

# Designing software in support of workplace activities – embedding e-science applications

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## Abstract

The development of large-scale, distributed computer systems for e-Research requires the engagement of multi-disciplinary teams in design activities as well as the management of multi-institutional partnerships. Both the design process and its associated management are demanding activities. The first requires skills in communication and negotiation between different cultures; computer scientists conducting research in parallel to the project's demands, and end-users who want useful applications that support their research activities. The second requires skills in the coordination of distributed academic and commercial partners, conflict resolution, management of expectations and team building.

These challenges are discussed from the viewpoint of participants involved in three e-Science projects. From their experiences, we present lessons learned that can be used as a resource for e-Social Science project work. The success of any e-Research project lies in its ability to engage end-users in the design and eventual deployment of software and collaboration tools – the embedding of applications into actual work settings. A number of key challenges are identified that involve issues such as the need to recalibrate the project vision, recognize application developers as users of infrastructure, working with constraints, developing shared understandings between project partners and addressing sustainability issues.

## Introduction

e-Science technologies offer significant opportunities and benefits; enabling access to distributed data, computational resources, visualisation tools and expertise. However, the complex nature of the technologies developed and the corresponding infrastructure often create considerable challenges for researchers and practitioners who wish to take advantage of these technologies in their work environment (Hey & Trefethen, 2003). Within the UK, e-Social Science projects are working towards the development of infrastructure and tools that are relevant to the concerns of social science research. The technical solutions developed by the UK e-Science programme are being leveraged particularly in the implementation of infrastructure (Daw *et al*, 2007). In addition to this infrastructure development, the e-Social Science programme is also designing tools specifically for social science research purposes (See for example Crabtree *et al*, 2006; Fraser *et al*, 2006). Whilst e-Social Science endeavours may benefit from technical solutions developed from the e-Science programme, we argue that

they may also learn much about the unique characteristics of the design process by referring to the many discussions related to the challenges of designing large-scale, distributed digital research environments (Olson & Olson 2000; Edwards *et al*, 2003; Jirotko *et al*, 2005; Hartswood *et al*, 2005; Proctor *et al*, 2006; Zimmerman & Nardi, 2006; Lee *et al*, 2006; Welsh *et al*, 2006; Lawrence, 2006; Ribes & Baker, 2007).

If prospective e-Social Science tools and technologies are to be successfully deployed to support social science researchers' everyday work, they need to be designed in a manner that reflects the needs and requirements of both end-users and their institutions. A key challenge addressed in this paper is that of embedding e-Science applications which we argue can be achieved through close contact with end-users and developing an understanding of their everyday work practices and organisational contexts and concerns with a view to effectively incorporate this knowledge into the software development process. Making available end-user knowledge for a system's design requires the support of project management to ensure that time, resources and project members are allocated in the project plan for these activities.

This paper describes the outputs of three case studies that detail the challenges of designing, managing and embedding e-Science applications. We hope that our preliminary findings will provide useful insights that can inform design activities within an e-Social Science context. We will examine how members of e-Science projects collaborate in the design of software and how the mechanisms within the software development cycle support their collaborative activities.

## The e-Science case studies

e-Science projects bring together a wide variety of stakeholders; target end-users, software engineers, project managers, academics, industrialists, professional practitioners and funding bodies all of whom come from a diverse set of disciplines and institutions to work together on the development of large-scale, distributed and collaborative projects (Hey & Trefethen, 2002; Hey & Trefethen, 2003). Such a combination of stakeholders could be found in any large-scale distributed collaborative project. However, there are some unique characteristics found in e-Science projects which include providing virtual shared resources for researchers in which they can share data and collaborate using large, distributed datasets, remote tools, synchronous, distributed experimentation and a means to distribute research outputs. This technical infrastructure aims to support a wide diversity of disciplinary practices ranging from the natural sciences, medicine and most recently social science and humanities. For the successful development and deployment of e-Science technologies a working understanding of the skilled knowledge, experiences and practices of scientific practitioners is crucial. However, how such information is best elicited and incorporated into design and how the resulting system is best evaluated for usability is yet to be addressed (Proctor *et al*, 2006).

To investigate these questions more thoroughly, this paper will examine how an understanding of users' skills and practices and the ways in which those skills are utilized in and through collaboration with others in their day-to-day working worlds were taken into account in the software development cycle of the three project case studies. Our chosen case studies are from the domain of e-Health, where the acceptance of such systems is crucial and can have life or death implications. Furthermore, e-Health is a domain that has possibly suffered from a poor understanding of the end-users' work practices. Hence, we go on to detail the challenges that emerged in these projects when attempting to 'fit' users' and their organizational requirements with the vision of global collaboration and the technical infrastructure that underpins it. Our research objective is to understand in detail how e-

Science projects can effectively coordinate the embedding of computer systems into workplace settings by attending specifically to the ways in which project plans and management of these large, distributed projects promotes and supports the understanding and communication of end-users' needs and their organisational practices in the design process.

Our first project, eDiaMoND was a 2-year flagship UK e-Science project jointly funded by the Engineering and Physical Sciences Research Council (EPSRC), the Department of Trade and Industry (DTI) and a multi-national ICT company. Oxford University and the major industrial partner in collaboration with three other universities, four hospitals and one other ICT company drove project activities. The aim of the project was to apply the e-Science vision of distributed data sharing and collaboration to the medical field of breast screening. It created an archive of some 10,000 mammography images and associated meta-data that would be used as a test bed for the development of four applications: breast screening, student training, epidemiological research and computational research.

The second project, Integrative Biology is funded for 3.5 years by the EPSRC and leverages the experiences of eDiaMoND. The project is investigating collaborative environments for computational biology in the development and use of computational models for heart and cancer research. The project was required to use the outputs from first round e-Science projects. Thus, whilst capitalising on the experiences of these projects it is also heavily constrained by those existing technologies.

The third project, Neurogrid is funded for 3 years to explore whether stroke, dementia and psychosis neuroscience research could benefit from the application of grid technology. It follows on from EPSRC e-Science initiatives and is funded by the Medical Research Council (MRC). Neurogrid, as with eDiaMoND and Integrative Biology constitutes a large consortium of multidisciplinary research staff working in distributed academic locations.

## Methodology

We conducted a retrospective analysis of the eDiaMoND project as an initial case study of a series to be conducted in order to identify and analyse the challenges encountered in the design and embedding e-Science applications. A series of semi-structured interviews were carried out with key project participants, these focused on descriptions of collaborative activities and management processes within the projects. Further ethnographic work and informal interviews were conducted with participants from the Integrative Biology and Neurogrid projects. In addition to interviews, project documentation such as project proposals, requirements documents, project management documents and project workshops outcomes were used as further sources of data to complement interview data.

In the following section we discuss the preliminary findings drawn from our case study analyses, which highlight issues that emerged as projects progressed. A number of key challenges were identified that involve such issues as; the need to recalibrate the project vision, recognising application developers as users of infrastructure, working with constraints, developing shared understandings between project partners and addressing sustainability issues.

## Preliminary Findings

Whilst a great deal of research has already been generated from the eDiaMoND, Integrative Biology and Neurogrid projects, ranging from discussions of technical concerns and

innovation (Power *et al.*, 2005) to issues of trust (Jirotko *et al.*, 2005) and IPR (d'Agostino *et al.*, forthcoming), there has been less focus on the ways in which user requirements were acquired and managed (See Lloyd & Simpson, 2005; Hartswood *et al.*, 2005, Welsh *et al.*, 2005; Ure *et al.*, 2005). The notion of embedding e-Science applications of necessity entails developing a deeper understanding of end-users' individual and collaborative work practices, their organisational concerns and IT deployment strategies all the while taking into account the contingencies of design and the emerging complexities of software development. This research aims to create awareness and discussion around design and management practices that facilitate the embedding of e-Science applications and the challenges described span the entire development process. However, a key issue originates before the project even starts – at the proposal initiation where the project vision is defined.

### The project vision and its interpretation

In the eDiaMoND case study, the Principle Investigator (PI) proposed a project vision – to create a shared repository of digitized mammography images using a grid infrastructure and the development of four core applications that would draw upon the data archive. Both the infrastructure and applications were envisioned to support the work practices of radiologists at four National Health Service (NHS) Breast Screening Units (BSUs) in the UK. However, a number of challenges emerged as the initial vision was expressed in the *High Level Requirements* document. First, there were different interpretations of the vision between the project partners and associated stakeholders (Lloyd & Simpson 2005). Second, there was some tension between the PI's vision of the use of applications and the radiologists' concerns of how those applications would impact their day-to-day work practices and influence their professional expertise.

Many research proposals start with an overall goal or objective of what they hope to achieve – a 'vision'. However, due to a project's high-level objectives, the vision is often open to interpretation especially as both technical research and requirements activities progress. In the eDiaMoND project, the academic partners were concerned with engaging in highly innovative research, whilst the commercial partners were more inclined towards producing marketable deliverables. The high level description of the project vision generated a certain amount of tension between project partners and associated stakeholders at the beginning of the project and members early on attempted to reconcile their concerns.

“There was a lot of arguing at the beginning – What are we doing: a demonstrator; a proof-of-concept; or a production level system?”

Varying expectations between project partners led to different interpretations of the project vision. As project partners were brought in to lead various work packages their different interpretations of the proposal became clear. One reason for this is that work packages are of necessity described at a high-level as the details cannot be anticipated in advance of emerging requirements and technical constraints.

For Integrative Biology, the long-term vision of global collaboration was seriously challenged in the initial stages by the need to first of all create an interested community of scientists. Only then could an infrastructure be built to support it. The development of such a community took much longer than initially expected.

A further cause of concern lay in the “hype” that was put on e-Science projects in the early stages of the programme. Previous studies have argued that the hype surrounding e-Science

and associated expectations has put tremendous pressure on projects (Usability Task Force, 2004). This hype seems to be a consequence of competing demands; in order to secure funding from research councils the project must be highly innovative and contain a strong research component. In addition, commercial partners were required hence the proposal needed to attract commercial interests, specifically, the potential of offering a production-level deliverable or some other commercial gain such as media publicity. Due to the differing goals of project partners expectations also differed creating 'a web of confusion' (Lloyd & Simpson, 2005).

### Project vision and end-user needs

There were also a number of differences between the PI's vision and the radiologists' work practices in the eDiaMoND project. First, the PI envisaged the ability for mammography images to be read by any BSU from around the country thereby distributing the workload of radiologists across the UK. However, radiologists raised a number of issues with regard to trust issues between unknown radiologists who might read mammography images from clinics other than their own. Mammography images may differ from clinic to clinic due to differences in films, inks and equipment used. Radiologists therefore, may be unfamiliar with the practices of clinics other than their own. This could in turn potentially lead to incorrect screenings. The following excerpt from one of our interviews illustrates this.

"Great idea, but this is not how we work. If I am in London, I don't know your work practices, what are your standards?"

We see here how the vision for distributed reading is constrained by the use of different technologies across BSUs and by radiologists work practices. For the eDiaMoND vision to be realised, standards would have to be consistent across clinics, which would require an infrastructural refit of Breast Screening Units across the UK. Furthermore, trust relationships between radiologists from different clinics would have to be established and supported within the system.

In addition, the eDiaMoND vision intended to implement a 'find one like it' search facility. It was envisioned that if a radiologist was unsure about the status of a mammography image being read, she would be able to search across a number of other mammography images that were similar to the one being viewed. It was believed that this would assist the radiologist in detecting potential cancers. While the radiologists considered the 'find one like it' search mechanism interesting, they commented that it would not be useful in practice. An excerpt from one of our interviews illustrates this point.

"They [the clinicians] showed for example how in reading an image it was necessary in a sense for the clinician to account for every kind of possible cancer that they might look at. They'd look around and where something was suspicious they would come to a kind of opinion and judgment about whether that was suspicious or not. It wasn't really clear how displaying 10 images that the computer thought was like it necessarily helped. As a consequence you're left saying, 'I just don't know how this is useful'".

In the Neurogrid project and similarly in Integrative Biology, the project vision of sharing data across the various research institutions was also seriously challenged. Data sets in neuroscience research are considered extremely valuable, particularly because data images are collected through a time intensive and costly procedure requiring patient involvement and thus ethical clearance in the collection of such data. The Neurogrid vision is to provide researchers with grid middleware to support the sharing of data and to validate techniques

across a wider statistical set. From these examples, it appears that barriers for sharing data may involve complex ethical concerns and ownership of data priorities in which a research group has yet to publish sufficient results to warrant or allow its use by others.

### Shared understandings between project partners

During the eDiaMoND project the requirements engineers built upon and conducted a number of ethnographic studies aimed at understanding radiologists work practices. However, the requirements engineers and some of the developers had different views of the need for ethnographic field studies. The requirements engineers wanted the design to be informed by an analysis of current work practices of the breast screening units.

“You couldn’t just do the workstation and the requirements for the screening unit. You had to have embedding... fitting into the whole breast screening unit itself and the administrative work of it, because the whole thing about, how a woman comes in, the paperwork that is taken around that, how the image is taken, how the images are then put up on the light boxes, how they are stored. I think the first thing that you discover ...is that typically doctors tend to follow the career of an illness. This is very important.”

However, some of the developers did not support the ethnographic activities as the following interview excerpt demonstrates.

“They [the developers] didn’t want to know how breast screening units worked. They [the large and small industrial partners] seriously did not want to. They didn’t think that we ought to be looking at that kind of ethnographic work.”

The developers were not particularly interested in knowing about radiologists’ work practices *per se*, rather they wanted a technical specification from the requirements engineers of the exact granularity, describing how the system was to be built, without engaging in design discussions. As a systematic iterative development process was not possible in the time frame, a lot of the richness of the ethnographic work that had been done was lost when passed onto the development teams. Rather than this work being integrated into the technologies under development the outcomes of the work were disseminated through the *Blueprint* document for future reference.

Two factors constricted requirements engineers' efforts to involve users in the design of the system. These were the software development model, which tended to frame design activities in a sequential order and a project 'development culture' that preferred to design from requirements specification documents and not make use of iterative co-design activities with end-users or to draw upon ethnographic fieldwork data. Even though the project was positioned in this manner and the requirements engineers did engage in usability practices, their impact had a limited effect on design. In addition, the framing of the project within an implicit waterfall software development model and the tendency to favour a development culture privileged the project's pre-defined technical goals as specified in the *High Level Requirements* document over participatory usability practices creating a technology-focused, not a user-focused environment for design.

Requirements activities in the Neurogrid project focused on asking end-users to describe what they do in terms of image analysis and to walk through their processes with the requirements engineer. These walkthroughs were then used as discussion points in workshops where scenarios were created and given to developers. This type of activity was less successful in Integrative Biology as a solid community of users had not yet been formed at the time the requirements for the project were formulated.

Though many of the issues that have emerged from these case studies are concerned with the challenges of incorporating the knowledge of end-users' practices and procedures into the design process, they have also revealed concerns for middleware and application developers regarding infrastructure usability.

### Application developers as users of infrastructure

In our interviews with application developers they turned the discussion around by asking us the question 'usability for who?' What followed was an interview session where application developers described the difficulties of integrating their tools into a series of infrastructural standards and APIs. As they explained, the design of a system's architecture can have implications for how application software may be designed, because it must take into account the workflows and constraints built into middleware software. These technical constraints can implicitly determine the features and functionality available to end-users.

"Usability for who? I've got a grid API against which I had to program in order to get images over and so on. Was that usable for me as a user of grid technologies, probably not. I was also a user of some software produced by [the small industrial partner], which I had to build the workstation on and they had an API I had to go to... was that API usable to me? No, it's.....awful for various reasons."

From this, we can see that it is advantageous for application developers to be involved in the design of infrastructure in partnership with middleware developers. Application developers from the eDiaMoND project expressed that such an approach would produce far more useful end-user software. In addition to involving application developers in middleware design, another approach to improve infrastructure and application usability would be to conduct situated evaluations (Crabtree, 2003) where both are used in local settings with end-users performing real work tasks. The data captured from this type of technology evaluation in the field could then be used to document the initial successes and failures of the technology in use, as well as help develop an understanding of emerging practices. Both these approaches, involving application developers in infrastructure design and situated evaluations can be used to support a 'design in use' software development process (Voss *et al*, forthcoming).

### Working with constraints

The most critical constraint on eDiaMoND was time. The project had a very short timescale of two years and this put immense pressure on project partners to meet their deliverables. In addition to this, there were also a number of external pressures as described by one of our interviewees.

"I think there was a lot of pressure to show something and they [the project partners] were getting so much publicity and press releases. There was a lot of pressure to be able to demonstrate something – from the university, the e-Science programme and of course [the large industrial partner], especially the people who were reading about it... they wanted to see something."

The management and software development approach taken was often influenced by the constraints placed on the project. For example, in the eDiaMoND project, less iteration was possible during data acquisition activities because there was an urgent need to scan data quickly. Hence, the project practicalities of prioritising hard deliverables to meet time constraints needed to take priority over incorporating an iterative design process.

## Sustainability

As well as the challenges discussed thus far there is also the challenge of sustaining e-Science systems once designed and made available to end-users. Providing a sustainable infrastructure gives end-users confidence in adopting new tools because they will be available in the long-term. For example, in eDiaMoND, once the project had ended the system was dismantled. This meant that the target end-users of the system had invested their efforts in the design of tools that were not going to be made available at the end of the project. If e-Science technologies are to fulfil their potential, e-Research environments need to be sustained, enabling them to become a core part of researchers' everyday work activities.

However, sustainability is inhibited due to the funds required to support and maintain e-Research. In the UK, research councils currently fund research and development projects however, they do not fund ongoing support and maintenance costs. Hence, once a project ends the infrastructure and applications developed are dismantled. While most e-Science applications are not available beyond the funding period of a specific project, the Open Middleware Infrastructure Institute (OMII) and National Grid Services (NGS) are two services available that are working towards providing mechanisms for both developers and computer-savvy scientists to access past e-Science software outputs.

## Recommendations

In this paper, we have identified some of the challenges of embedding e-Science applications, which were derived from case study data of three e-Science projects. Based upon the reflections of project members and how each project strove to overcome some of its difficulties, we suggest a number of preliminary recommendations for future projects.

- When developing the initial proposal clearly identify the processes the team will use and the resources needed to develop the system. For example, the data acquisition feature of the eDiaMoND project required a substantial time commitment from end-user clinicians – this needs to be factored into the proposal.
- The project vision needs to be flexible enough to evolve to meet end-users' needs and their organisational practices. This may be achieved through an iterative process of workshops and discussions between project initiators, software engineers and end-users to recalibrate the vision.
- Engage in iterative development and prototyping activities. This enables early feedback to the design of the system so that it can reflect the needs of end-users' and support their work practices.
- Ensure that there is early engagement with the end-user community and project partners by sending out questionnaires and scheduling workshops to ensure participation and feedback. Questionnaires were found to be invaluable for identifying project members' interests and potential skills.
- Engage application developers in the design of middleware. This may be achieved through a technical steering committee where both middleware and applications developers work in partnership in the design of infrastructure.

- Conduct regular cross-disciplinary workshops to facilitate shared understandings. Encourage project participants to go beyond their normal sphere of activity, collaborating closely with other project participants to facilitate the transfer of knowledge between team members. Make use of key personnel who act as evangelists for the project and who are skilled at facilitating collaboration.
- A great deal of effort should go into detailing who the stakeholders are and to securing their involvement. (See Tovar & Pacheo, 2006 for a comparison of methods for Stakeholder identification in Requirements Engineering). Stakeholders often change throughout the lifetime of the project. It is healthy to engage with new, interested end-users to ensure that the technology will be applicable to the wider research community.
- Where a solid user community exists, it may be easier to engage them in requirements gathering exercises than, as in Integrative Biology project, where the community was still emerging. Ensure the process includes ongoing community engagement activities such as the circulation of a project newsletter where each partner has a slot to detail their progress. Create a project identity through wikis, newsletters, common publications and presentations to assist with community building.
- Reduce heavyweight decision-making, for example waiting to sign off a design at six monthly project board meetings. Project teams need to be empowered to make decisions. Use management boards for exceptions.
- Manage expectations of project partners. The eDiaMoND project created a *Blueprint* document for highlighting the complexities of large-scale, distributed software development. The *Blueprint* document has subsequently been used in the Health Technology Assessment<sup>1</sup> report in Scotland.
- Develop security mechanisms to support the needs of researchers. For example, Neurogrid had a sample case of a very limited set of images from patients with family histories of psychosis. This data set is rare; however, researchers will permit others to use the data on the condition that the analyses are validated. Thus, the ways in which data may be shared is tightly controlled because it specifies what may be done with the data. Making such compromises can facilitate controlled collaboration, where researchers have an interest in maintaining a degree of ownership of the data that in most cases is time-consuming to acquire.
- Develop exit strategies. If there is no plan for sustaining the technology beyond the lifetime of the project the research community that the system is being designed for may disengage. Such exit plans might include securing support from institutions such as OMII for continued development or creating follow on projects that continue to support the technology.

Faced with the challenges that such complex large-scale, multi-institutional, multi-disciplinary projects produce, the recommendations that emerge are often those that require support for communication between individuals and teams across distributed locations that, in some cases, have no history of working together, support for collaborative design practices that actively include end-users and the flexibility to adapt to change. Our future work will explore ways of overcoming such challenges and produce a toolkit, which will consist of

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recommendations to support collaborative design practice and management methods to facilitate effective communication and collaborative working.

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