *tinkering* (Knorr Cetina, 1981a) or *bricolage* (Jouvenet, 2007; Lynch & Woolgar, 1988) process described on many instances by the participants as absolutely crucial in *making the protocol work,* i.e. in adapting it to the local circumstances. Thus, the protocol may be updated, i.e. change state several times, to reflect the reality of the local situation before it becomes fairly stable. This process of adjustment of the protocol is supported by carefully considering the details captured in the lab book during each run of the experimental procedure.

It was reported in the analytical account that, at this stage, a local validation process is systematically undertaken by the leading experimenter (see section 5.5.1). The scientist authoring the protocol tests locally for the *repeatability* of their own experimental work (and thus of their experimental protocol) to ensure that the experimental procedure produces similar results when run multiple times in identical lab conditions. Repeatability is considered a cornerstone of the scientific method and thus it is seen by experimenting scientists as key to conducting scientific enquiry work thoroughly (Benestad & Laake, 2007), as reported by the participants in our study of NanoArth (c.f. section 5.5.1 for details). The validation of their own experimental work in their own lab conditions, referred to as *local repeatability* in the thesis, is mediated by the utilisation of their own lab book. The lab book is relied upon to document any possible variations between the experimental operations and expected results as specified on the protocols, on the one hand, and the actual experimental manipulations performed locally at the bench, and the real results produced from running those, on the other. These variations may in turn lead to the adjusting and editing of the protocol to improve the quality of the experimental design, as several procedural iterations are undertaken, and thus to multiple changes in the state for the protocol, and this until a certain level of local stability is attained. This parallel use of the protocol and the lab book is denoted in figure 7.1 by the double arrow [a] to illustrate how the changes made to the experimental procedure result in another running of the experiment (documented in the lab book) and how the logging of data about the experimental manipulations, observations and interpretations in the lab book, as the experiment is run, leads in turn to adjustments being made to the protocol and thus to the state of the protocol being changed.

[b] Distributed repeatability

On occasions, the opportunity may arise for the scientist to test and validate the designed experimental procedure defined on the protocol at a different site (N+1), the site of a partner with whom they co-operate. This can be the case particularly if the experimental work conducted by a scientist at a site (N) is highly interdependent with the one taking place at the second site (N+1), as reported on several instances in the analytical account (see sections 5.4.2 and 5.4.3). If the practical conditions allow it (e.g. the close proximity between the two sites), the experimenter who devises the experimental procedure may have the chance to directly test it at the site (N+1) of their co-operators (particularly if the co-operators have a direct interest in the procedure for their own experimental work). The purpose of running the experiment stipulated by a protocol in a partner's lab can then be two-fold: (i) verifying that the experiment is sound and produces comparable results in different lab conditions, and (ii) directly showing the experimental operations to the partners, if they are involved in the same experimental work arrangement. The process of testing a protocol on multiple instances at a different site extends the initial validation of *local repeatability* to what is labelled in this thesis as *distributed repeatability*. It is also supported by the iterative design of the protocol initiated by the experimenter from site (N), as complemented by the use of their own lab book at their co-operator's site (N+1), to capture the changes and variations that need to be made to the experiment to then update the protocol accordingly. The joint use of the experimenter's protocol and their lab book remotely at site (N+1) is illustrated by the double arrow [b] in figure 7.1 to denote that changes made to one artefact are reflected by changes made to the other one, and *vice versa*.

[c] Local reproducibility

In an intensely distributed setting, the experimental design process often involves more than one scientist creating and validating a protocol. The analysis of our study has shown that this can be either because the experimental design has been set up in a way that it relies on interdependent activities between scientists operating on different sites (see sections 5.4.2 and 5.4.3), or it could be that the experimental work is undertaken locally in the lab by a group of scientists with complementary skills (see section 5.4.1). Then, the scientist behind a protocol may want to find out whether the written experimental procedure can be run by someone else and still produce similar results. The ability for an experiment to be *reproducible,* i.e. to still produce the same results when undertaken by another individual, is also regarded by scientists as essential to the scientific method, and as a key step to ensure the quality of experimental design (Benestad & Laake, 2007). Thus *reproducibility*, like *repeatability* mentioned earlier, is ascribed an essential meaning by all experimenters as part of scientific enquiry work. However, the analytical account shows that *reproducibility* appears to be verified a lot less systematically than *repeatability* and that while many experimenters saw it as essential, others appeared to engage with it to a lesser extent (see section 5.5.2). This can be related to the practicalities of the experimental work, and the perceived difficulties of having someone else carry out the work, if it is not considered appropriate, particularly if the researcher is very specialised and works autonomously. It can also be due to tight time constraints that may impede the involvement of a partner in the verification of an experimental procedure. Hence, it appears that in most cases, the reproducibility testing is performed locally, on an ad-hoc basis, insofar as the leading experimenter at site (N) prompts a co-located team member to run the protocol to see if its outcomes are comparable. In this process, the protocol may be further adjusted as reproducibility is tested locally by the experimenter's direct collaborator. The variations resulting from the actual testing are documented in the lab book of the collaborator, in this case, and can then be fed back to the main experimenter to enable them to modify and improve the protocol being tested. The parallel utilisations of the experimenter's protocol and their partner’s lab book to support this experimental validation, labelled as *local reproducibility* in this thesis, is shown by the double arrow [c] in figure 7.1. The arrow again denotes the interplay between the experimental protocol and the lab book, and the respective changes in state that take place for both as they are used jointly in this validation process.

[d] Distributed reproducibility

The last type of validation, *distributed reproducibility*, denotes the capacity of a protocol to stipulate an experimental procedure that can be undertaken by another individual but in a different setup (i.e. site (N+1)) and still to yield similar results. The extent to which *distributed reproducibility* may be verified depends largely on the nature of the interdependence between the parties involved in a particular unit of experimental work. It was reported in our empirical study that in cases where similar experimental work run in parallel at two different sites for comparison purposes, and that once the scientists from both sites have become familiar with each other’s work, then the researchers at one site may ask their counterparts to test how reproducible their experiments are (see section 5.4.3).

For distributed reproducibility, we argue that it is the interplay between the protocol initiated by the first experimenter (i.e. at site (N)) and the lab book of their distributed partner (i.e. at site (N+1)) that support the interactions that allow for this type of validation to be verified. Upon request by the researcher who initiated the experimental activity at site (N), the collaborator may run the experiment several times in their own lab at site (N+1), with their own material, and equipment and document the process in their own lab book to determine whether the protocol leads to a set of results that are comparable to the results produced when run in the initiator’s lab. By making notes in their own lab book and sharing their thoughts on the testing of the protocol based on these notes, the remote partner provides the protocol’s author with useful information to allow for the latter to modify and improve their written procedure, and thus lead to changes in the state of the protocol until it becomes stable. This is shown in figure 7.1 to illustrate the interconnected utilisations of the protocol and the remote partner’s lab book.

This detailed examination of the ways in which the protocol and lab book are used and maintained jointly across sites to support experimental validation leads to the characterisation of the EP/LB ordering dyad, discussed next.

7.2.4 The EP/LB ordering dyad

The extent to which the four types of experimental validation aforementioned are implemented may vary greatly, depending on the actual nature of the experimental work, the degree of interdependence between experimental activities (co-located or distributed, with flexible or tight co-ordination) and the practical constraints associated to these experimental work arrangements. The analysis of our study pointed out that these variations were in fact considered problematic by the management team, as they were greatly concerned with harmonising different validation practices across the project consortium (see section 5.6). This thesis suggests that the exchange of scientific content afforded by the EP/LB dyad supports a set of co-ordinative practices that assist co-operative work by facilitating articulation work needed to align the different work trajectories required by distributed experimental design and experimental validation. Therefore, this set of co-ordinative practices combined with the artefacts that support and enable them can be viewed as an *ordering dyad*, as inspired by the concept of *ordering system* explored in section 2.3.3 (Schmidt & Wagner, 2004). In line with this notion of ordering system, we suggest that the interactions enabled by the *EP/LB ordering dyad* could be supported through the design of interactive digital technologies, so that the combined use of both artefacts can be configured to assist with the distributed design and validation of experimental work.

The abstracted representation of this *ordering dyad* (as shown in figure 7.1) aims to provide a better theoretical understanding of how the use of the experimental protocol and the lab book information artefacts are combined and integrated with and within a set of practices to facilitate the co-ordination of experimental design and validation activities. This perspective and the understanding it produces has relevance to both the scientists in the labs as well as representatives of management to help them have a more holistic view of these integrated practices and hopefully enhance them across the project. We see in fact this EP/LB ordering dyad as being part of a larger ordering system that mediates a more complex set of interactions around, not only the design and validation of experimental work, but also the actual management of the conduct of experimental work, which includes the organisation of exchanges of experimental materials and the logging of experimental data. This larger co-ordinative cluster is considered next.

7.3 The EP/LB/ML co-ordinative cluster

The analysis of our study of NanoArth has shown that in the settings of intensely distributed nanoscience, researchers also need to organise the synthesis, distribution and sharing of experimental materials as an integral part of designing, conducting and validating experimental work and to manage key information in relation to the sharing of materials (see sections 6.2 and 6.3). In the NanoArth project, the exchanges of materials between sites could be somewhat complex, as illustrated on the diagram in figure 6.1. We contend in this thesis that it is the integration of the experimental protocol (EP) and the lab book (LB) with the material log (ML), that plays a key role in supporting the co-ordination of intensely distributed experimental work. When used together, these three information artefacts form a *EP/LB/ML co-ordinative cluster* (i.e. an experimental protocol / lab book / material log co-ordinative unit) that allows *a system of exchange of scientific content* that supports the *interactional practices* needed to articulate the various dimensions of distributed scientific enquiry work, as identified by the seven key thematic areas of concern used to frame the analysis: (1) *Experimental Design*, (2) *Experimental Validation*, (3) *Experimental Quality*, (4) *Experimental Material Distribution*, (5) *Experimental Material Exchanges*, (6) *Multi-type Exchanges,* and (7) *Experimental Logging* (see section 5.1).

This section closely examines the interconnected utilisations of these three key information artefacts – the protocol, the lab book and the material log – in the settings of intensely distributed experimental work. This discussion seeks to develop a better understanding of how they are used together to mediate the social interactions and allow the sharing of key scientific content between the scientists who co-design, co-conduct, and co-validate their experimental activities and manage the synthesis, distribution and exchanges of nanomaterials and other experimental materials to assist with these activities. Ultimately, it aims to better understand how these artefact-mediated interactions help co-ordinate the various work trajectories in intensely distributed co-operative work settings to integrate their practices and achieve concerted action, so that to explore ways to design interactive solutions that can better support this integration.

Figure 7.2 shows an abstracted diagrammatic representation of the exchanges of nanoscientific information mediated by the interlinked utilisations of several instances of the key information artefacts to support the *interactional practices* of distributed scientists operating across three sites:

- Site (S) (right-hand side) where a team synthesises the nanomaterials and distributes them to the other sites for their experimental work;
- Site (N) (top left-hand corner) where an experimenter and their team conduct experimental work that relies on the nanomaterials supplied by the site (S);
- Site (N+1) (bottom left-hand corner) where a distributed partner and their team undertake experimental activities that are interdependent with those carried out at site (N) and that rely on experimental materials sent by site (N) and by nanomaterials sent by site (S).

The aim of figure 7.2 is to abstract from the empirical findings the ways in which scientists at these three remotes sites organise their work collectively, and how they use these artefacts in interconnection to record, retrieve, edit, share, track and monitor the scientific information they require to co-ordinate their efforts and achieve common action. It aims to provide a simple rendering of what we have identified as typical relationships between the utilisations of different types of artefacts across different organisations and different sites. These relationships do not intend to be generalisable to all projects; rather they seek to capture what we see as happening typically in multi-sited arrangements. The next section discusses this system of exchange of scientific content supported by the interconnections between the cross-site utilisations of instances of the three identified information artefacts.

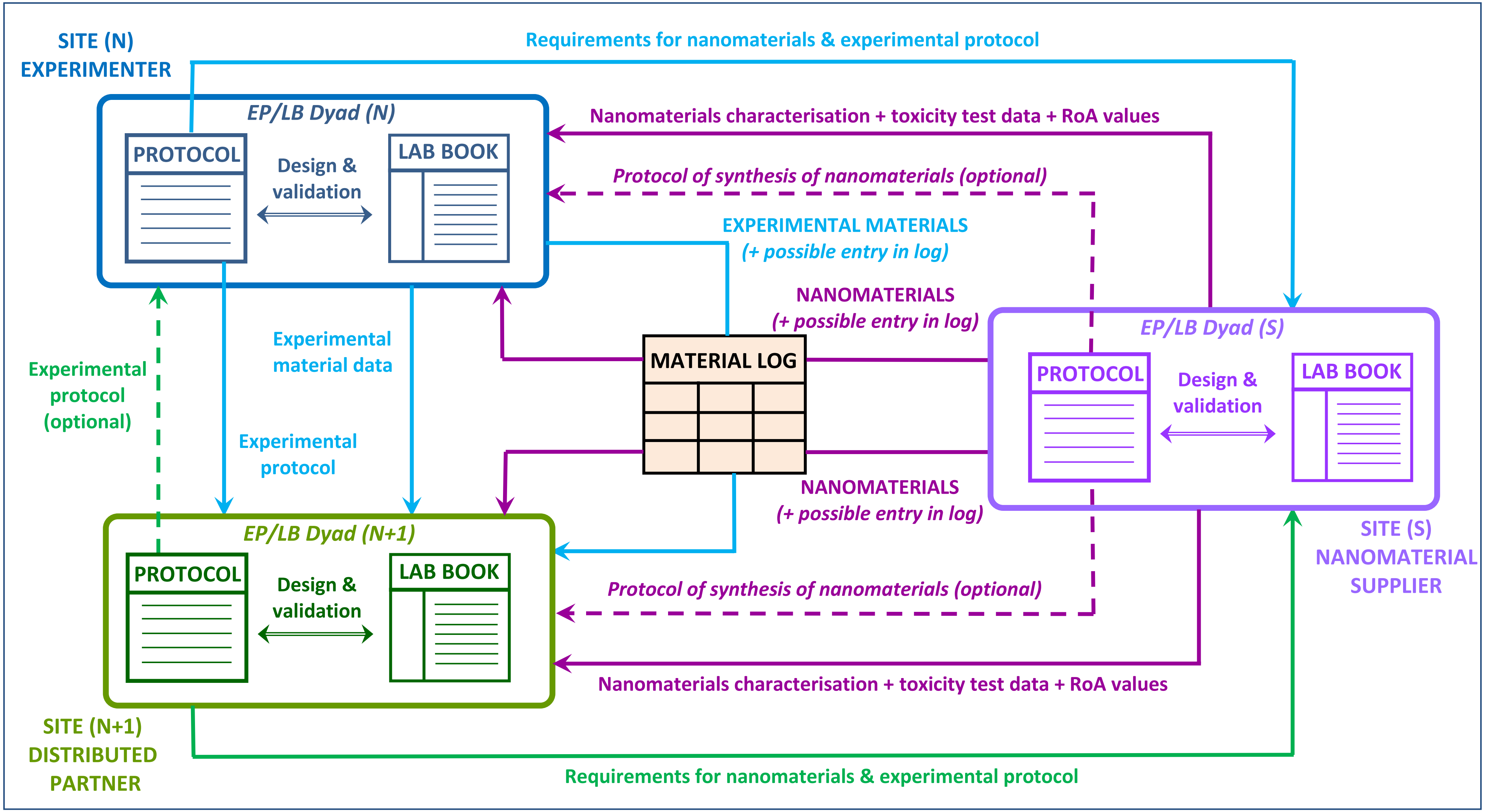


Figure 7.2: Abstraction of the system of exchange of scientific content supported by the EP/LB/ML cluster

7.4 Supporting experimental conduct

The following sections seek to unpack this complex *system of exchange of scientific content* enabled by the integrated utilisations of the protocol, lab book and material log, and to explain their precise roles as information artefacts in capturing, retrieving, editing, sharing, tracking, and monitoring key scientific data needed to articulate co-operator's nanoscientific activities. Based on the abstraction of the artefact-mediated system of exchange of scientific content (see figure 7.2), the ensuing discussion is concerned with dissecting how the protocol, the lab book, and the material log are used together to manage the complex co-deign and co-conduct of experimental work across sites by supporting the sharing of key information about the actual experimental operations and procedures to be undertaken collectively. The respective roles of each of the three sites in our abstraction are discussed first.

7.4.1 Site roles and work arrangements

The site (S) (S for Supplier) is an abstraction of the site that probes how to synthesise nanomaterials that can be supplied to consortium partners and fulfil their experimental requirements. Thus, in our abstraction, the site (S) is the locus of experimental work concerned with the research, development and processing of specific nanomaterials so that they can be used by scientists at other sites for their own experimental work. On the other hand, the sites (N) and (N+1) represent two research sites of the project consortium that are engaged in a co-operative work arrangement with each other and with the site (S). This means that in this abstraction there are a number of distributed scientific work arrangements that involve the teams at site (N), (N+1) and (S), and that the experimental activities at each site are interdependent with those taking place at the other sites. Consequently, many social interactions, communications, exchange of data and of physical materials may take place between the scientists in the different labs involved in these work arrangements. In order to better characterise these various experimental work ensembles, we provide an abstracted categorisation of the different types of distributed experimental work arrangements that may occur in intensely distributed scientific settings, like the NanoArth project. These are derived from our analysis (see section 5.4) and are presented in table 7.1.

Experimental work arrangement	*Indicative characterisation and typical description*	*Identified example in NanoArth*
Multi-sited & flexibly co-ordinated	Main experimental work at single site. Experimental materials required by other sites and/or experimental activities at main site interdependent with experimental design that take place at other sites. Typically, not overly constraining need for timely alignment of tasks with other sites.	In-vitro toxicity tests in rheumatology department in Berlin to evaluate impact of nanoparticles on survival functions and differentiation of immune cells. Requires synthesis of nanomaterials and experimental know-how from Lausanne with regards to nanomaterials
Multi-sited & tightly co-ordinated with sequential components	Experimental work distributed between various sites and/or experimental activities at a site interdependent with activities at other sites following a certain sequence. Experimental materials required from multiple sites and may be passed onto another site as part of sequence of experimental activities.	Study of the effects of nanoparticles on stem cells in rheumatology department in Berlin followed by tracking of these stem cells in rodents using MRI techniques in radiology unit in Geneva.
Multi-sited & tightly co-ordinated with parallel components	Experimental work distributed between various sites and/or experimental activities at each site interdependent with a number of experimental activities being undertaken in parallel at multiple sites. Experimental materials required from multiple sites and may be passed onto multiple sites which conduct parallel activities.	Evaluation of clinical processes related to cartilage degradation over time through: (1) function measurements using MRI techniques at musculoskeletal centre in Berlin; (2) volume measurements using MRI techniques at musculoskeletal institute in Salzburg; (3) biomarkers measurements at rheumatology and skeletal biology lab in Lund.

Table 7.1: Abstracted categorisation of different types of experimental work arrangements

It is to be noted that the different types of distributed experimental arrangement presented in table 7.1 are in no way exhaustive or intended to be completely generalisable. They just seek to capture and represent what we suggest are various ways in which experimental design and experimental activities can be distributed between a number of sites operating as part of a large cross-disciplinary project. Furthermore, these arrangement types are non-mutually exclusive, can overlap, and can be combined in a number of ways. For instance, it is entirely possible for a multi-sited and tightly co-ordinated experimental work arrangement to have both components organised in an interdependent sequence, while other components run in parallel. As an example, we identified that in NanoArth, the scientific study conducted in the rheumatology department in Berlin on the ways nanoparticles can affect stem cells was followed sequentially by two studies running in parallel: the imaging of stem cells in rats at the Imaging Unit in Geneva and the imaging of stem cells in mice at the Rheumatology Department in Nimjegen (Netherlands).

For the purpose of the abstraction that we present in figure 7.2, and in an attempt to provide an illustrative representation of the key interactional practices probed in the empirical study of NanoArth (and of the ways artefacts help the sharing of scientific information in an intensely distributed setup), a combination of co-operative experimental work arrangements is considered. In this abstraction, both sites (N) and (N+1) are involved respectively in cross-sited experimental work arrangements with site (S) that requires flexible co-ordination. The experimental activities at site (N) and site (N+1), respectively, depend on the experimental work conducted at site (S) that explores the possible development and synthesis of nanomaterials. The interdependence of experimental activities between site (N) and site (S) is *flexibly co-ordinated*, insofar as the work is designed and conducted at site (N) makes direct use of the nanomaterials synthesised at site (S) (and benefits from the know-how of the researchers at site (S) to develop the tailored nanomaterials), without the articulation of activities between the two sites being overly constrained by time. The same applies with regards to the interdependence between the experimental work at site (N+1) and at site (S).

In contrast, in our abstraction, the co-operative work arrangement bringing together site (N) and site (N+1) relies on tighter co-ordination insofar as the experimental work is completely distributed between site (N+1) and site (N), and the timing of the exchanges of both information and physical materials between the two sites is a key factor in the experimental co-design laid out across the two sites. Thus, site (N+1) not only requires information and material from site (S) but also needs to link up with site (N) to undertake its enquiry work, as it needs information and/or materials from site (N). It is to be noted that, despite what the naming of sites (N+1) and (N) may imply, the actual setup of experimental activities between them is not necessarily sequential, and that some experimental activities can be conducted in parallel, or that there might be a combination of both sequential and parallel experimental activities. To sum up, the enquiry work running at site (N) depends mainly on the experimental design at site (S) (*flexibly co-ordinated*) while the enquiry work at site (N+1) depends on the experimental design at site (S) (*loosely co-ordinated*) and on the experimental design at site (N) (*tightly co-ordinated, with sequential and/or parallel components*). Thus, our abstraction considers various combinations of experimental arrangements.

The next sub-section discusses the role of the experimental protocol information artefact in the settings of our abstraction.

7.4.2 Sharing protocols to support awareness

Referring to the abstraction presented in figure 7.2, at each site, every researcher manages their experimental design by iteratively developing a protocol and uses their lab book to record data about the various stages of validation of the protocol (see section 7.2). This is illustrated in figure 7.2 by the representation of the EP / LB dyad at every site (S), (N) and (N+1). The double arrow between the protocol and the lab book denotes that a change of content in one artefact results in the content being modified in the other, and the other way around (see section 7.2.3).

The design of scientific enquiry work at site (N) (and at site (N+1)) is very closely related to the experimental work that takes place at site (S) since the team at site (S) looks to find ways to synthesise, characterise and functionalise nanomaterials to be used by the team at site (N). Hence, the experimental work at site (N) is typically co-designed with the one at site (S) as part of a *flexibly co-ordinated* distributed multi-sited work arrangement, as mentioned previously. Right from the start of a work package, when drafting their initial protocol, the experimenters at site (N) set up a number of exchanges with their counterparts at site (S) to outline common ground and initiate the negotiations that subsequently steer their experimental co-design (see section 5.4.2). Continuous negotiations have often been recognised in STS as playing a major role in this type of co-operative scientific work arrangements (Collins, 1991; Latour & Woolgar, 1986; Knorr Cetina, 1981a; 1995). The exchanges of protocols for experimental work co-designed and co-developed across sites (and thus of procedural content imprinted on these protocols) subsequently help define and shape the negotiating interactions that are continually held between the different co-operating parties to work together. Typically, when the scientists on a site (N) feel that they have a workable protocol (that requires nanoparticles from site (S)), they tend to send it to site (S) to provide them with background and context information and an initial idea of their experimental work. This can help the partners at site (S) define the direction of their own enquiry work to help them synthesise, characterise and functionalise the right type of nanoparticles to best support the experimental work at site (N). We argue that the sharing of this initial protocol can be seen as a way to provide the team who generates the nanomaterials a sense of *task awareness* (Gutwin et al., 1996), i.e. an understanding of the purpose of the experimental work at site (N) that relies on the produced materials, the goals and requirements of this experimental work and an idea of how this experimental work fits into the larger plan.

As the researchers at site (S) design and test their own experimental protocol to explore the possibility to engineer nanomaterials that can satisfy the needs of the experimental work at site (N), negotiating interactions continue to take place to refine the *requirements for nanomaterials*, i.e. a description of the specific properties of the nanomaterials sought after by site (N) for their experimental design. As these continuous negotiations are held to find a common ground, the protocol authored at site (N) is repeatedly edited and adapted to be *made to work* with the nanomaterials that can be engineered by the team at site (S). Many different versions of the protocol authored at site (N) can be sent to site (S) so that the experimental procedure imprinted on that protocol can help guide the engineering of suitable nanomaterials at site (S) (see light blue arrow at the top of figure 7.2). In this sense, we suggest that the protocol iteratively (re-)designed at site (N) is sent across multiple times so that to allow their partners at site (S) to track the changes that are made to the design of the experimental procedure and thus support *asynchronous change awareness* (see section 2.2.4 and Schumann et al., 2013; Tam & Greenberg, 2006).

Conversely, various versions of the protocol developed at site (S) to engineer, characterise, and functionalise specific nanomaterials required by a site (N) may be sent to the team at site (N) (see section 5.4.2). This is represented in figure 7.2 by a dotted line between site (S) and site (N) to indicate the more ‘optional’ nature of this exchange of content. The sharing of protocols from site (S) to site (N) typically happens on a more ad-hoc and informal basis. Usually, when the synthesising scientists becomes more confident of the stability of their experimental nanosynthesis protocol, they may send it to their partners at site (N) (more regularly so as the level of familiarity between the two sites increases). Even though it can be argued that the scientists at site (N) may not need to know all the specifics of the investigatory work that produced the particles, we suggest that the purpose of this sharing is for the nanomaterials developers at site (S) to give their co-operators who use the produced nanomaterials a sense of what the manufacturing process entails. Therefore, the sending of the synthesis protocol (which may occur at various stages of the nanoengineering process and/or at the end with the nanomaterials themselves, their characterisations and toxicity test data) can play a role in providing what can be referred to as *process awareness* (Kusunoki et al., 2014). This means that, in addition to the characterisation (that describes the properties of the nanomaterials), and the toxicity test data (that gives information about their toxicity levels), the nanosynthesis protocol is used as an information artefact to give the scientists who are using them an understanding of the different methods and techniques used to produce the materials. We suggest that, from a symbolic interactionist understanding, this protocol is attributed the meaning of a document able to give a sense of the ‘overall story’ i.e. of the full experimental development process with a view to provide material users with a complete understanding of the materials they will be handling in their own work.

We could also conjecture that this system of interchanges of protocols at different stages of their development between site (S) and site (N) (or site (N+1)) may also provide an awareness of *shared intentionality* (the understanding of each other’s goals in relation to one’s own goals in the experimental co-design and the common objective of the co-design, see section 2.24), and thus support *we-awareness* (Greenberg & Gutwin, 2016; Tenenberg et al., 2016).

The ways in which protocols both stipulate experimental operations and assist with negotiations is considered next.

7.4.3 Protocols as boundary negotiating objects & boundary specifying objects

In intensely distributed cross-disciplinary settings, the scientists at site (N) (and site (N+1)) may be working in very different disciplinary areas than those at site (S) who engineers materials for them. For instance, the scientific work in NanoArth project required the complex engineering, characterisation and functionalisation of nanomaterials with specific contrasting properties. Our analysis showed that this necessitated the development of innovative methods at the Materials & Powder Lab in Lausanne to enable the synthesis, coating, characterisation and toxicity testing of these nanomaterials, and that this complex work involved a material chemist, a biochemist, a cell biologist, an informatics engineer and a reactor engineer (see section 6.2). On the other hand, as illustrated in figure 6.1, the scientists who utilised the nanomaterials in their enquiry work (i.e. at sites (N) and (N+1) in our abstraction) worked in a wide range of institutions (including radiology services, musculoskeletal centres, rheumatology units, departments of medicines, biotechnology providers, pharmaceutical companies and nanotechnology R&D firms) and thus in a variety of different disciplines and may come from very different *epistemic cultures* (Knorr Cetina, 1999; 2007).

We maintain that the protocol plays a key role as an information artefact that is used to define common ground between heterogeneous work arrangements and to bridge across different work practices. As discussed in the previous section, the scientists at site (N) may send experimental protocols in different states of completion to the suppliers of nanomaterials at site (S) to make them aware of where they are with their experimental investigation, while the researchers who engineer the nanomaterials may share different versions of their nanosynthesis protocol with the experimenters who use them to inform them of the current state of the nanomanufacturing process. Hence, we suggest here that these draft versions of not yet stable experimental protocols are used as *boundary negotiating objects* (Pennington, 2010) as they help support negotiating interactions to continuously articulate the respective working practices and create co-operation spaces between scientists with different disciplinary expertise (see section 2.5.3). The experimental protocol helps the scientists producing the nanomaterials, or those using them, consider the experimental co-design from the other party’s viewpoint, and thus help create the conceptual connections which allow them to align their experimental procedures. As the “recursive mediation and negotiation processes” (ibid., p.193) lead to more stable experimental procedures, scientists at site (N) (or site (N+1)) and at site (S) exchange procedural content through the sharing of protocols that have reached more stable states, which allows both teams to conduct and validate their experimental work locally knowing that it is now reasonably well aligned with their counterpart’s enquiry work. Thus, it suggested that both sets of stabilised experimental protocols are used as *boundary specifying objects* (ibid.), that can help create a common field of work in which both parties can work independently, yet in synergy, on their respective experimental work, so as to integrate it with one another.

The next section focuses on the co-ordinative role of the experimental protocol.

7.4.4 Protocols as coordination mechanisms

In an attempt to widen the field of application of the abstraction presented in this section, the distributed work arrangement between site (N) and (N+1) considered next allows for a more tightly co-ordinated experimental co-design and co-development. The experimental activities designed at site (N+1) are interdependent with those at site (N) in a time-critical manner: their timings need to be carefully aligned with the timings of the activities at site (N), as defined when planning the work package and breaking it down in a number of experimental units. As explained in section 7.4.1, the activities at site (N+1) can be running either in parallel or sequentially with those at site (N), or the experimental setup may require a combination of both. Therefore, the scientists co-designing experimental enquiries need to engage in complex *articulation work* (Strauss, 1985; Gerson & Star, 1986; Schmidt & Bannon, 1992) both locally within their lab as well as across sites to align the work trajectories of the different co-operating parties so that their efforts can be integrated to produce meaningful results (see section 2.2.4). This involves carefully developing and managing the interconnections between the various tasks and subtasks which make up the activities of the distributed experimental work arrangement, as well as allocating actors, materials, and equipment to these tasks and subtasks to ensure that these interconnections are defined (Bossen & Foss, 2016).

We contend that the exchange of procedural content between sites (N) and (N+1) afforded by the sharing of various versions of protocols on which the experimental procedures are inscribed is what provided the required *coordination mechanism* (Schmidt & Simone, 1996) to support the required articulation work both locally and across sites (see section 2.3.2). The experimental protocol is used *in-situ* on site (N) and (N+1) to help assemble the necessary resources, i.e. the required materials and equipment, to accomplish and validate the task locally and to ensure that any arising contingencies can be handled to improve the experimental procedure. In this sense, it is used internally at the site where the experimental work is conducted to assist with *local articulation* (Gerson, 2008) between different co-located co-operators. Besides, it also plays a key role in supporting *metawork* (ibid.) across sites, i.e. the work that needs to be undertaken to align and integrate units of experimental work between the different teams involved in the distributed experimental work arrangement.

The sending of the experimental protocol from the scientist on site (N) to their partner on site (N+1), who needs it to closely align their work with the specifications that appear on it, is done in a rather systematic manner. The tightly co-ordinated nature of the co-operative arrangement tends to lead to a scientist authoring a protocol to send it to their partners whose work closely depends on it. A solid blue arrow from site (N) to site (N+1) labelled "Experimental protocol" illustrates this exchange in figure 7.2. On the other hand, we think that the scientists on site (N+1) may also want to share their protocol with their partners on site (N) to make them aware of their own experimental setup, as indicated by the dashed 'optional' blue arrow from site (N+1) to site (N) in figure 7.2. Thus, we suggest that the interchange of procedural content between sites, through the sharing of various versions of protocols in both directions, help inform the other team(s) of the changes being made continuously to the experimental procedure to steer what needs to be done to organise, manage and monitor the respective activities to align them with those of their counterparts across sites. Timely access to the other party's ever-changing states of their operating procedures is critical, particularly as the co-operative arrangement requires tight co-ordination. Accessing others' continuously modified protocols helps identify who has the right skills, commitment and availability, and who is accountable in the distributed experimental arrangement, as well as the different tasks and actions already undertaken and those to be undertaken. Having this access also assists with identifying which informational resources is available and can be interacted with, which material and technical resources are available and their properties, and which logistical facilities are at disposal and their characteristics. In summary, this interchange of continuously evolving states of operating procedures supports the different components of *articulation work* i.e. articulation with regards to *actors, responsibilities, tasks, activities,* and *resources* (Schmidt, 1994).

7.4.5 The sociomateriality of the protocol

When applying a sociomaterial lens (see section 2.5.4), we posit that the experimental protocol can be regarded as an artefact that is sociomaterially configured as part of the distributed co-operative arrangement between the three sites (S), (N), and (N+1) of our abstraction, as described in section 7.3. In this view the protocol is not a monolithic stable object through which co-operation is enabled or constrained, but rather an integral component of the distributed co-operative arrangement between the three sites. It is being continually (re)configured as part of the experimental co-design setup between sites (N) and site (N+1), when verifying for repeatability and reproducibility (see section 7.2), but also as part of the complex system of interchanges of experimental information and materials that involve all three sites. We suggest that these continuous reconfigurations shape communications and scientific content sharing between the three parties, which in turn effects the way experimental activities are designed and conducted at their respective locations, and thus influence the collective action and direction of the co-operative scientific enterprise. This illustrates what the proponents of sociomateriality refer to as the “constitutive entanglement between the social and the material” (Orlikowski, 2007; p.1437). In short, the capacity of use of the protocol is shaped by the contingent ways in which it is designed, maintained and configured in practice. Its coordinative ability is entangled with the choices scientists make with the way they engage with experimental work, individually at the bench or co-operatively with their distributed partners (Orlikowski, 2007; 2009).

Our abstraction of the exchange of scientific content afforded by the relationships between information artefacts also takes into consideration how the exchanges of materials are organised and co-ordinated to support the conduct of distributed experimental work. This is discussed next.

7.5 Supporting the sharing of experimental materials

The sharing of experimental material between co-operating sites is an integral part of a global intensely distributed scientific project, like NanoArth. The complex nature of the nanodiagnostics problem in the NanoArth project required the setting up of multi-sited cross-disciplinary experimental work arrangements and the organisation of multiple flows of exchanges of experimental materials between the partners taking part in these arrangements (see figure 6.1). The empirical study of NanoArth has shown that the exchange of materials between teams co-operating across sites was essentially driven by the interdependence between their experimental activities as defined by the details of the co-operative scientific work arrangements across multiple sites (see section 6.3). What also became apparent is that these exchanges were not restricted to just physical materials, but that a wide range of heterogeneous information was shared in parallel with the materials, such as descriptions, properties, storage conditions, instructions for manipulation or toxicity levels. In fact, the analysis of our study has uncovered a wide variety of practices and issues in relation to managing these exchanges of physical experimental materials and supporting information, as well as a wide array of interactions and negotiations between the distributed actors to organise and monitor these complex exchanges (see section 6.4). These are summarised in tables 6.1, 6.2 and 6.3.

As far as our abstraction is concerned (see figure 7.2), the sharing of materials is organised and managed iteratively through a series of artefact-mediated interactions as the co-operative scientific investigation is developed progressively from an initial idea, all the way to a set of relatively stable experimental protocols that have been validated. We suggest that these interactions are essentially mediated by the integrated utilisations of the lab book, the protocol and the material log information artefacts as part of the co-design and co-conduct of experimental work in distributed settings. These exchanges of physical materials are also complemented by complex multi-directional sharing of other heterogeneous information artefacts that convey key information on the materials sent across sites, e.g. characterisation documents, toxicity test data sheets and CofAs. These complex multi-artefact exchanges are examined in the next sections.

7.5.1 Exchanges of materials and challenges

In the abstraction of the sharing of scientific content mediated by the three information artefacts (see figure 7.2), the exchanges of experimental materials occur essentially between the supplier site (S) and the experimenting sites (N) and (N+1) (essentially nanomaterials) and between the sites (N) and (N+1) (any other materials). When abstracting an exchange of experimental material, for instance between site (N) and (N+1), information relevant to the material is typically collated and compiled from one or more entries in the lab book of the scientist who has undertaken experimental with this material on site (N) and who organises the sending of the material across to their partner on site (N+1). These can include descriptions of the material samples, characterisations, and toxicity data, instructions for storage and manipulations, and any other comments or observations that might be required. This information is typically sent to the partner on site (N+1) via email, but can also be physically enclosed with the posted samples, usual as a hard copy, or sometimes digitally using electronic devices like probes (see section 6.3.1). This flow of information is illustrated in figure 7.2 by the solid blue arrow between sites (N) and (N+1) labelled “experimental material data”.

What emerged from the analysis of our study of NanoArth is that, for the most parts, the exchanges of materials and additional content across the various research sites in that project seem to be rather unstructured and fraught with a number of difficulties and challenges (see tables 6.2 and 6.3). In NanoArth, the organisation of these exchanges was mainly negotiated, set up, and monitored in a specific way by each pair of sites which are involved in a distributed experimental co-design arrangement. This implies that each pair of co-operating sites found their own ways to work out and define the terms of their own arrangements to manage the sharing of both physical and digital materials. However, if this tailoring of the sharing of materials gave the flexibility to each pairs of collaborating teams to organise the exchanges of materials in a manner that suited them best, it made it very difficult for those teams involved in multiple arrangements to manage several complex exchanges, each with their own approaches. A number of instances of errors were highlighted in relation to the handling of multiple complex multimodal exchanges of heterogeneous materials i.e. exchanges of various materials, that rely on different types media to assist them, such as emails or the use of digital probes, to provide additional content associated with the physical materials (see tables 6.2 and 6.3).

In the NanoArth project, a number of solutions, from which we can learn, were devised to address the issues of the fragmentation of the sharing of physical and digital experimental materials across sites and are discussed in the following sections, in relation to NanoArth but also in relation to our abstraction. They involved the use of additional informational artefacts relied upon to mediate the sharing of content and the interactions between the co-operating partners to collectively organise, manage, and monitor the interchange of materials. It is to be noted that, however, these initiatives tended to be driven mostly by the management steering group who was concerned with ensuring that practices were being aligned across the various consortium members so that activities could be monitored and that any arising issues could be dealt with swiftly. These solutions were adopted by the scientists with varying degrees of acceptance, as shown in the upcoming discussion.

7.5.2 Central role of the material log

The primary motivation behind the introduction of a centralised digital material log accessible to all partners of the NanoArth project was the eagerness of management to encourage the systematic recording of all exchanges of materials to facilitate the monitoring of exchanges. In our abstraction of the artefact-mediated exchanges of scientific content in figure 7.2, the material log information artefact is shown right at the centre.

When reflecting on the role of the material log for the different parties involved in the exchange of content in this abstraction from an interactionist perspective, we argue that, for management, this information artefact holds the value of of an efficient *coordination mechanism*. For members of the management team, it has been introduced as a standardised procedural tool instantiated by a central artefact to harmonise local practices (that differ across sites) in a coherent manner (Schmidt & Simone, 1996). From their point of view, the material log supports *articulation with regards to material resources* (Schmidt, 1994), i.e. it provides the scientists involved in distributed experimental work arrangements a straightforward process to log and standardise all the exchanges of experimental materials they handle, with a view to ensure consistency between local practices. But also, it is for management a mechanism to monitor the potential changes in practices and track the repercussions these may have on the interlinking of activities, with a view to enforce accountability (Redaelli & Carassa, 2015).

As far as the scientists in the labs are concerned, the material log can also be seen as a useful repository of information that supports both the offloading (for a sender) and easy retrieval (for a receiver) of data about exchanged experimental materials and a helpful point of reference to track these exchanges and support their articulation. Yet, we argue that the interactionist meaning they ascribe to the material log may be one of an overly constraining control device. The scientists can see the material log as an intrusive tool to track their activities in an intrusive manner, whereas they highly value the flexibility to organise exchanges between themselves informally without feeling they are being checked on continually.

The organisation of the exchanges of experimental materials, particularly those that were critical to the conduct of distributed experimental work, could be complemented by the use of additional information artefacts, as considered next.

7.5.3 Integrated use of other standardised information artefacts

Other artefact-based initiatives to introduce more consistency and standardisation in the ways materials are shared were introduced in the NanoArth project. Our analysis has shown that the Materials & Powder Lab in Lausanne, which was involved in the highest volumes of transactions with the other members of the NanoArth consortium (see figure 6.1), adopted standardised initiatives to harmonise the ways they manage their distribution of nanomaterials, and the sharing of associated information. This was motivated by the challenges they faced when having to engineer, upon request and after negotiation, different types of nanomaterials that could fulfil the requirements of a wide array of partners. These requirements could evolve as negotiations unfolded and a common ground between the parties was identified. To make matters even more complex, the materials they synthesised at the nano-scale had properties and behaviours that could change over time.

As part of our study of NanoArth, a number of participatory learning exercises were conducted to define standardised methods and techniques to support the synthesis, characterisation, functionalisation, and sending of the nanomaterials to the consortium partners and minimise the risks of nanotoxicity (see section 4.4.6). The development of a *master batch* and *initial batches* of nanoparticles led to the definition of RoA values that were used as standard to accept or reject subsequent batches. *Preliminary toxicity tests* were introduced at different points in times to ensure nanosafety (i.e. the safety of the synthesised nanomaterials). Characterisation and toxicity data along with RoAs were collated in a CofA artefact that was systematically sent in parallel to the particles, with sometimes the nanosynthesis protocol, for additional *process awareness* (Kusunoki et al., 2014) and increased safety.

When relating this to our abstraction, we represent how these artefact-based standardised practices can be integrated with the ones of the protocol, the lab book and the material log in figure 7.2. As the nanomaterials are sent between site (S) and site (N), an entry is typically made in the material log. In parallel, a characterisation document, PTT sheet and RoA values (that could be all compiled in one CofA document) may be sent electronically and/or in printed version with the shipped nanomaterials (Roubert et al., 2016). These may be used as a point of reference for the scientist on site (N) to get a precise description of the materials they have received and that they are going to use in their own experimental work. The sending of this information from site (S) to site (N) (or site (N+1)) is represented by solid purple arrows while the sending of the nanosynthesis protocols are illustrated with dotted purple arrows in figure 7.2.

7.5.4 The EP/LB/ML cluster as an ordering system

We posit that the sharing of content enabled by the interlinked utilisations of the protocol, the lab book and the material log (potentially assisted by several additional artefacts discussed above) supports a set co-ordinative practices that allow the integration of the work activities towards the common goal of an intensely distributed project. Building on the definition of the EP/LB *ordering dyad* in section 7.2.4, we argue that the cluster of co-ordinative practices together with the supporting information artefacts can be viewed as a *scientific ordering system*. It draws on Schmidt's *ordering systems* CSCW framework (Schmidt & Wagner, 2004), insofar as it models a cluster of interconnected co-ordinative artefacts and practices that afford a number of interactions that allow the scientists to organise, manage, and articulate their experimental activities (see section 2.3.3 for more information on ordering systems). Thus, it describes an artefact-centric view of distributed co-ordination (Cabitza & Simone, 2013) in that it focuses on how a number of interconnected information artefacts play the role of *coordination mechanisms* (Schmidt & Simone, 1996) that are used to help researchers integrate their distributed experimental work trajectories in a coherent manner with a view to achieve concerted action.

We suggest that this construct of *scientific ordering system* provides a useful lens to understand how scientific co-ordination in intensely distributed and cross-disciplinary settings can be supported through the design of supportive interactive technologies as it can help us to think about ways to design computational technologies that facilitate the articulation of distributed activities.

7.5.5 The EP/LB/ML cluster as part of a sociomaterial assemblage

Another way to look at the EP/LB/ML cluster is offered by the proponents of sociomateriality in organisation studies (see section 2.5.4). From a sociomaterial perspective the protocol, the lab book and the material log information artefacts can be regarded as an integral part of the sociomaterial assemblage that is set up to co-ordinate distributed scientific activities in global cross-disciplinary projects. This sociomaterial assemblage involves the co-operating students designing and adapting the materialities of these three artefacts to enact the co-ordination of their activities. Expressed differently, the co-ordination of distributed scientific activities can be viewed as a sociomaterial assemblage that is dynamic, relational, situated in everyday practices and enacted by particular configurations of the EP/LB/ML cluster of artefacts (Orlikowski, 2009). These configurations define various ways scientific content can be shared between distributed partners to emphasise specific practices and knowledge, and thus have specific effects on the interactions between co-operating scientists to align and integrate their practices co-ordinatively (Alcadipani & Islam, 2017).

A theoretical framework based on the findings in this section, and implications for design and practice, are considered next.

7.6 Sensitising tensions and implications

From the rich data uncovered in the multi-method multi-sited empirical study of NanoArth, and from the abstraction of how the exchange of scientific content and material mediated by the use of information artefacts support interactional and co-ordinative practices in intensely distributed settings, a number of *sensitising tensions* have been identified and are discussed in this section. The construct of *sensitising tensions* draws on, and extends, the symbolic interactionist notion of *sensitising concepts* (Blumer, 1954; Menzies, 1982). In the interactionist perspective, *sensitising concepts* denote concepts that emerge from the analysis of practices and help focus the attention on specific aspects to describe a range of ways in which social interactions help produce interpretations of the activities and meanings essential to the co-operating actors.

The *sensitising tensions* we put forward here represent a number of key dimensions, structured as a series of tensions between key concerns for intensely distributed scientists. They look to identify salient features of intensely distributed scientific work that emerged from the analysis of the NanoArth project and from the abstractions presented in this chapter, and to which, in our view, the scientists ascribe a great deal of meaning and need to manage in global multi-sited settings. Essentially, the *sensitising tensions* that we propose in this research intend to capture a number of key *interactional strategies* that we think the scientists have to continuously manage to conduct and co-ordinate distributed scientific activities through the artefact-mediated interactions examined in section 7.3. Notably, they are also meant to be seen by technology designers as guiding devices to think of ways to create digital representations to support the design of supportive co-ordination mechanisms, and by practitioners to think of ways in which distributed co-operative work arrangements can be (re)configured to support the achievement of co-ordinated action. Therefore, in line with the design-oriented perspective of ethnography adopted here (see section 3.6) which can help sensitise designers and practitioners to features of work (Perry, 2009), these *sensitising tensions* are used to inform a number of implications for the design of interactive co-ordinative artefacts and for the practice of co-ordinating intensely distributed scientific work.

7.6.1 Sensitising tensions to inform design and practice

The *sensitising tensions* have emerged from the analysis of our empirical study of NanoArth presented in chapter 5 and 6 and from the discussion on the abstractions of the artefact-mediated exchange of scientific content discussed in this chapter so far. These sensitising tensions are represented in figure 7.3.

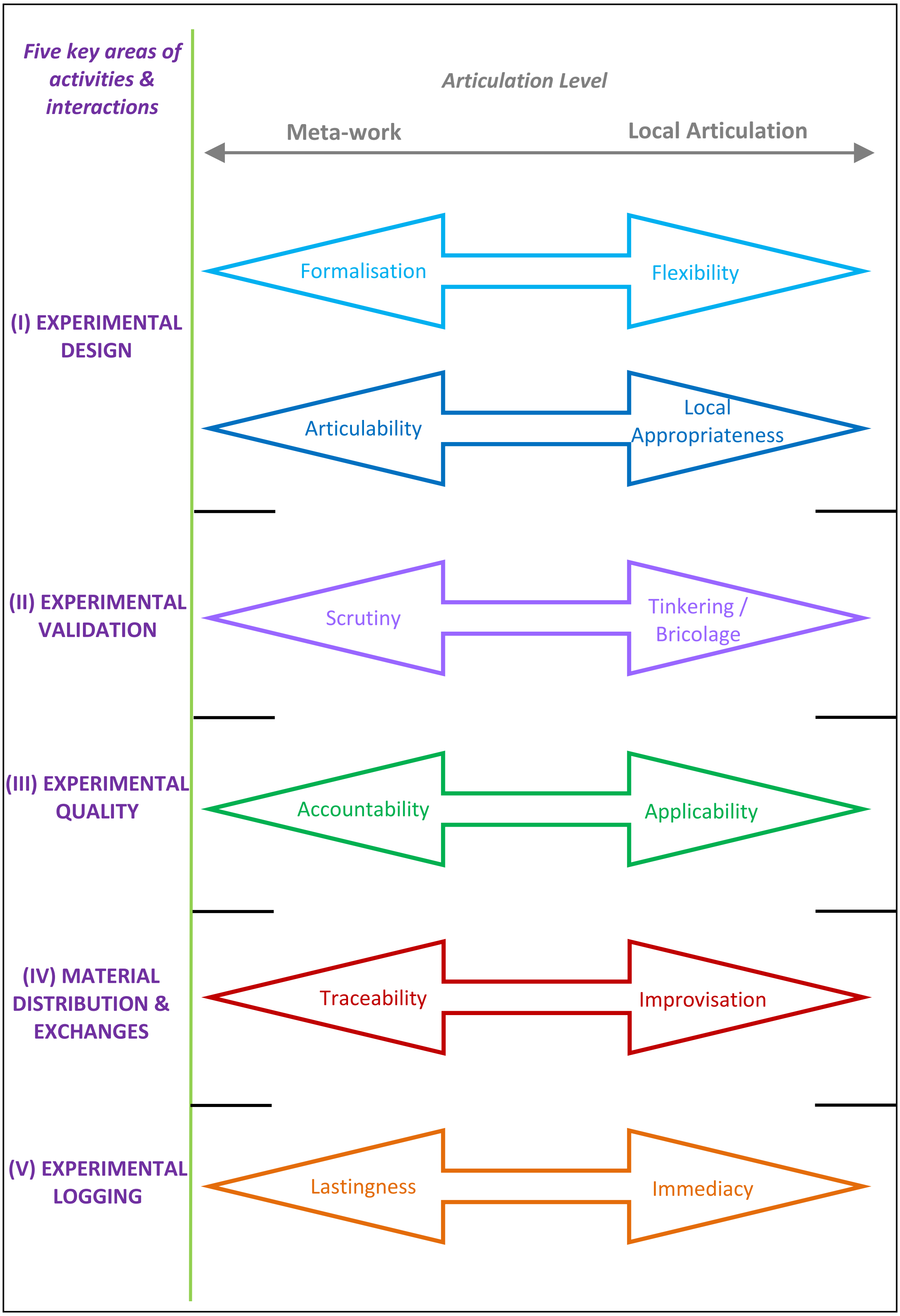


Figure 7.3: Sensitising tensions framework

The *sensitising tensions* are now identified in relation to five *key areas of activities and interactions* (represented on the left-hand side of figure 7.3):

(I) *Experimental Design;*
(II) *Experimental Validation;*
(III) *Experimental Quality;*
(IV) *Material Distribution & Exchanges;*
(V) *Experimental Logging & Archiving*.

These five new *key areas of activities and interactions* have been adapted from the seven initial ones that were used as analytical categories to frame the analysis of our study of NanoArth (see section 5.1): (1) *Experimental Design*; (2) *Experimental Validation*; (3) *Experimental Quality*; (4) *Experimental Material Supply*; (5) *Experimental Material Exchanges*; (6) *Multi-type Exchanges*; and (7) *Experimental Logging*. For greater clarity and concision, (4) *Experimental Material Supply*, (5) *Experimental Material Exchanges* and (6) *Multi-type Exchanges* have been merged into (IV) *Material Distribution & Exchanges.* Besides, this characterisation is not meant to be a one-to-one mapping between the sensitising tensions and the five new *key areas of activities and interactions*, as some of the latter could possibly be related to more than one *sensitising tensions* and each tension could very well apply to more than one *key area*.

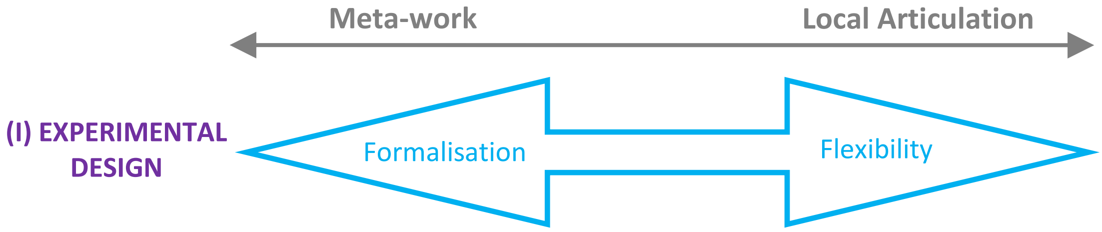
The *sensitising tensions* are also structured in relation to *articulation work* and aligned with its two facets *local articulation* and *metawork* (Gerson, 2008) (see section 2.2.5). The concepts on the right hand-hand side of the diagram in figure 7.3 tend to be oriented towards *local articulation.* They refer to the *interactional strategies* that need to be handled locally to ensure that the right conditions are in place for activities to be carried out *in situ*. The concepts on the left hand-side are directed towards *metawork*, i.e. the strategies adopted by the scientists to manage and align their distributed activities or larger units of scientific work so that to ensure that they work well together to achieve co-ordination.

With regard to technology design, these *sensitising tensions* are intended to inspire technologists to think of innovative ways to design computerised technologies to support the co-ordination of intensely distributed scientific work practices. These implications for design are in no way meant to be short-term system requirements, formal constraints, or prescriptive recommendations aimed at technology designers (Dourish, 2007). Rather they are intended to be “new ways of imagining the relationship between people and technology” (Dourish, 2006; p.548) and to be used to understand the role of technologies as “both means and embodiments of […] globalized practices” (ibid.). These implications are derived from the interpretative materials presented in this synthesis chapter, via the *sensitising tensions*, to understand phenomena of importance to designers (Dourish, 2007). In brief, the implications for design presented in this section are used as devices to suggest practical approaches for the design of a range of interactive solutions that consider key features of intensely distributed work and practioners’ strategies to manage the tensions underlying this work. These implications can in turn provide additional interesting insights into the ways the information artefacts are used to mediate the co-ordination of distributed scientific activities.

Concerning implications for practice, the *sensitising tensions* are means to provide opportunities for distributed scientific practitioners and their managers to think of ways to (re)configure their *common field of work* (Schmidt & Simone; 2016), i.e. the shared understanding of the work settings and activities across sites. We suggest that they can be used to better define and embed the use of (digital) information artefacts within this common field of work, to better share scientific content, mediate interactions, and ultimately support the co-ordination of intensely distributed scientific practices towards better achieving common action. It is ultimately about developing shared understandings of the work settings with different technological initiatives to (re)design both work practice and system possibilities (Blomberg & Karasti, 2013).

The following sections discuss these *sensitising tensions* one by one and describe how they can inform implications for design and practice. The implications for design and practice are emboldened for greater visibility.

7.6.2 Formalisation and flexibility



In relation to *experimental design*, the first *sensitising tension* can be defined between two poles: *formalisation* at one extremity (in relation to meta-work) and *flexibility* at the other (with regard to local articulation). It applies to the actual process of (co-)designing experimental work in a distributed setup and to the continuous (re)writing of the experimental protocol that supports and mediates the experimental design, and the complex interactional negotiations around it.

Mostly, distributed scientists seek to design and conduct scientific enquiry work in a formal, consistent and rigorous manner so as to ensure repeatability and reproducibility, following the principles of the scientific method. As for the information artefacts used, the researchers may be inclined (or are incited by management) to adopt highly structured formats to document their experimental procedures (protocols) and log the details of their experimental attempts (lab books), consistent across the many sites, if they feel it suits their practices. This was reflected by the introduction in the NanoArth project of a standard protocol template, consistent naming and versioning conventions for all protocols (see section 5.3) and a highly structured lab book organisation to provide chronological and semi-permanent records (see section 6.5). These initiatives were adopted with varying levels of eagerness; the data from our empirical study showed that several scientists found these approaches overly constraining and sometimes ill-suited to their local scientific practices which required more flexible ways to design their experiments and record their observations. Those scientists highlighted that if they often naturally strived to formalise the design and recording of their experimental work and the authoring of their protocol, they felt the strong need to be able to modify their approaches to experimental design and logging at will to accommodate the multiple changes of direction that would occur in complex interdependent experimental arrangements.

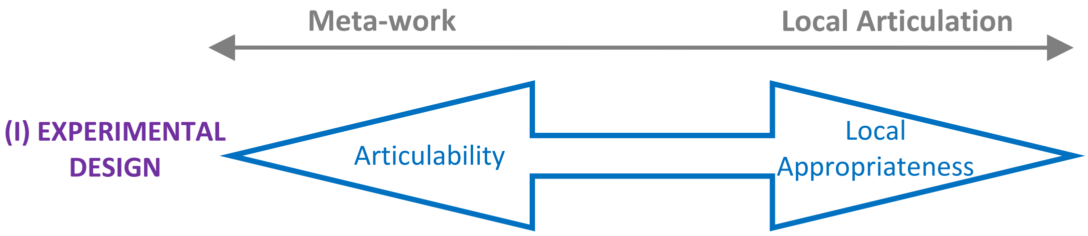
Finding innovative ways to manage this tension between *formalisation* and *flexibility* is key to supporting intensely distributed scientists in their co-operative endeavours. The design of computerised systems that can interpret and support *flexibility* in the co-ordination of activities in distributed environments has been a key area in CSCW research (Cabitza & Simone, 2013) and many studies have described how actors find ways to adapt or bypass technologies, if they do not fit their needs, or create their own methods to articulate their distributed activities (Carstensen & Sørensen, 1996; Berg, 1999; Mark, 2002; Heath et al., 2002; Schmidt & Wagner, 2004).

The artefact-mediated approaches of *coordination mechanisms* (Schmidt & Simone, 1996) and *ordering systems* (Schmidt & Wagner, 2004) drawn on here offer us inspiring guiding principles to designing systems for co-ordination that can help manage this tension between *formalisation* and *flexibility*. The view of the experimental protocols as c*oordination mechanisms* can help design experimental design-supporting information artefacts that are flexible yet still formalised. Such coordination mechanisms can offer well-defined consistent pre-computations of experimental tasks to reduce the number of possibilities (and thus facilitate the systematic undertaking of experimental tasks), and at the same time be sufficiently underspecified and malleable to be modified and redefined to accommodate changing needs (Schmidt & Simone, 1996). Furthermore, the view of the protocol, the lab book, and the material log integrated together (with the co-ordinative practices they support) into a EP/LB/ML *scientific ordering system* (see section 7.5.4) can help design a set of interoperable digitalised information artefacts that dynamically convey the state of execution of the co-design of experimental work and of the exchanges of materials in a way that they combine both high level of standardisation with flexibility (Bosssen & Markussen, 2010).

Alternatively, it may be helpful to adopt an *infrastructuring* lens, and consider the protocol, the lab book, and the material log as components of a larger interconnected e-science information infrastructure (see sections 2.2.6 and 2.3.6). It could be used as the infrastructural base on which to progressively and iteratively construct a more complete information infrastructure (Young & Lutters, 2017). Thus, this infrastructure could be constituted of a number of interoperable modules that could be locally designed and then globally assembled (Edwards et al., 2007; Jackson et al., 2007), iteratively as the result of continuous negotiations and adjustments (Starr, 1999) to ensure contextual suitability.

In practice, we suggest the design of digitalised experimental protocols, based on the introduction of a **digital template and modularisation**, with the capacity to tailor the modules to suit local needs. A project management steering group may decide on a minimum set of components that need to feature on all experimental protocols across the consortium. The scientists may then be able to customise the provided components to suit their own needs for experimental design and validation. More broadly, one approach to help manage the multitude of generated protocols and associated versions and manage protocol access in a non-invasive manner, may be the implementation of a **comprehensive protocol development and management strategy**. This could include the design of sound **version control mechanisms** that support different levels of access handling, with temporary locks to manage the parallel editing of protocols. **Targeted notifications** of edits may further be sent to the scientists involved in the co-operative experimental arrangements who have access to the protocols under development to convey the state of execution of the experimental procedure in real-time. Additionally, a dynamic visual representation in the form of an **interactive map of experimental protocols** that shows the entire set of protocols (with all different versions) could help the scientists get a sense of the progress made in different experimental work arrangements, and interactively access the details of any procedures they have an interest in. By allowing the researcher to customise their view of the map and operate their own searches using a number of parameters and the dynamic update of the map when protocols are added or edited, the visual representation would better support *process awareness* (see section 7.4.2).

7.6.3 Articulability and local appropriateness



The second *sensitising tension* is related to the previous tension and lies between the *articulability* of the design of distributed experimental work on the one hand and ensuring that experimental design is *locally appropriate* on the other. *Articulability* refers here to the ability of scientists to set up experimental design that can be interconnected and aligned with the experimental design of their partners, with whom they are involved in co-operative work arrangements, to achieve concerted action and effectively contribute to the collective research endeavour. *Local appropriateness* denotes the ability of researchers to design experimental work that is adapted to the local circumstances, can accommodate the local conditions, and handle any arising contingencies.

What has emerged from the analysis of our empirical study is that the researchers involved in the co-operative experimental arrangements of the NanoArth project strived to find ways to organise their activities so that they could be interlinked with those of others in practice. This was particularly significant for the site which produced and distributed the nanomaterials to the other sites, and which was consequently involved in a great number of co-operative arrangements. The nanosynthesis team adopted a variety of artefact-mediated approaches to ensure that their experimental enquiries of the synthesis of different types of materials could be effectively articulated with those of the scientists requiring the materials for their own work. These included the continuous sharing of information artefacts (protocols, characterisation documents, Preliminary Toxicity Tests and Certificates of Analysis) with each set of co-operators to provide them with details of the inner mechanisms of the synthesis to allow them to integrate their own experiments with the investigatory synthesis process.

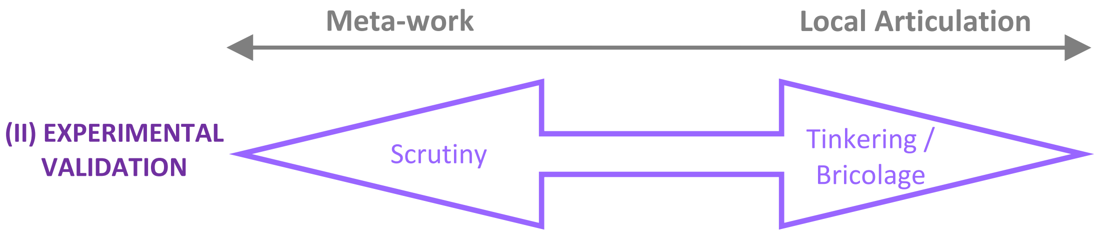
At the same time, it was made very clear in the data from our empirical study of NanoArth that designing, conducting and validating experimental work required a great capacity of adaptation to local circumstances and the ability to handle arising contingencies creatively (see section 5.4 and 5.5). Owing to the variations in scientific cultures and institutional perspectives, local conditions and contingencies are handled very differently at different sites. Therefore, blanket initiatives to harmonise experimental work practices with a view to make them connect better (through the introduction of different devices such as uniform protocols, centralised logs or standard lab books, for instance) were viewed by some scientists as a hindrance (see section 5.6).

We contend that the design of interoperable information artefacts with reviewing, annotating and bookmarking capabilities (and additional supporting features) and shared data repositories may afford *articulability* while at the same time support design experimental work that is *locally appropriate* and thus play a key role in assisting scientists operating in intensely distributed work settings. We recommend the design of technologies that allows users (or group of authorised users) to **review and annotate** experimental protocols, as well as lab book and material log entries, to enable users to make meaningful and targeted contextualised contributions to the co-operative experimental design process. Annotating refers to the ability to append different types of data to existing information sources. These could be multimedia annotations to allow scientific co-operators to attach multiple types of data items in a variety of formats, such as text, diagrams or spreadsheets of results, but also potentially images, sound snippets or videos. This variety in the different types of media practices may allow for more details to be captured, support different kind of interactional practices and bring notes and data together to provide a greater understanding of the recorded facts (Myers, 2003). These annotations may also be stored as separate files that are linked to one or more specified information sources and protected using access control mechanisms (Myers et al., 2004). With this approach, researchers may also use annotations to ask specific questions about experimental procedures in protocols, observations in lab books, or entries in a material log. Their partners could also use them to respond to the enquiries asynchronously, in their own time, in a non-invasive manner. A system of annotation-based questions and answers may also assist negotiations around experimental tasks. This annotation system may further strengthen the role of the protocol as a *boundary negotiating object* (Pennnington, 2010) to support negotiating interactions during experimental co-design, and create co-operation spaces between scientists specialised in different areas. This system of annotation-based questions and answers might also be threaded and subsequently exported as discussions to be used further during meetings and presentations (cf. Myers et al., 2001).

Building on this idea of annotating, the introduction of video collaboration with **readable annotations of physical objects** (e.g. Chang et al., 2017) might be considered. This involves "attaching readable labels to objects to real-time video that is shared between remote collaborators" (ibid.; p.2246) to improve the ways co-operators refer and understand objects they handle. An experimental procedure could be video-recorded, for demonstration purposes, and readable annotations might be added to point at specific items in the recording. As intensely distributed experimental work involves the physical manipulation of materials and equipment that remote co-operators from different *epistemic cultures* (Knorr-Cetina, 1999; 2007) may not be necessarily familiar with, this might help provide a greater comprehension of the experimental work under discussion as part of a co-operating arrangement.

Additional tools might also be deployed to further support *articulability*. **Collaborative tagging** may provide a more lightweight solution to annotating as it can help co-operators annotate protocols, as well as lab book and material log entries, with keywords that are meaningful to them (Kamel Boulos & Wheeler, 2007). These tags can then be organised in tag clouds (visual representation of keywords displayed in order of utilisation) or concept maps (diagrammatic representation of concepts and relationships between them) to enhance the collective organisation and searchability of available information resources when working on experiments. This solution could also be supplemented by an **interactive glossary of terms** (with multi-lingual capabilities) and **updatable common set of standards** linked to all key information artefacts to provide a common frame of reference on which researchers with diverse backgrounds can converge (Lee et al., 2009).

7.6.4 Scrutiny and tinkering/bricolage



This tension relates to *Experimental Validation* and lies between *scrutiny* on the *metawork* pole and *tinkering/bricolage* on the *local articulation* pole. We maintain that scientific *scrutiny* is an aspect of scientific work that holds a great deal of value for all scientists. Ensuring repeatability and reproducibility is at the absolute centre of scientific practice as it enables the scientists to evaluate their own and each other's experimental work and is used as the basis for constructing scientific facts (Benestad & Laake, 2007). Our analysis has identified that in the intensely distributed settings of the NanoArth project four types of repeatability and reproducibility can be potentially verified – *local repeatability*, *distributed repeatability*, *local reproducibility* and *distributed reproducibility* (see sections 5.5 and 7.2.3 and table 5.3). However, in practice, there were great variations in the approaches adopted by the researchers to validate their experimental work.

Our analysis has shown that if the scientists in the NanoArth project typically reported that they strived to ensure repeatability and reproducibility, the extent to which all four components were verified could vary sensibly depending on time constraints and on the level of interdependence of their activities with those of others. As for the harmonisation of scientific practices (see section 7.6.2), several researchers disapproved of the deployment of a uniform approach to validation by which all experimental procedures would have to be validated identically across the consortium. In their view, such an overly rigid approach would be detrimental to the *bricolage* (Lynch & Woolgar, 1988) and *tinkering* (Knorr Cetina, 1981a) characteristics inherent to the scientific enquiry work they do in the lab, and very much required to make the necessary adjustments to align their activities with those of others.

A strand of e-science research (see sections 2.2.6 and 2.3.6). has been specifically investigating ways to design computerised technologies that can potentially support scientists with managing their experimental data flows. and in doing so with ensuring scientific *scrutiny,* and particularly experimental repeatability and reproducibility (e.g. Deelman et al., 2009; Gil et al., 2007; Star et al., 2010). In these research endeavours, ways to design innovative digital platforms have been investigated to automate and standardise the creation, representation, management, and sharing of experimental workflows. These technologies aim to digitally represent discrete data-driven experimental tasks as computational modules that can be interlinked as workflows. This way, they connect the various steps of experimental procedures following the flows of data and the interdependencies between them (Dudley & Butte, 2010; Tiwari & Sekhar, 2007). In addition to providing automation, these technologies may centralise and provide the necessary information to assist with experimental reproducibility, the derivation of results from experimental operations and the sharing of results between partners (Gil et al., 2007).

To support reproducibility, workflow systems need to capture *provenance data*, i.e. the data used during the execution of the experimental workflow (such as workflow inputs, parameter settings, environment variables or intermediate products), and associate this data to the produced experimental outputs, so that researchers can repeat techniques and analysis methods to obtain similar results (Deelman & Chervenak, 2008; Deelman et al., 2009; Ludäscher et al., 2009). However, earlier research has also shown that the implementation of a bespoke one-size-fits-all computerised system to represent and automate the workflow of the scientist is likely to be met with disregard or resistance (Dudley & Butte, 2010), as it may be seen as hindering the capacity of the researchers to tinker and improvise with their experimental procedures. Hence, a full-scale scientific workflow management system is not considered here to be a suitable solution for biomedical research conducted in intensely distributed settings. Our analysis has shown that it may be very difficult to deploy a single 'one-size-fits-all' system that may be able to cater for all the very diverse partners' needs and *modi-operandi* (see issues with centralisation and harmonisation of protocols in section 5.6, of material logs in section 6.3, and of lab books in section 6.5). Also, there is a sense that the rigidity of such a workflow-driven system might indeed deter many scientists (Grudin, 1994) and hinder creativity (Farooq et al., 2005). Furthermore, there are areas of a co-operative biomedical project that may not be covered by workflow management systems, such as the required flexible integration of patient data with experimental data (Stark et al., 2010). We argue that innovative and perhaps more flexible solutions need to be thought of to capture *provenance data* in a non-invasive way so that to help the scientists carefully manage the tension between *Scrutiny* and *Tinkering/Bricolage.* Drawing on the work of Stark et al. (2010) and Stevens et al. (2007), the capabilities for a CSCW system that integrates co-operative practices with the recording of data provenance may be suggested, as follows.

A **digital knowledge space** could be created by users for each experimental study (e.g. Sommerkamp et al., 2009; Stark et al., 2010). Scientists could allocate and upload their experimental protocols, i.e. those that stipulate the experimental procedures, but also the protocols for storage and manipulation of materials, and utilisations of equipment. Data resources could be added to the knowledge space to store and make available meaningful contextual information. This relevant data could include related publications, material characterisations, results of previous attempts made on-site or at a different site, as well as comments, observations, and interpretations on specific experimental manipulations. However, we suggest that this knowledge space should be designed as consisting of more than just a centralised repository of information (like a cloud-based synchronised storage tool) where scientists simply deposit files in an unstructured manner. In order to reduce the issue of over-proliferation of information (often highlighted as problematic in the empirical study of NanoArth), the experimental protocols and other context-providing documents should be interconnected and integrated together as part of the experimental unit of experimental work in a meaningful manner for the experimenters involved in the co-operative work arrangements. Linkages between files could be established using **categorisation tagging** so that to make the available files highly searchable using different search criteria. **Free text annotations** could also be used here to interactively provide additional information on the context, and perhaps generate new tags to enhance searchability. The **knowledge space** for an experimental study could then be **integrated with the interactive protocol map** (see section 7.6.2). The interactive map of protocols could be designed in a way that it visually represents key experimental work arrangements and experimental studies. By selecting a particular study, the user might be able to both view the protocols associated to this study, as well as the knowledge space for this study, and access all the relevant context-providing documentation.

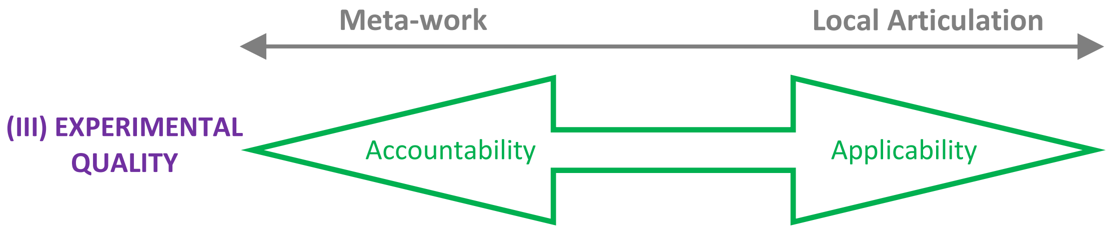
During the performing of an experiment, the CSCW system could provide non-invasive ways to capture provenance data related to the actual execution of the experimental procedure, following the Stevens et al.'s *model of provenance* (2007). The **originator** of the execution of an experimental procedure or of a new data item could be captured automatically by providing different access rights and logging the individual performing an experiment (*organisation provenance).* **Timestamps** could be used to automatically log events (*process provenance*). Input parameters, generated results and additional metadata (e.g. contextual description) could be entered through a simple interface (*data provenance*). Similarly, a very straight-forward entry system could allow for additional domain-specific observations, interpretations, descriptions, and explanations to be captured *in-situ* (*knowledge provenance*).

The interfaces for the recording of provenance data in relation to the latter two dimensions (*data provenance* and *knowledge provenance)* could be designed as part of a **metadata entry app** (e.g. de Waard, 2013; Tripathy, 2013). This could take the form of a very simple computer tablet app to enable the easy digital entry of key metadata as the experiment is being performed e.g. solution composition, temperature, species, equipment used, and calibration levels. The computer tablet could be held by a heavy-duty movable stand, located right by the bench, to avoid the tablet resting on the work surface and potential damage to it. This should be designed as a "highly lab-customized metadata capture system" (de Waard et al., 2013; p. 24), in a way that it is tailored to the experimenter's needs and flexibly supports offloading to capture key data during experimental manipulations. The electronic recorded metadata could then be shared with co-located partners and remote partners to verify *local* and *distributed repeatability* and *local* and *distributed reproducibility*.

To further support the validation of repeatability and reproducibility processes, different executions of an experimental procedure may be recorded as part of the knowledge space and connected to the protocol. A comparative analysis between different executions of an experiment may be conducted to help with *local repeatability*, *distributed repeatability*, *local reproducibility* and *distributed reproducibility* (depending on the required level of validation). An **experimental data dashboard** could be designed to provide **data visualisations** (of both input data and the experimental results produced) that are easy to access and interpret

(Tripathy, 2013). These visualisations should be highly tailorable to suit the experimenters needs and local conditions.

7.6.5 Accountability and applicability



We suggest that the previous tension between *scrutiny* and *tinkering/bricolage* (in relation to experimental validation) applies at the micro-level (Andonoff et al., 2004), i.e. at the level of the actor operating at their lab bench. It seeks to highlight meaningful facets of the actual validation of experimental work as carried out in the lab with *scrutiny* referring to the validation of experimental work by the scientists operating within an experimental work arrangement (Myers, 2003). On the other hand, the tension between *accountability* and *applicability* (concerning experimental quality) relates to the macro-level (Andonoff et al., 2004) i.e. the level of the larger experimental unit, work package or entire project. Thus, *accountability* goes here beyond internal scrutiny, and extends to all aspects of the design, conduct, logging, and validation of experimental work, with a view to ensure quality within and across all co-operating work arrangements. *Applicability* on the other hand refers to the level of suitability and pertinence of the methods and techniques adopted to ensure that the quality of scientific enquiry work is at the highest possible.

We posit that *accountability* drives and transpires across virtually every activity the scientist undertakes in an intensely distributed setting, i.e. designing an experiment, conducting and validating them, sending materials across or documenting and sharing experimental results. As widely reported in the findings of the NanoArth empirical, there was a continuous push from the management team to adopt and apply robust and consistent quality control methods in all areas. Harmonisation of practices and centralisation of resources are seen by management as key to increase the visibility and transparency of all work activities that are carried out in the project. The management team advocated consistency in the naming, versioning and structuring the experimental protocols (see section 5.3, 5.6) and in the formatting of the logging mechanisms, i.e. standardised lab books to capture experimental data (see section 6.5). They also pushed for the centralisation of all protocols (see section 5.6), material logs (see section 6.4) and various experimental supporting documentation, such as material characterisations, CoFAs and toxicity test data (see section 6.3). The increased transparency and ease of access enabled by this push for harmonisation and centralisation were viewed by management as crucial in ensuring greater quality control and offering greater accountability internally, among participants in the consortium, but also externally with the representatives of the European Commission.

Ensuring the overall quality of the scientific enquiry work was also at the centre of the preoccupations of the scientists performing experimental activities and the analysis of our empirical study of NanoArth reported that a great deal of emphasis was put on it. The participants in our study made it explicit that they consider quality control as embedded within their practices, as it at the core of the scientific enquiry method and central to their ethos as scientists. On the other hand, it was reported on several instances that the tendency to harmonise all practices and centralise all resources in a uniform manner could be perceived by researchers as a lack of confidence that managers expressed towards the experimenters' abilities to follow the principles that steer their scientific work (see section 5.6). This view was not shared by everyone, as a number of scientists in NanoArth saw the direct benefits of harmonising practices and introducing more thorough quality control measures, particularly if they operated or had operated previously within a more strictly regulated environment, such as pharmaceutical industries (see sections 5.3 and 5.6). What seems to be mostly relevant and meaningful to the scientists involved in distributed scientific work is the *applicability* of quality control approaches. This entails the implementation of accountability and quality control measures appropriate to the actual work being undertaken, in a way that they can be viewed as meaningful and beneficial rather than constraining. Thus, we suggest that what they saw as essential, for the high-quality conduct of their work, is what could be referred to as *targeted accountability*, i.e. accountability at the right level of depth as applicable to the particular experimental setup under consideration.

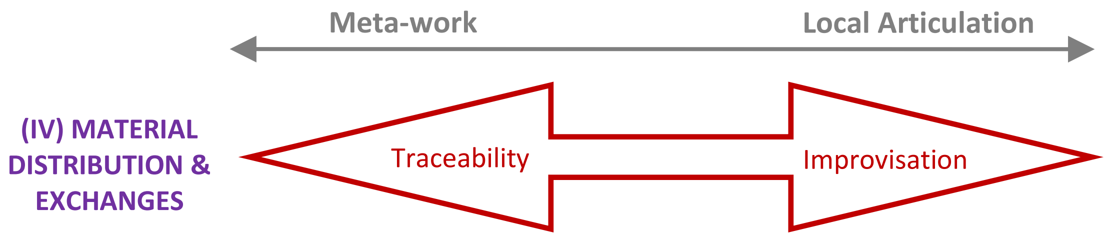
Designing for accountability is a real challenge, as shown by the wide areas of understandings of the term within just the CSCW discipline. In the case of the cross-disciplinary multi-sited scientific work of interest to our research, it is about finding ways to design technologies that can support accountability of work within and across distributed experimental work arrangements and can help manage that duality between global and local co-ordination (Stisen et al., 2016) to ensure experimental quality. The design needs to provide ways to support the *ordering* of experimental work (i.e. the ability to align work trajectories and articulate activities between co-operating partners) (Bossen & Markussen; 2010; Redaelli & Carassa; 2015; Schmidt & Wagner, 2004), while at the same time being *applicable* locally, i.e. relevant to the local settings and thus enforcing personal responsibility. Supporting both *accountability* and *applicability* through CSCW systems in this type of distributed arrangements calls for a design that can support the negotiation of the visibility of work (Star & Strauss, 1999; Bossen & Foss, 2016). The design of CSCW systems for this purpose should offer the ability for an actor to modulate how visible their work is to other co-workers and thus support a type of *appropriate obtrusiveness* (see section 2.2.3 and Schmidt, 2002a) adapted to asynchronous work setups.

It has been discussed previously (see section 7.6.4) that a fully-fledged scientific workflow system might not be the best suited solution to co-ordinating scientific work in intensely distributed settings like in the NanoArth project. Rather, we suggest that an **interactive visual timeline-based planning and co-ordinating solution** (e.g. Farooq et al., 2005; Stracke et al., 2013), with personalised views, may support overall accountability while at the same time facilitating access to targeted and relevant time-critical project information to the scientists operating *in-situ* in the labs. The interactive visual timeline may provide updatable representations of key project events. These could include, at the macro-level, work packages, large experimental work units, or larger patient studies. At the micro-level, co-operative work arrangements and localised experimental studies could be featured. Crucially, the interactive visual timeline may also incorporate essential milestones, deadlines and required deliverables. Members of the management team and Leading Partners may be able to create, retrieve, edit, and delete events in the timeline. Scientists doing lab work ought to be able to easily access and upload items relevant to their own experimental activities, such as protocols, lab book entries and records of material exchanges using a ‘drag and drop’ approach. An effortless

integration of the timeline system with the visual protocol map (suggested in section 7.6.2) would help timestamping the different versions of the authored experimental procedures. The scientists may also upload any experimental results or any other relevant documents onto the interactive timeline so as to keep an historical record of the experimental process (and thus contribute to generating provenance data as mentioned in section 7.6.4). **Integrating the timeline system with the knowledge space and the metadata entry app** suggested in section 7.6.4 could provide even further connectivity in terms of experimental validation. The scientists seeking to validate repeatability and reproducibility could use the timeline to view previous experimental attempts (and easily access the related data) and upload information related to their own attempts. Again, this would greatly differ from centralised repository of information (like a cloud-based synchronised storage tool) as it would enable for an interactive time-based visualisation of different components of units of experimental work to be viewed and interacted with.

From an *infrastructuring* perspective (see section 2.2.6), the timeline system, the visual protocol map, the knowledge space and the metadata entry app could be integrated into an e-science infrastructure, and potentially embedded within the [experimental protocol / material log / lab book infrastructural] infrastructural cluster proposed in section 7.6.2. *Synergizing* strategies (Bietz, 2010) could be considered, to find ways to combine the human and social-technical entities involved into this infrastructure to optimise the effects of their integration on the co-ordination of distributed activities and help manage this tension between *accountability* and *applicability*. Additional research would be required to thoroughly investigate the synergistic effects of infrastructuring on the type of intensely distributed projects under consideration in this PhD and the potential appropriation and use of such an infrastructure by the scientists involved in those projects.

7.6.6 Traceability and improvisation



This *sensitising tension* essentially concerns the *Material Distribution & Exchanges* area of activities and interactions (mainly discussed in chapter 6). It may also relate to other areas of activities, such as (I) *Experimental Design*, (II) *Experimental Validation* and (III) *Experimental Quality* (see section 7.6.1). Indeed, it lies between seeking transparency and visibility to support articulation of distributed practices (at the *meta-work* pole) and cultivating spontaneity and improvisation (at the *local articulation* pole), seen as crucial by scientists to perform their work at the bench and exchange materials in an ad-hoc manner when required by the conduct of a specific experiment (see section 6.3).

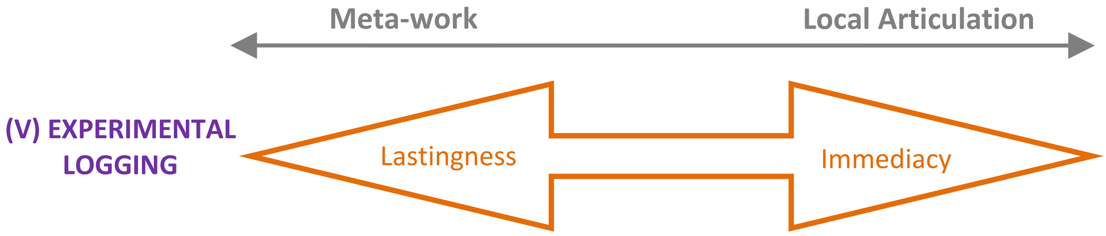
As in previous tensions, the empirical study of NanoArth showed that the pressure on the scientists to manage the process of requesting, sending, and receiving materials easily as part of their creative trial-and-error experimental practices while at the same time being required to meticulously log the exchanges of all materials. From a management perspective (see section 6.3.3), and for a number of scientists, the systematic logging of all exchanges made it much easier to locate, assemble, and distribute materials of very different types, and thus could help handle and monitor better the complex multi-directional exchanges of physical and digital materials. We maintain that a methodical logging and tracking of materials and their behaviours was seen as particularly crucial in NanoArth because of the additional approaches introduced to further ensure a higher quality in the synthesis and supply of nanomaterials. The development of several interrelated batches (master batches and initial batches to define RoA values as references for subsequent batches) further justified the need to keep an accurate record of the produced and shared nanomaterials to keep a track of the many batches and how they evolved over time (see section 6.2).

To formalise and standardise logging, the centralised material log was introduced in the NanoArth project to make it easier, in principle, for all co-operators to capture and keep a track of all the materials sent back and forth between various sites. However, scientists across the projects expressed several reservations. There were concerns over the ability to develop a common understanding of which information should be logged. Because of the great heterogeneity of the types of materials involved in experimental work, a single uniform approach was not seen as suitable, as not every exchange needed be logged or logged in the same way (see section 6.3.3). Other concerns related to the perceived complexity and rigidity of a single standardised approach and the perceived sense of intrusiveness and disruption resulting from it (also see section 6.3.3), which resonates with the point made in the previous section 7.6.5. The capacity to *improvise* and organise spontaneous exchanges of materials to support experimental activities was considered essential by those doing work in the lab.

To help manage this tension, we suggest innovative ways to design and/or configure technologies that can help tracking physical materials and the accompanying information artefacts in a non-obtrusive way so that not hinder spontaneous ad-hoc exchanges. Inspired by the work of Bardram and Bossen (2005), and Grønbæk et al. (2003), who have probed ways to bridge and blend the handling of physical and digital materials, two suggestions are put forward. The first, and perhaps more straightforward, entails an extended design of the digital probes that are in used in the NanoArth project (i.e. the USB-powered thermos-hygrometer, see section 6.3.1). An **enhanced digital probe** could be systematically added to shipments made between sites to transfer data that is directly relevant to the materials (e.g. description and characterisation, toxicity levels, instructions for storage, and manipulation, etc.), as well as information on the shipment conditions to monitor any changes of state (e.g. temperature, atmospheric pressure, moisture levels, etc.). On receipt, the digital information conveyed by the device could be uploaded effortlessly onto a digitalised version of the material log (perhaps through a simple ‘drag-and-drop’ design) so that the information is made accessible to the partners who have an interest. Eventually, this data could be linked to the logging of an experimental execution (see section 7.6.4) to provide additional useful provenance data and the planning and co-ordination system for a more meaningful integration (see section 7.6.5).

The second suggestion advocates a closer link between physical materials and digital representations of these materials using technologies like bar codes and RFID. A Radio Frequency Identification (RFID) system is a type of sensor network that uses radio frequency transmission to identify objects. It involves the use of tags that are attached to objects and readers that can communicate with the tags through radio signals (Xiao et al., 2007). In the first instance, all physical materials could be fitted with the RFID tags to allow for their tracking, both physically and within a digital workspace (Bardram & Bossen, 2005). One of the advantages of this method is that certain RFID systems (referred to as *collectional RFID systems*) can be used to detect and trace simultaneously a grouping or collection of artefacts – both physical and digital (Grønbæk et al., 2003). In the settings of intensely distributed nanoscience, **collectional RFID tags** could be attached to a physical artefact (e.g. a batch of nanoparticles) and to all the other physical items in that collection (e.g. other related batches of particles) as well as to all the associated information artefacts (e.g. protocols, characterisation documents, toxicity test data sheets and Certificates of Analysis, diagrams, MR images, etc.). For this to function, cross-modality changes need to be insured, in the sense that changes in one modality (physical or digital) needs to be reflected in the other. Eventually, the design of such a system should allow for both physical and digital representations to be combined in a coherent and easy-to-use way. We posit that this would constitute a low-cost, non-intrusive method to manage complex interchanges of physical materials and related information artefacts without restricting the improvised nature of the exchanges. Integration with the timeline-based system (see section 7.6.5), the knowledge spaces and the medata entry app (see section 7.6.4) might be useful to provide further connectivity and real-time updating capabilities.

7.6.7 Lastingness and immediacy



This final tension regards the logging, management and maintenance of experimental data. It lies between the push (often by management) for scientists to make long-lasting records of the experimental data they generate (at the *meta-work* end) and the need to capture scientific facts (and to share it with co-located partners) in a straight-forward manner, as they do bench work (at the *local articulation* end).

Our empirical study of NanoArth has indicated that *immediacy* is given a great deal of prominence in the lab. The analysis showed that the researchers highly valued the capacity to log key data in a simple way as the experiment is unfolding, without it interfering with their experimental operations (see section 6.5.2). They also required the ability to interpret it and formalise it in a way that it can be shared with and used by their co-operators (see section 6.5.3). Therefore, the analysis has highlighted that often the view of the lab book was not one of a single monolithic rigid information artefact; rather it was a metaphor for different flexible media that allow them to capture meaningful data *on the fly* (Roubert & Perry, 2013). In contrast, for the management team, the ability to keep a tangible, standardised, and uniform record of all captured data was considered paramount. As for the standardisation of the use of protocols and the material log, aligning the practices of the logging of experimental data across the different sites was seen by the steering group as key to improve the monitoring of activities and increase transparency (see section 6.5.1). Furthermore, permanently storing historical data (in the lab book but by keeping all versions of protocols) is seen as by managers absolutely crucial by managers towards the production of patents (see section 5.2.2). Additionally, external partners such as project funders, Research Programme Officers or Project Technical Advisors (see section 4.2.4) may also require access to intermediate project data for auditing purposes, specific technical guidance, or general transparency.

We contend that a number of different approaches to the design and/or configuration of digital technological platforms may help managing this tension between *lastingness* and *immediacy*, and help intensely distributed scientists better manage the logging, interpreting, sharing and archiving of their experimental data. **Ubiquitous technologies** may be a technical solution that can support content creation in a lightweight and non-obtrusive manner while allowing for a digital trace of the captured data to be kept for any other utilisations. **Portable hands-free recording devices** with a headphone/microphone adapter for spoken note-taking may be considered. The chronological dimension of current lab book practices (which was highly valued by several NanoArth scientists) may still be maintained, if required, as the recorded entries may be timestamped. The downloaded recordings may also be organised thematically or on a project-basis, if the researcher is working on more than one project or work package at the same time and needs to arrange their notes slightly differently. For the capture of visual elements such as text, diagrams or sketches, the use of **digital writing solutions,** such as **digital pens**, **digital notebooks** or **digital tablets**, may be suggested for those labs in which conditions allow it. For the scientists who may prefer the feel of using paper, **digital pens that track users' handwriting on paper** (e.g. Anoto AB (2016)), or **digital magnetic paper notepads** that can be placed on an electronic device to digitally capture written characters or sketches (Kelion, 2016), may be adopted. Several other **hybrid options** that can **augment the affordances of paper notebooks** may also be explored, as investigated in the work of Mackay et al. (2002), Tabard et al. (2008) or Yeh et al. (2006). These endeavours might provide helpful solutions to record live experimental data using a range of modalities without hindrance to the scientist while subsequently storing data digitally so that it can be later manipulated. These could even be adopted by experimenters at the bench providing that they do not add further overhead to their work, and further investigations would need to be conducted to verify it.

With regards to longer-term archiving, a useful design may offer intensely distributed scientists and their managers the ability to set **levels of permanence** for specific data entries. This could help determine how important it is for the recording of specific facts to be stored on a long-term basis. Entries with different levels may be allocated different access levels so that the researchers retain the flexibility to share intermediate experimental data when and with whom they feel it is appropriate for them to do so. The multiple data entries that are recorded (with their levels of permanence) could be made **highly searchable** using a number of criteria. Ideally, the records made of experimental data (with varying permanence levels) may be linked to the interactive timeline-based co-ordination system (see section 7.6.5), and possibly to knowledge spaces (see section 7.6.4), for specific experiments, larger units of enquiry activities, or work packages so that a capture of experimental data is timestamped and contextualised. This may help provide additional provenance data and may be used subsequently for periodic reports, publications and patent applications.

7.7 Chapter Conclusion

This chapter has unpacked the findings from the rich body of data presented in the previous two chapters as a result of the multi-method multi-sited study of the interactions within an intensely distributed nanoscientific project. It has shed light on the meaning (from an interactionist perspective) ascribed to the experimental protocol as a dynamic artefact (continuously co-designed, co-tested and co-refined) that is used as a *co-ordinative map,* i.e. a coordination mechanism used to disseminate instantiations of the state of execution of experimental procedures to allow partners to interconnect their own activities. It has also characterised the lab book artefact as enabling a variety of ways of capturing experimental information to support *offloading*, *reflection* and social distribution. We contend that when used in conjunction, the protocol and the lab book form an *EP/LB ordering dyad* that support a system of interactional practices to help conduct the validation of four levels of repeatability and reproducibility. We also posit that, when used together, the protocol, the lab book and the material log form a *EP/LB/ML scientific ordering system* that allows a *system of exchange of scientific content* that supports the interactional practices needed to articulate the different components of distributed scientific enquiry work: experimental design; validation and quality; material distribution and exchanges; and reporting and archiving. We have produced abstractions of the ways both the *EP/LB ordering dyad* and the *EP/LB/ML scientific ordering system* mediate the social interactions to articulate distributed nanoscientific activities to provide a better theoretical understanding of the ways these clusters of information artefacts support the integration of intensely distributed nanoscientific activities.

From this meticulous study of the interactional practices in the intensely distributed nanoscientific project under enquiry and the roles of information artefacts to support these practices, a number of sensitising tensions have been derived. They represent salient features of intensely distributed scientific work that the scientists consider as essential, and that they need manage in relation to the key areas around which their activities and interactions take place. In parallel to these, a number of implications have been suggested as devices to think of innovative ways to design interactive systems that can help manage these underlying tensions between key features of intensely distributed work.

These implications are summarised in table 7.2, for each of the five new key areas of activities and interactions (adapted from the seven initial ones that were used as analytical categories to frame the analysis of our empirical study, see section 7.6.1).

Key areas of activities & interactions	**Sensitising tension**	**Implications for design and practice**
(I) Experimental Design	**Formalisation ←→ Flexibility**	• Flexible **digital template for protocols** with module/component-based structure. ○ Key components as default. ○ Ability to add customisable components. • **Protocol development & management strategy**. ○ Management of protocol iteration development. ○ Version control system for protocols with access handling. ○ Notifications of edits to dynamically convey state of execution of experimental activities. • Interactive **visual representation of** complete set of **protocols**. ○ Visual **protocol map** to provide overview of experimental design. ○ Dynamic updating when protocols added or edited.
(II) Experimental Design	**Articulability ←→ Local Appropriateness**	• **Review and annotation system** ○ Multimedia annotating of protocol, lab book and log book entries with text, images, diagrams, audio and video to annotate own and others' protocols. ○ Readable annotations of physical object on video demonstrations of experimental procedures. ○ Collaborative tagging: Multimedia annotating of protocol, lab book and log book entries with keywords. • Interactive **glossary of terms** and common **set of standards** to provide common frame of reference. ○ Interactive multi-lingual glossary. ○ Updatable common set of standards.
(III) Experimental Validation	**Scrutiny ←→ Tinkering / Bricolage**	• Creation of digital **knowledge spaces** with ○ Protocols. ○ Data resources. ○ Categorisation tagging ○ Annotations. • Capturing **provenance data**. ○ Originator of the data. ○ Timestamping. ○ Metadata entry app. ○ Experimental data dashboard. • Integration of knowledge space with protocol map.

(IV) Experimental Quality	**Accountability ←→ Applicability**	• Interactive **visual timeline-based planning and co-ordination system**: ○ Macro-level: working packages, larger experimental units, larger patient studies. ○ Micro-level: co-operative experimental arrangements, experimental activities. • Integration of visual timeline with: ○ Visual protocol map. ○ Knowledge spaces. ○ Metadata entry app.
(V) Material Distribution & Exchanges	**Traceability ←→ Improvisation**	• **Enhanced digital probe** ○ Transfer data that is directly relevant to the materials e.g. descriptions, characterisations, toxicity levels, instructions for storage and manipulation. ○ Transfer data on shipment conditions to monitor changes of state. • **Collectional RFID tagging** ○ RFID tagging of different interrelated collections of experimental materials and associated information artefacts. ○ Physical tracking and digital tracing in a workspace. ○ Cross-modality changes. ○ Combining physical and digital representations. ○ Link with timeline-based co-ordination system. • Integration of probes and/or RFID tags with: ○ Visual timeline. ○ Knowledge spaces. ○ Metadata entry app.
(VI) Experimental Logging & Archiving	**Lastingness ←→ Immediacy**	• **Ubiquitous technologies** to offer lightweight mobile solutions to capture information *in-situ* ○ Portable **hands-free recording devices** for spoken note-taking. ○ **Digital writing solutions** to capture text, diagrams and sketches. ○ Hybrid options to augment paper notebook. • Archiving. ○ Setting levels of permanence. ○ Searchability. • Integration with visual timeline

Table 7.2: Summary of implications for design and practice

Conclusions are drawn, and research contributions are discussed in the next and final chapter.

Chapter 8 Conclusions

8.1 Chapter Introduction

This final chapter first revisits the aims and objectives stated at the start of the thesis, then highlights and discusses the contributions that our study of intensely distributed scientific work makes to academic research. Finally, the chapter outlines a number of limitations for our study and links them to research directions that could be explored in the future.

8.2 Synopsis, aim, and objectives

This section provides a brief synopsis of the research presented in the thesis and discusses how the activities undertaken in this PhD contributed to the completion of the research objectives and the overall aim presented in section 1.4.

This PhD seeks to understand how scientists working on intensely distributed projects to resolve complex translational biomedical problems use information artefacts to co-ordinate their activities towards achieving their common goal. As stated in the first chapter, the overall aim of our study was to probe and explain the practices of the conduct and co-ordination of intensely distributed scientific work within a multi-sited cross-disciplinary project and to consider ways to design computerised technologies to better support these practices.

A theoretically-motivated review of the CSCW and STS literature was conducted first to identify the conceptualisations best suited to examine intensely distributed scientific work and the co-ordinative roles of information artefacts. ***Articulation work*** (Strauss, 1985; 1988) was considered as a useful conceptual lens to explore the ways co-operative scientists assemble tasks and units of activities into workable arrangements, both locally (*local articulation)* and in a distributed manner (*metawork)* (Gerson, 2008). In connection with articulation work, ***ordering systems*** (Schmidt & Wagner, 2004) offered a valuable theoretical perspective to consider specifically how information artefacts are used jointly, as part of a cluster of interconnected ***coordination mechanisms*** (Schmidt & Simone, 1996) and practices, to support the complex articulation of local and distributed activities. ***Boundary objects*** (Star & Griesemer, 1989) were deemed to provide a helpful conceptual apparatus to study how information artefacts were used to create co-operation spaces between diverse distributed partners. The finer distinction between ***boundary negotiating objects*** (information artefacts that can support heterogeneous negotiation to help define the space for co-operation) and ***boundary specifying objects*** (information artefacts that are in a more stable state and can help align work activities) has been particularly insightful (Pennington, 2010). The precise contributions made by these conceptualisations to help explain the roles of information artefacts in the conduct and co-ordination of intensely distributed scientific work are discussed further in section 8.3.

A review of several ethnographic fieldwork perspectives and underlying ideas was then undertaken to identify those best suited to inform our study of intensely distributed scientific work and to probe the supporting roles of information artefacts. A multi-perspective multi-method multi-sited methodological approach was then adopted and is inspired by three different orientations of ethnographic fieldwork: ***design-oriented*** (Randall et al., 2007), ***interactionist*** (Clarke & Star, 2003; Strauss et al.; 1964), and ***multi-sited*** (Marcus, 1995, 2011). The interactionist orientation provided a useful lens to comprehend how distributed actors allocated and negotiated meanings around specific information artefacts and developed commonly accepted characterisations to interpret each other's conduct in the negotiations of their work activities. The deployment of a multi-sited study was beneficial in capturing the complexities and the challenges of the work practices of distributed actors operating across multiple teams, laboratories, organisations and scientific disciplines. Lastly, the design-oriented perspective helped us bring together the understanding of work practices with opportunities for the design of digital representations of artefacts that can both shape these practices and support their co-ordination.

An in-depth mullti-method multi-sited empirical study of a large European cross-disciplinary research project (the NanoArth project) was conducted to investigate the ways in which co-operating scientists organised their scientific work, using information artefacts, and the multiple challenges they faced. To this effect, a number of situated interviews with project scientists, participant observations and participatory learning exercises were designed and deployed. Several areas of practices and interactions were identified and framed the analysis e.g. *Experimental Design, Experimental Validation, Experimental Quality, Experimental Logging* and *Exchanges of Materials*. For each of these, the ways in which key artefacts were designed, maintained and used to support and mediate the practices and social interactions have been thoroughly analysed. The actual contributions made by the conduct of our study is described in section 8.3.

The rich empirical data collected on the activities, interactions, and challenges in the project led to the formulation of two abstractions of the roles of information artefacts in mediating the interactional practices across sites to co-ordinate their actions. These abstractions show how key information artefacts are designed and used collectively to assist with the exchange of distributed scientific content and thus support their social interactions as they work together on complex experimental arrangements. From this abstraction and from the empirical analysis, essential salient features of intensely distributed work were identified and articulated as *sensitising tensions.* These tensions were then used to inform a number of implications for the design of interactive technologies solutions for co-ordinative information artefacts and also, from a CSCW viewpoint, as opportunities for co-operative practices to be re-thought and re-configured. The following section provides a detailed explanation of the actual research outcomes.

8.3 Key research findings and contributions

This section discusses the contributions that this thesis makes to academic research. If the previous section emphasised the activities undertaken to achieve the objectives defined at the start of the thesis, this section highlights the tangible findings that have emerged from our research. The contributions to research made by this study on intensely distributed nanoscientific work are listed as follows:

1. A detailed analytical account of practices and challenges of co-operative scientific work, and of information artefacts utilisations, in novel intensely distributed nanoscientific settings.

2. Abstractions of the interaction-mediating roles of information artefacts to support the co-ordination of distributed scientific activities.

3. A framework of *sensitising tensions* to be considered when designing, maintaining, and deploying information artefacts to support the organisation and co-ordination of intensely distributed scientific work.

4. Implications for the design of digital co-ordinative artefacts, and for the configuring of co-ordinating practices, to assist with the co-operative organisation and conduct of intensely distributed experimental activities.

Each of these contributions are discussed further in the following sub-sections.

8.3.1 A detailed empirical account of scientific practices and challenges

The first research contribution of this thesis answers directly several calls in CSCW research for detailed empirical studies of large-scale scientific collaborations (see Blomberg & Karasti, 2013; Jirotka et al., 2013; Schmidt & Bannon, 2013). This is supported by the widely acknowledged need for the CSCW community to develop a better understanding of the ways in which actors in general, and scientists in particular, organise their work practices collectively to achieve concerted action in the type of complex dispersed co-operative work setups that are becoming increasingly prominent.

To address this, a multi-method multi-sited empirical study of NanoArth, a large intensely distributed scientific project, has been undertaken in great depth and is at the centre of this PhD research. The NanoArth project offers multifaceted settings that satisfy some of the requirements expressed in the calls by Blomberg & Karasti (2013) and Jirotka et al. (2013), as it is:

- **Transnational**: it involves fifteen partners from seven countries;
- **Cross-institutional**: it involves a wide array of organisations;
- **Scientifically innovative**: it is centred on nanomedicine;
- **Cross-disciplinary**: it requires a wide range of disciplinary specialisms;

- **Translational:** it covers the entire clinical research continuum, from the lab to the patient.

As a tangible outcome of our study, a detailed analytical account has been produced of the practices adopted by, and of the challenges faced by researchers from diverse scientific cultures conducting nanoscientific work co-operatively in the intensely distributed settings of the NanoArth project. In this account, the multiple utilisations of key information artefacts to support the collective organisation of scientific activities have been given particular attention. From this account of scientists' artefact-mediated practices and related challenges, the following findings have been identified and discussed.

- **Protocol-driven scientific work**.

  We have found that the co-design and co-development of experimental protocols drive individual and collective action. The protocol is not just a fixed repository of procedural data but it is a dynamic information artefact that is continuously co-designed and co-operatively tested iteratively in many different conditions to steer the experimental work design, validation, and conduct. In this sense, it is used as a *dynamic plan* to organise complex experimental work arrangements that is continually (re)developed to accommodate the local circumstances and handle contingencies through a process of continuous adjustment (see sections 5.2, 5.3, 5.4).

- **The protocol as a driver for co-ordination**.

  We have found that the experimental protocol is a key driver of the co-ordination of distributed actions. The experimental protocol encapsulates standard procedures and arrangements that can be used to disseminate continuously updated experimental information across space, time, and co-operating partners to enable the co-ordination of their actions. Its structural features (versioning and structuring using a template) can help provide a precomputation of tasks interdependencies that is used by all parties to articulate tasks both locally (local articulation) and globally between sites (meta-work). In this sense, it is used as collective *map* to orient the co-operative scientific work by displaying and propagating instantiations of the execution of an experimental procedure so that partners can interconnect their own work with these instantiations across space and time (see sections 5.4, 7.2.1, 7.4.2 and 7.4.4).

- **The protocol in support of cross-boundary negotiations and experimental specifications**.

  We have found that the experimental protocols both mediate negotiations and stipulate the specifics of experimental activities. During its incremental co-development to steer experimental design, the protocol is used to mediate negotiations within and across geographical, organisational, disciplinary and epistemic boundaries. It allows the progressive construction of a partial comprehension of each other's activities, sufficiently for partners to agree on a shared understanding of the distributed experimental work. When this understanding is reached and the protocol has been stabilised, it is then used to stipulate the agreed co-operative experimental procedure (see sections 5.4, 5.5 and 7.4.3).

- **The multiple shapes of the lab book**.

  We have found that the use of the lab book can take many different forms and be supported by a range of diverse media, depending on the approach that best suits the work requiring experimental data to be logged. The traditional view of the lab book as a highly structured physical medium tends to be promoted by management, as it allows a more permanent storage of data and the tracking of the experimental results for longer term upscaling towards commercialisation of research findings. This view of the lab book as a hard-bounded copy can be helpful to those scientists who highly value the ability to use a chronological structure to organise their experimental data. On the other hand, many scientists tend to rely on a combination of unstructured media to document manipulations, observations and results. They typically use any digital and/or physical media available at the bench to immediately offload the data they capture while experimenting (see section 6.5 and 7.2.2).

- **The material log in support of experimental conduct**.

  We have found that the material log plays a key role in the co-ordination of complex exchanges of materials. The material log has been introduced specifically as a centralised and standardised tool to harmonise local practices with regard to the exchanges of materials of very heterogeneous types, sizes and properties. However, a number of scientists consider that its usage is overly constraining, leads to an increase workload and may hinder the spontaneity of the exchanges that take place between teams as part of regular cross-sited experimental co-operation (see sections 6.3, 6.4 and 7.5.2).

From these empirical findings on intensely distributed scientific work in the NanoArth project, and on the ways information artefacts are used to support the organising of distributed activities, we produced two abstractions to represent the typical relationships and collective utilisations of these artefacts across sites.

8.3.2 Abstractions of artefact-mediated interactions

The understanding of the practices and challenges of conducting and co-ordinating scientific work in an intensely distributed nanomedical project, and of the ways key information artefacts were used to support these practices, led to the second contribution made by our study. This second contribution comprises two abstractions of the interactional practices and exchanges of scientific content supported by the combined use of key information artefacts. These abstractions describe how the protocol, the lab book, and the material log artefacts are incrementally co-designed and co-maintained to allow the exchanges of scientific content between teams across sites to articulate the design, conduct and validation of complex distributed experimental activities.

- **The EP/LB dyad in support of distributed experimental validations.**
  We have found that the joint utilisations of the experimental protocol and the lab book allow an exchange of scientific content (experimental procedure and experimental data respectively) which drive four different types of experimental validation: (1) *local repeatability*, (2) *distributed repeatability*, (3) *local reproducibility,* and (4) *distributed reproducibility*. The EP/LB dyad is used to steer the implementation of this validation system. Experimental observations are logged in the lab book as the protocol is tested and the protocol is gradually adapted as it is taken through multiple validation stages, informed by the experimental data captured in the lab book.

- **The EP/LB/ML cluster in support of the conduct of distributed experimental work.**

> We have found that the utilisations of dyads of experimental protocols and lab book at respective sites, combined with the use of a central material log, form a co-ordinative system that drives and integrates the distributed activities related to the design and validation of experimental work, as well as the supply and exchange of materials needed to assist the actual conduct of the work. Different versions of experimental protocols are exchanged between sites to communicate the state of completion of experimental work and define a common understanding. Lab books are used in conjunction with protocols to support experimental validation and continuous experimental development. The material log may be used to keep a record of all supplies and exchanges of experimental materials, alongside information, such as characterisations, toxicity, acceptance values and instructions for storage and use. These three artefacts are used together to afford a complex exchange of scientific content (experimental procedure, experimental data and material data respectively) that supports a set of co-ordinative practices that allow the integration of the distributed work activities towards the common goal of an intensely distributed project.

These two abstractions offer an artefact-centric view of distributed co-ordination that describes how these three key information artefacts are used co-operatively to help distributed researchers integrate their experimental work trajectories in a coherent manner in order to achieve concerted action. They are descriptive in the sense that they provide a simple rendering of what we understand to be typical relationships between different types of artefacts across different organisations and different sites.

8.3.3 A framework of sensitising tensions

Building on the understanding of intensely distributed scientific activities and challenges and on abstracting the roles of information artefacts, a theoretical framework was developed and is the third research contribution made by our study. This framework encapsulates the *sensitising tensions* that need to be managed when designing and maintaining key co-ordinative artefacts to support the articulation of distributed scientific activities. The tensions are organised as a series of two-dimensional strategies that should be considered to support, both the *local articulation* (Gerson, 2008) of situated resources and tasks, and, the *metawork* (ibid.) necessary to interlink these local tasks with those of others into distributed activities.

This framework offers the opportunity to think of approaches to both inform the design and development of interactive technologies and configure the *common field of work*, i.e. the shared understanding of the work settings and activities across sites (Schmidt & Simone; 2016), for which these co-ordinative artefacts are employed to articulate distributed practices. The *sensitising tensions* framework draws attention to the following key features of intensely distributed scientific work, as highlighted in our study:

- **Experimental Design: formalisation / flexibility and articulability / local appropriateness.**
  We contend that consistency in the structural features, naming, organising and versioning of the key co-ordinative information artefacts, i.e. the protocol, the lab book and the material log, can help scientific rigour and support the development of a common understanding of work. However, the co-ordinative artefacts need to be designed and configured in ways that allow them to accommodate the reality of local situations, situated contingencies, continuous changes in direction, and activities' interdependencies that result from exploratory scientific investigations.

- **Experimental Validation: Scrutiny / tinkering.**
  We argue that co-ordinative artefacts need to be developed with a view to encourage *tinkering* and experimental creativity, while also facilitating the thorough *scrutiny* of scientific tasks and operations at the bench level, both of which are integral to scientific enquiry. Identifying non-invasive methods for capturing *provenance data* (e.g. timings, experimenters' details, experimental inputs, parameter settings, environment variables or intermediate products), as the experiment is run, and linking this provenance data to the experimental outputs are key to help managing this duality.

- **Experimental Quality: accountability / applicability.**
  We maintain that at the macro-level of the larger experimental unit or project (Andonoff et al., 2004), co-ordinative artefacts need to be configured with both *accountability* and *applicability* as primary concerns to strengthen scientific enquiry quality. These artefacts should be organised to enhance the visibility of work (Bossen & Foss, 2016) and encourage personal responsibility to help users evaluate the consequences of their actions (Button & Dourish, 1996; Eriksen, 2002). However, when designing interactive

technologies and configuring practices, it is essential to ensure that their usages remain non-disruptive and applicable to the local settings

- **Material Distribution and Exchanges: traceability / improvisation**
  We suggest that the interplay between the main co-ordinative artefacts need to be considered so that it does not hinder the *improvised* exchange of materials that is an integral part of the trial-and-error experimental practice, while still allowing for the meticulous logging of the sharing of materials for *traceability* purposes. Setting up information artefacts so that they effortlessly enable the capture of experimental material-related data without impeding spontaneity could help support this duality.

- **Experimental Logging: lastingness / immediacy**
  We contend that logging artefacts need to be devised such that they can handle the duality between *immediacy*, steered by the need to capture key data *in-situ* as the experiment is unfolding, and *lastingness*, motivated by the necessity to keep a semi-permanent record of the experimental outputs to potentially upscale the experimental results and develop patient-focused solutions. Designing ways to facilitate the immediate capture of data while also affording different types of archiving effortlessly can help with this tension.

The actual implications for design and practice that we derived from this framework of *sensitising tensions* are discussed in the next subsection.

8.3.4 Implications for design and practice

The framework of *sensitising tensions* has been developed to inform the design of interactive technologies to support the co-ordination of intensely distributed scientific work. In the view of CSCW research subscribed to in this PhD, the empirical understanding of the practices and interactions can inform design while design considerations also shape the practices of setting up and conducting co-operative work (Bjørn & Boulus-Rødje, 2015). The empirical findings in our study have highlighted critical features of intensely distributed scientific work and the sensitising tensions have revealed theoretical considerations that should be taken into account when making decisions for the design of co-ordinative artefacts (Crabtree et al., 2012). The enactement of this sensitising process – what Bjørn & Boulus-Rødje (2015) refer to as *enacting analytical sensibility* – consists of bringing together the understanding of work practices with opportunities for the design of digital representations of artefacts which can both shape these practices and support their co-ordination.

The implications for the design of interactive solutions and the ways these can influence the practices of intensively distributed scientific work are reviewed as follows:

- **Protocol design based on a flexible template.**
  We suggest the design of experimental protocols based on a simple, flexible and scalable template-driven structure. The capabilities to easily create, name, version, and edit experimental protocols in a highly responsive manner should be provided to all co-operating scientists. They should also be able to view and dynamically update an overall visual map of the complete array of interlinked protocols, so as to have a current awareness of other's activities and the opportunity to easily inter-link their experimental design with those of others

- **Multimedia annotating of protocols (and possibly lab book and material log entries).**
  When co-designing protocols, we suggest the introduction of multimedia annotating, and possibly collaborative tagging, in order to provide additional contextual information in a range of formats, support negotiations, and improve shared understanding. These can also be used for lab book and material log entries to allow co-operators to comment on and query experimental data items or movements of materials. This would help make the experimental design more contextually suitable, while at the same time providing partners with the opportunity to interconnect their own experimental activities with those being designed.

- **Flexible four-level strategy for experimental validity.**
  We recommend that a flexible four-level strategy should be adopted to ensure experimental validity. Experimental arrangements with various levels of distribution should be highlighted, and a suitable level of *repeatability* and *reproducibility* (local and/or distributed) should be recommended in a non-invasive manner to help scientists evaluate

the applicability of experimental validation and make decisions for the right level accordingly.

- **Digital knowledge spaces for protocols and contextual data.**

  We advocate the creation of knowledge spaces for each experimental study to bring together all related experimental protocols and additional data resources to provide the multi-sited project team with access to a current and consistent repository of additional contextual information. This could include publications, material characterisations, results of previous attempts made on-site or at a different site, as well as comments, observations and interpretations on specific experimental manipulations.

- **Provenance data capture.**

  We recommend the creation of a simple metadata entry app to enable the non-invasive capture of key data about an experiment e.g. solution composition, temperature, species, equipment used and calibration levels. It should be designed to be highly tailored to the experimenter's needs and to flexibly support offloading to capture key data during experimental manipulations. Timestamping and capturing the experimenter's details may further help to capture relevant provenance data, essential to the articulation of experimental work across teams.

- **Timeline-based planning and co-ordination.**

  We recommend the introduction of interactive visual timeline-based planning and co-ordinating solution that provides time-critical project information and updatable representations of key project events. This solution could improve the common understanding of time-critical specifics of the experimental work arrangements and inform individuals' personal responsibilities to better support and enforce accountability.

- **Standardisation for the synthesis and supply of highly variable experimental materials.**

  We suggest the adoption of a digitally-mediated standardisation strategy for the development and distribution of highly variable materials such as nanoparticles. A master batch and related primary batches should be characterised, tested, and tracked regularly to ensure their stability and the validity of their range of acceptance. Periodic programmed alerts should serve as a reminder for these regular checks. All data relevant to the synthesis of materials (characterisation, toxicity test data, range of acceptances, additional properties) should be effortlessly accessible to all to help decide whether to accept or reject batches or to test them further. Adequate feedback mechanisms should be implemented to improve the quality of the synthesis and decision-making.

- **Digitally-enhanced exchanges of all experimental materials.**

  We recommend the use of digital probes to capture data during shipment and RFID tagging, when possible, to track the status and utilisations of material in a non-invasive manner. Access to the data should be straight forward and customised to these scientists involved in the exchanges of materials.

- **Lightweight mobile solutions to log experimental data.**

  We propose the possible introduction of digital pens or equivalent to help capture multimedia-based data (rough notes, numerical data, diagrams, sketches, mind maps, concept maps, etc.) as the experiment is being performed.

- **Flexible lab book solutions.**

  We suggest the use of flexible lab book solutions with multi-structure capabilities to accommodate multiple activities in parallel, and the ability to collectively annotate experimental observations and provide reflective commentaries.

- **Integration of suggested interactive solutions.**

  Finally, we recommend the integration of a visual timeline-based planning solution (which provides information on collective experimental work units and arrangements) with the digital knowledge spaces and the visual protocol map (which brings together protocols and visually displays the interconnections between protocols, respectively) and with the metadata entry app (which allows the straight-forward capture of experimental data). Furthermore, we could also propose that the lab book (or equivalent digital logging tool), the material tracking solution (e.g. using RFID tags) and the material log be also integrated with the timeline, the knowledge spaces, the protocol map and the metadata entry app. We contend that integration of the above-suggested interactive solutions for the key information artefacts under investigation would allow for the exchange of scientific content represented in the proposed abstractions of artefact-mediated interactions (see section 8.3.2) to be digitally implemented and would thus contribute to a greater co-ordination of intensely distributed activities towards achieving concerted action.

These general orientations provide a great opportunity consider how intensely distributed science can be designed, conducted, and co-ordinated to manage the key dualities of this type of co-operative work as highlighted in the previous section 8.3.3.

8.4 Research limitations and future directions

Our study in this PhD does not aim to provide an exhaustive account of the various roles of information artefacts in supporting the complex co-ordination of intensely distributed scientific work. Rather, it intends to provide in-depth insights into the ways in which a number of key information artefacts are used within the precise settings of a large cross-disciplinary, multi-sited and translational research project in the specific field of nanomedicine. Even though this project offers a great deal of complexity and the selected artefacts are representative of the type used in many other scientific projects, hasty generalisations are discouraged. Further studies on the use of information artefacts as co-ordinative artefacts in other scientific projects would help to establish whether these findings are applicable to other settings and whether new findings emerge. Variable factors which could increase the scope of representation may include the sizes of the projects, the degrees of distribution, and the ranges of organisations and scientific disciplines involved.

Another shortcoming may be identified in relation to the conduct of our empirical study. The multi-method multi-perspective and multi-sited adopted in this research allowed us to meticulously investigate the interactions between distributed scientist as enabled through the use of a number of key artefacts and to produce a detailed empirical account of these practices. Ideally, a greater immersion in the field at several sites of the investigated project could help capture both the synchronous and asynchronous effects of the changes made to the artefacts on the co-ordinative practices between co-operating scientists. However, this would most likely require an entire team of researchers to be operating in the field at the same time to capture the real-time impacts and longer term-effects of artefact-mediated interactions on the co-operative endeavour.

Additionally, criticism may be formulated concerning the nature of the suggested implications for design and practice and whether they provide helpful insights to technology designers and practitioners alike. If every effort has been made to base these implications for design and practice on the settings of the investigated project, and to make them applicable to the concerns of the NanoArth scientists (through the use of *sensitising tensions*), they have not been validated directly with the actors concerned. It could be greatly beneficial to take this research even further and use some of the identified implications for design and practice in the settings of other scientific projects to directly inform the design of co-ordinative IT solutions and the organisation of distributed scientific work and to evaluate their impact directly with the actors involved in these projects.

8.5 Closing remarks

Our research study has provided a unique opportunity to probe the various ways in which very diverse scientists operating in different disciplines come together from diverse locations and organisations and combine their efforts to research truly complex and fascinating nanomedical problems3, with the ultimate goal of designing diagnostic systems or therapies for patients. However, it is the combination of disciplinary, theoretical and methodological perspectives adopted in this work that has made it a worthwhile experience and placed me, the researcher and author of this thesis, in a unique position to investigate this phenomenon and provide in-depth insights. The STS positioning adopted in this work has offered me a very useful viewpoint to study the ways in which scientific knowledge is continuously negotiated through social interactions and the use of representations. Furthermore, the selected orientation, also greatly informed by the CSCW discipline, has been invaluable for me to examine the ways in which information artefacts are used to co-ordinate different practices and understandings and how digital representations can be designed to support this co-ordination and inform the optimal organisation of work. Lastly, the anthropologically/ethnographically-informed approach has given me a unique foray into the fascinating world of scientists working on an interdisciplinary translational nanomedical project and to gain insights on their daily activities, interactions and challenges “from within”. From all these findings, what stands out the most for me is the scientists’ relentless efforts, boundless creativity and infectious enthusiasm. The very strong relationships I have forged with them have truly inspired me to take this research to the next level, and construct an even better understanding of the ways they conduct intensely distributed science to tackle ever more challenging biomedical problems together and achieve concerted action to resolve them; and to ultimately use this understanding to design best suited interactive solutions to help optimise the co-ordination of their efforts in pursuit of their scientific endeavours.

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Appendix A ERA: Framework Programmes

The five biomedical translational research projects under consideration in our research study are all funded as part of the European Research Area (ERA). The ERA is a pan-European structure of scientific research programmes set up by the European Research Council (ERC) to integrate the scientific resources of the European Union (EU) members with the aim to cultivate cross-institutional collaborations with a view to tackle societal problems in the medical, technological, industrial, socioeconomic and environmental areas (European Commission, 2013).

As part of the ERA, a series of Framework Programmes for Research and Technological Development – referred to simply as *Framework Programmes (FPs)* – have been introduced by the ERC to provide the funding and foster these research collaborations (European Commission, 2012) as indicated below:

- FP1 started in 1984 and FP5 terminated at the end of 2002; each of these programmes covered a period of five years.
- FP6 spanned a five-year period from 2002 to 2006 and had a budget of over €19 billion.
- FP7 ran from 2007 to 2013 and saw a huge leap in regard to the funding as it was allocated a budget of over €55 billion.
- The current Framework Programme, renamed Horizon 2020, started in 2014 and will run until 2020 with a funding of nearly €80 billion.

Each Framework Programme is further broken down in a series of *Thematic Priorities* that aim to address a range of societal issues in various areas such as health, food, biotechnologies, ICT, nanosciences, energy, environment, transport, socio-economic sciences and humanities, space and security (European Commission, 2015). Thematic priorities are themselves divided into several *clusters or topics* (depending on the Framework Programme) pulling together projects that investigate similar issues to foster inter-project collaborations. Within a cluster or topic, projects can also be grouped in *sub-clusters* or *sub-topics* to create even closer ties between the project. Seminars and workshops may be organised to bring together scientists from different projects in the same cluster or sub-cluster to better encourage the sharing of information.

Appendix B Guide for initial interview-based study

1. INTRODUCTION

1.1. Can you tell me a little bit about yourself, about your background and your expertise?
1.2. Can you tell me a about your research?
1.3. Can you tell me about the research projects in which you are currently involved?
1.4. Can you tell me about any notable large research projects in which you are or were involved?
1.5. How many partners are/were involved? How many sites?

2. SETTING UP THE PROJECT

2.1. How did you find out about the large research project on which you are working?
2.2. How was the project team/consortium assembled?
2.3. Have you had any experience of leading a project? In which capacity?
2.4. Have you had any experience of leading the contribution of a site to a project?
2.5. How did you locate the other researchers with whom you are co-operating on the project?
2.6. How did you select the right partners to work on your project idea?
(OR) how were you approached and selected to work on a project idea?
2.7. Did you recommend any specific researchers or possible partner institutions you thought should be involved in the project?
2.8. How did you ensure that all partners fitted within the project consortium?
2.9. Were there any problematic instances in relation to the involvement of a partner or partners in the project?
2.10. Were any involvements terminated before the end of the project?

3. LAYING THE PROJECT FOUNDATIONS

3.1. Where did the main idea of the project originate?
3.2. How was the main project idea further developed?
3.3. Can you tell me about the configuration of the project consortium?
3.4. Can you tell me about the management structure in the project?
3.5. Can you tell me about how decisions were made in the project?
3.6. Can you tell me about the specific contribution of your site/your team to the project?
3.7. How was the initial project proposal produced?
3.8. Who had an input in the authoring of the proposal? Did you participate in it?
3.9. Were any external partners involved in writing the proposal?
3.10. How was the decision-making organised in regard to the authoring of the proposal?

3.11. How was the work allocated between the different partners of the project consortium in the proposal and later?
3.12. How were timings allocated to the different units of work in the project proposal?
3.13. How were the deliverables defined for each partner's contribution to the project?
3.14. Were there any problematic instances right at the start of the project with the allocation of the work to the various partners?

4. COMMUNICATING AND SHARING RESOURCES

4.1. How did you first initiate the communication with the project partners?
4.2. How do you regularly communicate with these partners?
4.3. How often do you communicate with partners?
4.4. What communication channel do you use to communicate with partners?
4.5. How often do you physically get together with partners on the project?
4.6. What happens when you meet with project partners?
4.7. What do you get out of these face-to-face meetings?
4.8. Were there any problematic instances of communication with/between partners?
4.9. What type of documents do you exchange with partners?
4.10. How do you share these documents with partners?
4.11. How do you work together on these documents with partners?
4.12. How did you first initiate the communication with the project management team?
4.13. How do you regularly communicate with management?
4.14. How often do you communicate with management?
4.15. What communication channel do you use to communicate with management?
4.16. How often do you physically meet with management?
4.17. What type of documents do you exchange with management?
4.18. How do you share these documents with management?
4.19. Were there any problematic instances of communication with management?

5. WORKING TOGETHER ON SCIENTIFIC STUDIES

5.1. How do you define the practicalities of work with a partner?
5.2. How do you find out about the experiments that your partners do?
5.3. How do they find out about your experiments?
5.4. How do you share ideas on experiments with a partner with different expertise or whose work you are not familiar with?
5.5. How does a partner explain you how they do their experiments?
5.6. How do you explain a partner how you do your experiments?
5.7. Do you get to show your experiments to partners? How?
5.8. Do you get to see partners conducting experiments? How?
5.9. How do you document the design of your experiments?
5.10. How do you document the conduct of your experiments?
5.11. Where do you capture and store data about your experiment?
5.12. How do you test whether your experiments work?

5.13. How do you document the results of your experiments?
5.14. How do you share the results of your experimental work? With whom?
5.15. How critical is it for you to have access to your partners' experimental design? Experimental data? Experimental results?
5.16. Were there any problematic instances when working with partners on experiments?

6. MONITORING AND REPORTING

6.1. How does management monitor your work?
6.2. Does management look at the inner details of your experiments?
6.3. Does management ask to have access to your experimental design? Experimental data? Experimental results?
6.4. How often do you report to management?
6.5. What channels do you use to report to management?
6.6. How do you share with both management and the rest of the project consortium your experimental outputs?
6.7. Do you share the details of your work with external parties outside the project consortium?
6.8. Do you interact with funding bodies? Do you report to them?
6.9. Were there any problematic instances in which deliverables were not met?

Appendix C Summaries of interview transcripts

1. Summary of interview transcript with MRI Physicist, Imaging Unit, Geneva, CH

(Code: Interv_MRIP; date: 23 May 2012)

– Role: MRI physicist i.e. medical imaging
- NanoArth
- Another Swiss national project with clinical aspect

– Collaboration
- Internally inside University
- Externally with sites in Nijmegen (rheumatology department), Berlin (rheumatology lab) and Salzburg (musculoskeletal institute)
- Close relationship with material and powder lab in Lausanne

– Work in NanoArth
- phase 1
  - developing sequences for MRI
  - optimising protocols
  - developing computer program to automate sequences
- phase 2
  - scanning animals
  - analysing images: measuring signals and densities i.e. post processing images
  - conducting statistical analysis

– Protocol design
- was given Work Packages and description of expected deliverables
- used experience of using nanoparticles for different diseases
- used experience in MRI imaging
- But randomness in whether sequences are going to work with these specific nanoparticles.
- initially tested animal models without complexities of SPIONs
- aim was to set up a protocol that would result in a model that works, that would be predictable and reproducible
- Refined protocol to make it work with the nanoparticles
- protocol was designed internally in Geneva with
  - radiologist who had knowledge of clinical techniques
  - PhD student in medical studies started developing biological models
  - biologist who helped developed the biological models at cellular level.
- Also got a protocol from Berlin which was then adapted

– Protocol development process

- collective process though brainstorming to add all different aspects
- need to interact with lab mates as some things may work with animal model but not necessarily translate on the image
- Need to align all the timings of all the experiments as they have an expiry date
- Informal protocol version management until end of the project when protocols are finalised for delivery and made accessible to everyone
- Protocol become quite stable fairly quickly
- Possibility to add a module or a treatment or change dose.

– Testing of the protocols

- testing own biology experimental work continuously
- tend to get the same person to test their own biology protocol for consistency
- biology has more variability
    - may depend on the person e.g. the way they inject the NPs.
    - may decrease with time as people get to work together and tend to harmonise their techniques.
- swapping within team analysis to repeat measurements and reading of the image

– Staff visits, training and demos

- Lausanne
    - proximity to the site that produces the NPs in Lausanne helps
    - Instances of collecting the NPs directly from producers in Lausanne, gives opportunity to find out how they operate
    - Lausanne brought both cells and NPs to Geneva to scan to see whether physical properties were correct before being added to the model.
- Berlin
    - Instances of visits from Berlin site who does cellular work, was interested to find out what was happening when doing imaging
    - Berlin Brought their cells loaded with NPs to Geneva to scan to see whether physical properties were correct before being added to the model.
- Salzburg
    - Instances of visits from Salzburg site who do analysis software for images who wanted to see images being used to tailor software to specific application
    - Brought the analysis software, imaging measurement software to customize it to the project.
    - Exchanges around tweaks to customize software e.g.
        - Add volume as well as intensity
        - Can we have the output as a histogram
    - Tested the software and gave them feedback via emails or during feedback
- Nijmegen
    - Instances of staff from Geneva going to Nijmegen to get trained on model to get bigger picture
- Drive by EU to organise knowledge exchanges particularly for younger researchers.

– Exchanges with nanoparticles developers in Lausanne.
- Instated direct communication with staff which produce nanoparticles i.e. with lab techs and scientists
- Exchanges with Lausanne every couple of months, on ad-hoc basis, once a month when deadlines
- Some technical problems e.g. Instances of batches of particles with different properties than expected or than required
- Quick feedback to them even though imaging may take a while to identify causes of potential problem
- Instances of need of producers to test again in their labs

– Communication via email
- Communication via email mainly as being lab-based prevent much else.
- Communication with one site is OK, copy management
- More general communication with all partners becomes very messy as not everyone replies to all
- Email overload with many documents, difficult to see what version of document and who has seen what.

– Lab book
- "Scribbly" lab book for personal use in heat of moment in-situ.
- Notes down observations with times
- Scribble things that are difficult to explain to other experimenters in same lab.
- Later compiled in documents
    - Lists of samples e.g. animals or histology slides to be shared internally
    - Results in powerpoint e.g. images, graphs, etc to be shared globally.
- Scanner records automatically imaging data with date and time for archiving.

– Archiving docs
- Local copies on individual PCs
- Uploading docs on cloud-based solution to share
- Important copies kept locally otherwise everyone could change them.

– Sample tracking
- Tracking movements of materials in centralised material log, in theory.
- Not really used in Geneva
- Need to combine various posting into one object e.g. Geneva receiving nanoparticles from Lausanne and then sending resulting image to someone else.

- Limitations
  - file sizes
  - large number of images
  - difficulty to upload image files
  - Problem of standardisation across sites
  - Issues of definition of what a sample is
    - Physical object or electronic piece of info?
    - Animal or part of an animal?
  - Not sufficiently tailored to activities in specific sites
  - Introduced late in the project, uploading information at this stage would create a lot of overheads
- Management wants to centralise protocols also.
- Send protocols to project manager at this stage and she uploads them.

– Reporting

- Monthly Reports needs to be uploaded to keep record of significant milestones.
  - Significant results
  - Admin stuff
  - Conference visits
- Useful to monitor activities of lab and other sites.
- Makes it easier to find out what has been done particularly as project is getting increasingly complex.
- Reporting practice has become more embedded, ongoing reporting at the end of every experiment. This feeds into bigger reports at the end of larger period of time, makes it easier to write, used as sources for producing larger reports.

2. Summary of interview transcript with Rheumatology Scientist & Leading Partner, Rheumatology Lab, Berlin, DE

(Code: Interv_RS; date: 08 March 2013)

– Introduction

- Head of lab
- Work on bioenergetics on immune cells and other cells.
- Translation work covers many fields in research.
- Leading partner in NanoArth.

– Experimental work

- In-vitro toxicity tests
- Test impact of nanoparticles on immune cells
  - immune cell survival functions.
  - Immune cell differentiation.

– Protocol design

- Start of project: Principal Investigator and Leading Partners had many discussions on
    - Types of materials to collect and analyse
    - NPs to be injected in cells to analyse in-vitro toxicity
    - Duration of experimentation phase takes into account the life expectancy of cells
    - Control mechanisms
- Design protocols at Rheumatology Lab in Berlin
    - Large quantities of cells to ensure generalisation
    - Sharing them with management of project
    - Sharing them with other partners at bi-annual meeting
- Design process
    - Read existing literature
    - Exchanges with other experienced member of staff who had used nanoparticles at clinical stage
    - Re-adaptation of other existing toxicity test protocols despite the fact that nanoparticles behave differently.
    - Trial and error process
- Exchange of protocols
    - Posting established protocols centrally for others to see.
    - Exchange became better as project unfolded as opposed to start of project when everyone tries their own thing on a trial and error basis
    - But transferability of data and protocols limited
        - in-vitro toxicity project in Berlin (rheumatology lab) different from in-vivo.
        - Using rats and mice is different
        - Berlin uses different quantities of nanoparticles.

– Exchanges with other sites

- Various sites
    - Lausanne (material and powder lab) and Geneva (imaging unit) sent material to Berlin (rheumatology lab): impact of nanoparticles
    - Geneva (imaging unit) also sent the bone marrow of rats they use to Berlin (rheumatology lab) to look at the iron nanoparticles content of these cells
    - Exchanges between Darmstadt (pharma) and Geneva (imaging unit) with many discussions
- Exchange of protocols via emails
- Exchanges regarding simple practical problems about exchanged materials
    - Number of particles
    - Medium used
    - Types of cells used: primary cells, tumour cells or other cells
- Importance of initial meetings and setting up good social relationships

– Staff exchange, training and demos

- Berlin (rheumatology lab) sent member of staff to Lausanne (material and powder lab) to learn how to handle nanoparticles
- Staff spent 2 weeks there and taught everyone else in Berlin
- Documentation of this learning process
    - Presentation slides
    - Protocols
    - Lab book to capture execution of the protocols which she made accessible to others on Berlin site

– Archiving Protocols

- Physically as draft in lab books as they are being worked on.
- Electronically as PDF file in a certain structure when they are finalised as imposed by German ISO norm which gives the certification to the laboratory but can be overhead.
- Uploaded them on cloud-based solution and admin uploaded them on centralised protocol web space.

– Sending of materials from nanoparticles developers in Lausanne

- Send nanoparticles alongside
    - Characterisation info., concentration, purity
    - Documentation of the development process.
    - Storage conditions
- Duplication
    - paper with postage
    - electronically via email.
- Initially sent nanoparticles back and forth to see how they were affected by transport
- Retesting of the nanoparticles once received
    - Own tests in Berlin for biological hazards i.e. toxicity tests.
    - Other tests of the physical and chemical properties cannot be redone as do not have the necessary equipment.
- Change in the transport procedure created problem and resulted in loss of some of the nanoparticles.
- Feedback mechanisms to nanoparticles producer
    - email works much better.
    - note in the centralised repository will not be picked up.

– Exchanges with particle developers

- Synchronous comm. over Skype.
- Common database for clinical data accessible to all partners.
- Provide info upon request.
- Attendance to seminar, workshops and summer schools.

– Lab books

- Paper-based lab books
- Institutional barriers to having electronic ones.
- Need to be thoroughly maintained.
- Need to be signed.
- Evolution over the years
    - Initially just a number of pages.
    - Had to be signed.
    - Couldn't leave the lab.
- Working at 2 different sites Rheumatology Lab and Arthritis Research Centre – Inter-lab work
    - Requires 2 separate lab books.
    - Lab books cannot leave premises.
    - Lab book cannot be disposed of for 10 years.
    - Sometimes duplication of work.
    - Cross-reference work between lab books for methods and results.
    - Also references experimental data in electronic format.
        - Raw data e.g. flow cytometry data (laser-based, biophysical technology employed in cell counting, cell sorting, biomarker detection and protein engineering)
        - Results e.g. microscopic images, images
        - All data saved both locally and remotely on server with automatic synchro.

– Introduction of electronic lab book: thoughts

- Benefits
    - Centralisation into one lab book
    - Increased reliability
    - Use of new techs such as smart cams or Google glass to document work in easy straight forward
        - Embedded within practice.
        - No writing required.
        - Capture verbal explanations and actual techniques.
        - Document for yourself and for others.
        - Ability to review your own work and learn from your mistakes.
        - Ability to come in and out of it.

- Issues
    - Cannot replace existing lab books
    - Becomes a massive overhead
    - Takes some convincing
    - Requires intervention from external IT experts which do not always deliver

3. Biomechanics Engineer, Musculoskeletal Centre, Berlin, DE

(Code: Interv_BE; date: 30 July 2013)

– Introduction

- Doctoral student since 2010 in engineering biomechanics at NanoArth
- Background in medical engineering
- 2 cohorts of patients i.e. intensive volleyball athletes to measure cartilage degradation. Higher risk patients, patients which had rupture with higher risks of arthritis
    - younger patients
    - older patients
- 3 types of measures
    - Function measurement: measure function within knee joint. Done in Berlin (musculoskeletal centre).
    - Development of cartilage volume analysis: function measurement is correlated with development cartilage volume over period of 2 years. Done in Salzburg (musculoskeletal institute).
    - Development of biomarkers measurement: take blood, serum and urine sample to evaluate development of biomarkers over time. Done in Lund (rheumatology & skeletal biology lab).
      Hypothesis that there are higher levels of biomarkers in these fluids when cartilage is damaged.
    - Longitudinal study of 2 years with two timepoints.
- Correlations between these 3 things.

– Exchange with other sites

- Berlin
    - Patients physically in Berlin
    - MRI scans
    - Serum sample measurements
- Salzburg
    - Salzburg researchers came to Berlin
    - Interacted with radiologists and experts in Berlin to develop MRI measurement plan/sequence i.e. a protocol of 9 sequences.
        - Cartilage
        - Ligaments
        - Overview of clinical process in knee joint
    - Tested MRI measurement sequences with test sample subjects in Berlin
    - Once sequence has established has being reliable and usable by Salzburg, measurements done with all subjects
    - MRI data was then sent to Salzburg for it to be analysed.

- Lund
    - Collected serum sample in Berlin with same subject at the same time as MRI scan were done at the same timepoints
        - Reuse same patients.
        - Avoid variability in their conditions “feel better on a different day”.
    - Storage of serum in Berlin.
    - Serum samples sent in Lund for analysis.

– MRI sequence protocol development process

- Intensive collaboration with Salzburg
- Trial and error approach: measurements in Berlin, analysis in Salzburg, back and forth several times

– MRI Protocol design

- Kick-off meeting in Berlin in early 2010
- Discussion of first draft or protocol and initial measures
- Involved
    - Radiologist
    - 2 Biomedical engineers
    - Physicist
    - Clinical Doctor
- Open discussion where everyone took part.
- Clinical partners with MRI expertise have decisive input.
- Use of previous research because of high expertise in Salzburg.
- First draft was document for the protocol of sequences which was sent around to everybody to review and comments.
- Tested with test sample of subjects i.e. researchers who were not athletes to test the methodology and technique to adjust and calibrate the sequence.
- Adaptation of the document from what was learnt from test measurements.
- Protocol then frozen, essential for it not to change as it has to be identical to take first and second set of measurements at different time points which then gets compared.

– Experimental Results

- Upload directly result files onto Salzburg server.
- Keep a separated log of uploaded documents.
- Regular meetings within the project help answering questions which have built up.
- Discussions over the phone on preliminary data.
- Upcoming in-depth discussions of the analysis of the follow up measurements when meeting next.

– Serum sample analysis Protocol Design

- Less interaction as expertise of the analysis of the serum sample resides mainly in Lund.
- But many interactions to discuss and finalise practicalities around protocol.
- Discussions took place during different visits and Skype talks.
- Protocol became stable rapidly and recorded on document.
- Minutes taken.
- Initially high-level protocol and then subsequently expanded.
- Protocol design was affected by change of directions in project.
- Protocol then finalised as one document.

– Recording of experimental data

- Use list of patients.
- Records measurements dates against patients.
- Updates status of analysation work.
- Use of a lab book.
- Phase transcription from notes to electronic format collectively to ensure internal validation.
- Use internal database where all results are collected as raw data.
- Access not required by management just by partners working on this specific work.
- Management needs reports of results but not raw data.
- Verification of data internally through meetings and discussions.

– Sending materials and samples

- Setting up Skype talk to finalise practicalities.
- Need to ensure that conditions are respected e.g. temperature.
- Need to interact with the other group in Berlin.

Appendix D Summary of learning exercise transcript

Scientific Coordinator, Project Manager and Nanoparticles Developer, Research Project Management Firm, Greater Lausanne CH

(Code: PLE_1; date: 20 February 2013)

– Protocols

- Issue of confidentiality: protocols have commercial and legal value; IP needs to be taken into consideration.
- Differences in availability between different projects:
  - some projects make protocols publicly available
  - other projects give out their templates.
- First level of standardisation.
- Specific to synthesis of particular type of nanoparticles, not transferrable
- Differences in standardisation of protocols between partners in the project consortium

– Quality control & lack of transparency of experimental results and methods

- Only positive results are shown.
- Negative results tend to be hidden.
- Results that are not quite the expected ones should be given more emphasis; it can help with writing protocols that are repeatable.
- Importance of how results are presented.

– Specific issues with regards to toxicity:

- Importance of risk perception and assessment
- Bias in the field: assumption that nanoparticles are toxic
- Lack of interest for research that shows that nanoparticles are not toxic
- Oversimplification of toxicity issues, toxicity only in specific conditions

– Realisation in research community for need

- To rebalance bias
- For greater transparency
- For a European standardisation body and lab to which particles can be sent for objective toxicity test

– European initiatives

- DaNa
- Nanommune
- EMPA
- Swiss Precautionary Matrix
- Cluster of EU project
    - 2 clusters
        - Nanomaterial and health i.e. nanomedicine
        - Nanotoxicity
    - Not always great interest from participating partners.

– Standardisation challenges

- Great variety of disciplines involved
- Involvement of academic and industrial partners with differing practices.
    - Standardisation in industry is de-facto.
    - Standardisation in academic research can be perceived as constraining.
- Time consuming.

– Challenges on research

- Increasing blurriness between fundamental research and R&D Research.
- Increasing prominence of applied research with huge pressure to patent which can delay publishing efforts and thus feedback from research community.
- Shortened development time i.e. pressure to develop marketable products very rapidly.
- Concern over confidentiality and nature of what can be divulged.
- Huge funding pressure with very high level of competitiveness to secure finding.
- Concern over separation between fundamental research in Europe and R&D/production in Asia.
- Pressure to clearly position research to address societal challenges.

– Particle production process

- Measures in place to ensure consistency in production of nanoparticles.
    - Production of a master batch.
    - Definition of a Range of Acceptance (RoA).
    - Creation of a Certification of Acceptance (CofA).

– Issues of consistency of nanoparticles

- Depends on industrial material used for coating.
- Apparently Identical nanoparticles can have very different behaviour in-vivo.
- Not addressed by other researchers.
- Need for finding ways to identify different types of materials and record them.
- Need for archiving materials used in synthesis.
- Need for keeping a track of which materials are being used by which synthesis and connected to which protocol.
- Need for providing every sample with an up-to-date appropriate CofA.

- Need for creating a master/mother batch and fully characterising it.
- Need for creating a small number of children batches to determine a RoA which is appropriately narrow.
- Use RoA as standard to accept or reject every subsequent batch.
- Need for re-characterising mother batch as it may change with time.
- Need for characterising at the source and at destination to see if it still fits within RoA.
- Need to send sample of particle with protocol on how it was synthesised but also protocol on how to store it.

– Interactions between nanoparticles developers and nanoparticles users

- Need to interact with recipient to establish how they are going to use the nanoparticles that are sent
  e.g. connect with pharma person to discuss how the formulation for injection is going to be produced.
- Challenge:
  - Lack of interest from recipient partner to understand synthesis process, just want to use them.
  - Differing perception of what nanoparticles are in different disciplines e.g. biologists only see them as carriers of drugs to organs.
  - Different scientific cultures have different perceptions of project and nanoparticles.
- Need to organise different levels of communication and feedback channels involving all partners and perhaps also external EC people.
  - Initiation exchange
  - Clarification exchange
  - Factual exchange
- Need to create different level of prioritisation to eliminate email overload.
- Need to create multi-dimensional communication
  - Internal communication between consortium members
    - protocols
    - Feedback and quality control
  - Internal communication between project management and various sites.
  - External communication with outside world for dissemination
  - Codes of conduct and ethical guidelines.

– Feedback from nanoparticles users to nanoparticles developers

- developers
  - Send fully characterised nanoparticles with CofAs indicating RoAs.
  - Conduct pre-toxicity tests on nanoparticles before sending them with neutral cells not related to the illness or infection being investigated.
  - Provide nanoparticles users with appropriate protocols for them to conduct the tests themselves.
- nanoparticles users
  - Feedback not to be given too early from very preliminary tests as premature testing may create additional problems.
  - Re-characterise nanoparticles upon arrival.

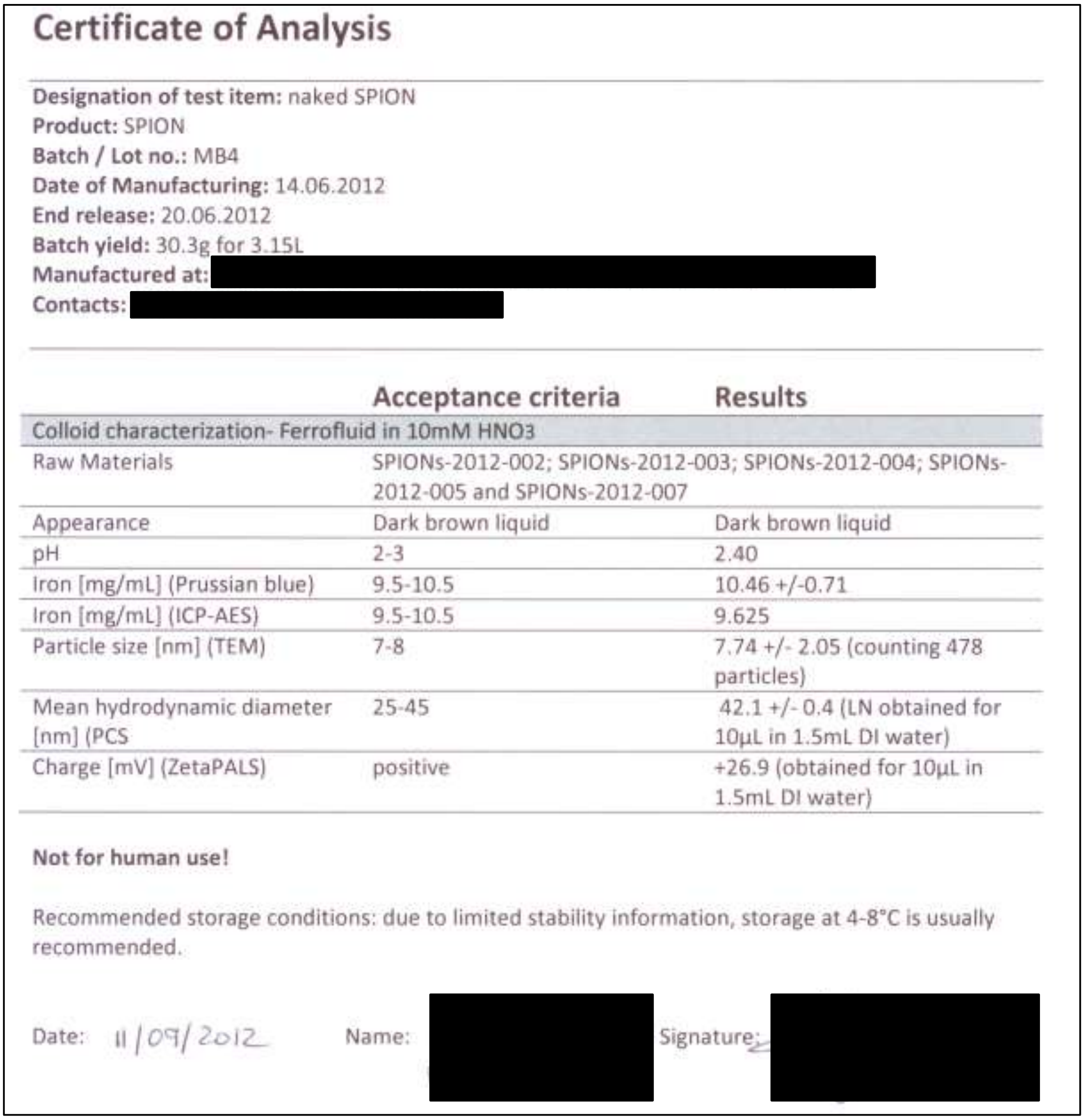
        - Conduct tests several times to ensure repeatability and reproducibility.
        - Record feedback and to communicate it on to more global meeting.
        - Record details of received nanoparticles.
    - Ideally, re-test for toxicity depending on time between prod and use and storage conditions
        - if nanoparticles produced a long time ago
        - if nanoparticles stored for a long time before being used
        - if storage faulty
        - but nanoparticles receivers may not have facilities to do it themselves

    → re-testing should be easy, flexible, customisable tests at different times depending on the utilisation of nanoparticles

– Need for tech transfer i.e. demo in person

- Sometimes training in private companies to learn about specific techniques e.g. assays.
- Intra-project visits to demonstrate specific techniques and see how partners using the nanoparticles.
    - Importance of informal networking opportunities to articulate work.
    - Need for “in the lab” researchers/junior researchers to meet other “in the lab” researchers without management.
    - Need for very practical workshops e.g. summer schools.
    - Possibility to join remotely e.g. on Skype.
    - Need for openness and spontaneity.
    - Need for centrally storing project-relevant information and to refer to central repository as part of intra-projects visits.

Appendix E Example of a Certificate of Acceptance



Certificate of Analysis

Designation of test item: naked SPION
Product: SPION
Batch / Lot no.: MB4
Date of Manufacturing: 14.06.2012
End release: 20.06.2012
Batch yield: 30.3g for 3.15L
Manufactured at: [redacted]
Contacts: [redacted]

	Acceptance criteria	Results
Colloid characterization- Ferrofluid in 10mM HNO3		
Raw Materials	SPIONs-2012-002; SPIONs-2012-003; SPIONs-2012-004; SPIONs-2012-005 and SPIONs-2012-007	
Appearance	Dark brown liquid	Dark brown liquid
pH	2-3	2.40
Iron [mg/mL] (Prussian blue)	9.5-10.5	10.46 +/-0.71
Iron [mg/mL] (ICP-AES)	9.5-10.5	9.625
Particle size [nm] (TEM)	7-8	7.74 +/- 2.05 (counting 478 particles)
Mean hydrodynamic diameter [nm] (PCS	25-45	42.1 +/- 0.4 (LN obtained for 10µL in 1.5mL DI water)
Charge [mV] (ZetaPALS)	positive	+26.9 (obtained for 10µL in 1.5mL DI water)

Not for human use!

Recommended storage conditions: due to limited stability information, storage at 4-8°C is usually recommended.

Date: 11/09/2012 Name: [redacted] Signature: [redacted]