Adoption of e-Infrastructure services: configurations of practice

BY ALEX VOSS1,*, MARZIEH ASGARI-TARGHI2, ROB PROCTOR2 AND DAVID FERGUSSON3

1 School of Computer Science, University of St Andrews, St Andrews, UK
2 Manchester Research Centre, University of Manchester, Manchester, UK
3 National e-Science Centre, University of Edinburgh, Edinburgh, UK

This paper reports findings from a study of researchers and research-computing support staff. It explores examples of the social relations supporting the adoption, adaptation and domestication of e-Research technologies and e-Infrastructures and makes recommendations for funding organizations, technology suppliers, service providers and institutions.

Keywords: e-Infrastructure; uptake; translation into practice

1. Introduction

In order for the e-Research community to realize the full potential of e-Infrastructures for research, issues of uptake and of embedding them in day-to-day research practices need to be addressed, and opportunities for widening the uptake need to be understood and exploited. Consequently, investments in the development of technologies and applications are now being complemented by active programmes of community engagement (Voss et al. 2007). Indeed, a recent international review of e-Science in the UK recommends that such programmes be strengthened in the future (Atkins et al. 2010).

The Enabling Wider Uptake of e-Infrastructure Services project (e-Uptake) was led by the Manchester e-Research Centre at the University of Manchester in collaboration with the Arts and Humanities e-Science Support Centre at King’s College London and the National e-Science Centre at Edinburgh University. It studied the inhibitors researchers face in taking up use of e-Infrastructures and possible enablers that may help to overcome them. The e-Uptake project interviewed more than 50 researchers from a range of disciplines and institutions about their engagement with e-Infrastructure. We took care to ensure that our sample of researchers included non-adopters as well as adopters and researchers at different levels of seniority (cf. Voss et al. 2008).

While we may regard researchers as the ‘end-users’ of e-Infrastructures, there are other kinds of e-Infrastructure users whose experiences are just as important, if we wish to understand fully the challenges of achieving wider adoption and

*Author for correspondence (avoss@cs.st-andrews.ac.uk).

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what kinds of interventions might be feasible to address barriers and inhibitors. Consequently, in a second phase of interviews, we talked to more than 50 staff based in Higher Education Institutions (HEIs), whose role is to plan, manage and support the provision of advanced research infrastructure at the local level and act as ‘intermediaries’ between service providers and researchers. Interviewees were recruited from research-computing groups at HEIs, as well as from groups of other intermediaries, e.g. from e-Science centres. The main emphasis was on representatives from HEIs with a large research volume and above-average success rate in securing research council grants. To ensure a degree of representativeness, we chose institutions from three groups: HEIs traditionally found at the top end of research league tables; HEIs that are outperforming their peers; and some small, specialist HEIs with strengths in particular research areas or that are particularly active in e-Research (Corbyn 2008). Interviewees included staff in managerial positions as well in front-line roles with routine direct contact with researchers.

The interviews were recorded and transcribed using a commercial transcription service. After a quality-assurance step, individual findings were extracted from the interview material, consisting of a short formulation of the inhibitor or enabler identified, a set of quotes from the transcript and references to a typology to allow subsequent retrieval according to the defined categories. We have described the approach we have taken for data collection and analysis in a previous paper (Voss et al. 2008).

2. Overview of findings

The e-Uptake project has now completed an analysis of both phases of interviews, and the material presented in this paper is based on a comparison and synthesis of the findings from these two phases. Overall, the project has identified more than 250 separate issues related to the e-Infrastructure adoption and more than 80 enabling factors. In order to reduce the analysis of the interviews down to a manageable list of findings of wider significance, we have made a number of analytical distinctions represented in a typology of issues and enablers that we have used as a structuring device for our material. The typology was initially drafted based on a literature review, but was subsequently revised and refined in light of the findings of our empirical work.

While it has been useful in that it has provided a systematic way into the data collected, the typology should not be seen as a way to produce a limited set of overall findings through aggregation, but rather as a way into the wealth of material collected. In reality, factors implicated in the uptake of technologies tend to be interrelated and do not lend themselves readily to the simplifications imposed by hierarchical representation. In the case of e-Research, we might expect and, indeed, the analysis of our data is now confirming, that there is a network of interrelated factors, some with complex or subtle interdependencies, embedded in a wide variety of situations or circumstances, that impact on the uptake of e-Research services and resources. Untangling these relationships is part of our ongoing data analysis conducted in conjunction with stakeholders. We aim to tease out findings that can inform possible interventions to foster the uptake of e-Infrastructure services.
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The analysis of interview material from the two phases of fieldwork has helped us gain insights into current research practices, as well as the state of adoption of e-Infrastructure and e-Research methods. It has brought to light a great variety of issues, barriers and enablers across the research fields that influence their uptake. The majority of these issues were broadly in alignment with the typology of barriers that resulted from our initial desk research, while others were added to the typology during the analysis of the data. The following high-level categories were identified as ones that we would classify as being mainly social in nature (Voss et al. 2009):

— training, education and outreach, e.g. lack of skills and awareness of e-Research;
— user–designer relations and user requirements, e.g. a lack of ‘common ground’ between users and developers;
— understanding disciplines, e.g. the sheer diversity of research practices, especially in the social sciences, and arts and humanities;
— collaboration, e.g. lack of ‘collaboration readiness’ (Olson et al. 2008);
— policy and funding, e.g. the challenges of sustaining new services and tools in a project-oriented funding regime;
— organization of disciplines, e.g. degree of collaboration, epistemological traditions or lack of dissemination of technical knowledge in teaching;
— individual issues, e.g. availability of time to invest in e-Research, career interests and pressures;
— organizational issues, e.g. lack of institutional support for research computing, lack of local infrastructure or barriers to accessing resources (firewalls); and
— ethical and legal issues, e.g. sharing of confidential data and protection of intellectual property rights (IPRs).

The interviews have also uncovered a number of issues to do with technologies, their role in infrastructures, dependability aspects such as security, rate of technological change, cost of adoption and scale. A third category of findings revolves around the notion of a digital resource: discovery, sharing and reuse, curation and ethical/legal issues such as ensuring the confidentiality of personal data and protection of IPRs.

While these latter categories are undeniably important, we find that the social issues listed above are equally significant, yet so far have not received sufficient attention. It is clear that many of the frustrations of current users and many of the inhibitors of wider uptake require the development of a supporting human infrastructure (Lee et al. 2006), by which we mean the support services and community knowledge networks (both formal and informal) through which awareness, advice and assistance are made available to researchers.

In this paper, we wish to consider specifically the findings relating to the local circumstances of adoption, appropriation and domestication of e-Infrastructure services. We begin by introducing a set of concepts from previous studies of science and technology that will be useful in the subsequent analysis of our findings. By providing a number of examples of the types of findings we have collected,
we wish to illustrate the kinds of social relations that underpin the uptake of e-Infrastructure services. While the space available does not allow us to cover all the findings, we believe we have assembled a set of perspicuous examples that we hope will feed into the discussions about future community engagement activities and the ongoing development of a sustainable e-Infrastructure for research in the UK and elsewhere.

(a) *Mutual shaping of technologies and research practices*

As Beaulieu and Wouters note, ‘if more fields make use of ICT, this will not be a simple wholesale adoption. Rather, we foresee an active transformation, in which the models of research prevalent in the relevant field shape the way ICT is conceptualized and used. Rather than a diffusion of e-science, we propose to think along the lines of translation of e-research’ (Beaulieu & Wouters 2009, p. 56). Following Fleck (1993), this viewpoint acknowledges that technologies do not consist of technical artefacts that are distributed by their creators and then simply used by their intended recipients. Rather, as technologies are developed and made available, potential users assess their potential and start to envisage possible ways in which they could be made useful by embedding them into local contexts and working practices: translation work is an active process involving experimentation with and adaptation of technologies. Beaulieu and Wouters speak of ‘funding schemes, tools, researchers, institutional frameworks and research agendas’ forming ‘coalitions’ supporting the adoption of technologies (Beaulieu & Wouters 2009, p. 58).

Of course, technologies and the coalitions that support them reflect back onto the ongoing formulation of research agendas and designs as researchers reflect on the new opportunities that they give rise to. Their influence is not limited to incremental improvements in research methods, concerned with how research is done (in the sense of its ‘logistics’; cf. De Vaus 2001, p. 9), but they can enable new research designs, that is, new logical structures of research. Whether or not the increased use of e-Research technologies constitutes a new ‘paradigm’ for science (Hey et al. 2009) may be debatable but in some areas at least, e-Research practices are becoming common and are changing the ways in which researchers go about their work. For example, Kell & Oliver (2004) describe how technological changes in molecular biology and bioinformatics are enabling researchers to work inductively as well as according to the traditionally predominant hypothetico-deductive paradigm. It should be stressed, however, that the use of inductive (or ‘data-driven’) approaches does not replace, but rather complements deductive approaches (De Vaus 2001).

We might say that e-Research technologies and the research practices they enable are *mutually shaping* each other (Williams & Edge 1996). In practice, technologies do not emerge ready-made from laboratories, ‘impacting’ on research practice, nor are research practices independent of the technologies that enable them. Rather, as technological options and research interests meet, people find innovative ways to configure technologies, social and organizational arrangements and their research designs and practices.
(b) Social learning in technology adoption

Often, socio-technical arrangements supporting the adoption and use of technologies emerge over time in interactions between different stakeholder groups in processes of socio-technical change facilitated by social learning (Stewart & Williams 2005; Williams et al. 2005). The social-learning perspective ‘seeks to understand how [...] technological capabilities are appropriated and become embedded in society’ (Williams et al. 2005, p. 48). The concept draws attention to a number of innovation processes that occur during the adoption and subsequent usage of technologies as well as to the diversity of actors involved in technological innovation and their roles, countering traditional supply centred accounts of innovation (Williams et al. 2005). It refers to the ‘negotiations and interactions between different players [...] subject to conflicts, and differences of power and interest’ (Williams et al. 2005, p. 49).

Our interest in this paper is to contribute to the discussion about how the adoption of e-Research technologies can be facilitated. Often, this problem is couched in terms of ‘usability’, suggesting that what is needed is a better understanding of ‘user needs’ through requirements engineering and their subsequent translation into more ‘usable’ technological arrangements. While it is certainly true that ‘usability’ problems can hinder the adoption of technologies and that the development of a better understanding of research practices can aid the development of technologies that are more ‘fit for purpose’, there is often more at play. As Williams et al. argue, it is a fallacy to believe that ‘the primary solution to meeting user needs is to build ever more extensive knowledge about the specific context and purposes of various users into technology design’ (Williams et al. 2005, p. 68). If the point is not to identify a priori what the features of arrangements that are ‘fit for purpose’ might be, then we need to turn our attention to the ongoing accomplishment of the adoption, appropriation, domestication and use of technologies within evolving coalitions and, as a consequence, to the kinds of interventions we can make in the post-design phase.

The social learning perspective suggests a view of the development and use of technologies that considers a whole spectrum of activities ranging from the immediate interaction with technologies in local settings (learning by doing) to the exchange of experiences in wide networks of technology design and use (learning by interacting). It also draws attention to the fact that the appropriation of technologies involves more than merely functional changes and learning, but also the development of meaningful relationships between technologies, social relations, organizational arrangements and working practices. To become fully integrated into our everyday lives and imbued with meaning, technologies have to be domesticated (Silverstone & Hirsch 1992; Sørensen 1994). From this perspective, the distinction traditionally made between the production and the consumption of technologies is challenged and, in contrast, the unfinished character and malleability of technological offerings are highlighted. It is important to stress that the process of domestication is not a linear, straightforward one that reaches an end point, as there tends to be only momentary closure (Williams et al. 2005) that can be opened up again by new developments. Domestication is also subject to potential conflict (Sørensen 1994, p. 7) between developers and users of technologies, but also between
different users or between different developers. In fact, as researchers often use each other’s outputs, the distinction between ‘user’ and ‘developer’ can become blurred.

(c) Configurational technologies

It has been argued in relation to some technologies, such as computer-aided production-management systems (Fleck 1994) or ‘Smart Home’ technologies (Peine 2009), that they are configurational, i.e. that they consist of some standard, commodified components and of customizations that link the former together to form an assemblage—or configuration—serving a wider purpose. The focus on the configurational nature of these technologies highlights the fact that they are not simply ‘delivered as systems’ that are ‘installed’ in a given setting. A traditional household item such as a washing machine may be relatively easy to deploy because it can be set up largely without knowledge of the specific circumstances of the household buying and using it, and it will be employed, by and large, in ways foreseeable and foreseen by its producer. In contrast, instantiations of configurational technologies embody a significant proportion of knowledge about the context in which they are deployed. As Fleck puts it: ‘successful implementation requires generic technology knowledge + local practical knowledge’ (Fleck 1994, p. 641).

The configurational nature of some technologies has important implications for the processes of adoption, appropriation and domestication. Inherently, a number of different actors are involved in the creation of a working socio-technical configuration, often with different backgrounds, interests and bodies of knowledge to draw on. Within e-Research, the challenge is often to bring these together for a period of time sufficient to create a ‘coalition’ (Beaulieu & Wouters 2009) strong and long-lasting enough to support the pursuit of a particular research agenda.

3. Social relations of e-Research adoption

The focus in this paper is on the space where the affordances of advanced digital technologies and ideas for new research practices meet. The question is what kinds of arrangements can be put in place by institutions, service providers and funding organizations to ensure that the innovative potential and the possible benefits of the use of advanced digital resources are fully realized. Apart from overcoming obvious barriers to the uptake of digital technologies and e-Infrastructures, there may be a need for more explicit support for processes of adoption, adaptation and domestication.

Arguably, e-Research technologies are often configurational in that no one product is sufficient, but a number of different tools, infrastructure services, datasets, organizational arrangements and working practices are needed in combination to address a specific (kind of) problem. Arguably, supporting the creation of such a configuration—a virtual research environment—is the main point of e-Research technologies and not just a property they happen to exhibit at this point in time. ‘Doing e-Research’ often means bringing together components to solve a larger research problem that none of them were specifically
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designed to address. This is perhaps epitomized by the notion of a scientific workflow, which treats the processes that are constitutive of research practices as first-order objects on an equal footing with the importance of research data (cf. Goble et al. 2008). Our findings show how the particular technical configurations are embedded into social arrangements around their development and use, so that we might talk of socio-technical configurations or, following Beaulieu & Wouters (2009), of ‘coalitions’.

We would argue, then, that this implies a set of social relations and a distribution of knowledge in e-Research that is essential to understand if one is to support the wider adoption of e-Research practices. On the one hand, there are providers of technological components such as grid middleware stacks, data-integration solutions, packaged scientific codes, as well as providers of e-Infrastructure services (compute, data or collaboration). These groups are concerned with the provision of tools and services that are generic, and while they may draw on knowledge about specific applications of their products and services, they will have an interest in these only insofar as they can serve as exemplars for more generic use cases and templates for generic types of configurations.

On the other hand, there are researchers who are concerned with research designs and practices. The provision of configurations that bind together multiple technological components may or may not be their concern, depending on how much technical expertise they possess and how immediately the research process can be translated into technical artefacts such as workflows. More often than not, a division of labour will be involved where the development of specific socio-technical configurations is a task assigned to other professions, who will draw on specific sets of skills relating to technologies or organizational arrangements. A highly developed division of labour is now typical of research in many disciplines (Knorr Cetina 1999), both within disciplines and across disciplinary and professional boundaries, where the creation of complex assemblages or those involving specific technologies requiring expertise not immediately available may require the involvement of professional expertise. Computing professionals may be involved either as staff members on a project, as collaborating partners or through provision by research-computing support functions in the institution.

In the following sections, we will look at the role that institutional support arrangements play, and the ways in which they are established and arranged. We will look at interactions between users of e-Infrastructure services and their developers and we will also consider the more informal arrangements and interactions among peers and between, for example, more senior members of the academic community and research students.

(a) Institutional support

In our study, we observed a number of institutions creating posts that aim to provide direct support for researchers. These are sometimes attached to larger research teams or departments, they might fulfil a liaison and outreach role for central information services or they may be funded through projects or as part of larger infrastructure investments. The following quotes provide examples of the different kinds of roles and circumstances of their creation (interviewees have

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been assigned pseudonyms, intermediaries have the prefix ‘IT’ and researchers a prefix that corresponds to a research council covering the area they work in, e.g. ‘ES’ for ESRC or ‘M’ for MRC):

‘information services has three academic liaison directors whose task it is to speak to the users and their colleges. [We have] monthly stakeholder meetings, and [two of our staff] in particular go out and meet with the research groups. So [...] actually when they say that they want to start using [our resources] they reply by saying can we come and visit you and discuss what [it] is you need. We’ve also had a researcher who has looked at research computing requirements throughout the University.’ (IT11)

‘we’ve got a number of posts that have just been filled for application developers within bioinformatics and one of the aims for those posts is that they will be able to do work with researchers who are more bench orientated and less computing orientated and tailor the creation of services that they can use, make that link between the computer and the bench.’ (IT6)

We can see from these examples that the roles differ in terms of the distance between researchers and intermediaries, and the frequency and occasion of interactions. The second example demonstrates the value of having support staff permanently embedded within research teams, a luxury that only larger teams will be able to sustain. The first quote provides an example of arrangements that have been made by a research-computing group to actively engage researchers who might want to make use of research-computing services. One problem, we have identified is that researchers are often unaware of the availability of research-computing support and are unaware of or uncertain about their research-computing needs, especially early on in the research life cycle when they would need to establish contact and consider the research-computing resources required that may need to be included in a research proposal,

‘We have contacts to quite a few faculties but quite [a] few people don’t even know we exist.’ (IT24)

Compared with the number of researchers in the institution, the number of support staff is relatively low. Consequently, an important part of the role of research-computing support is to provide effective triage, where decisions are made about the allocation of responsibilities, the extent of support and the resources used. When researchers face problems, it is sometimes not immediately clear where they might turn for advice and a candidate solution. An important role of local research-support services is to assess the problem and recommend an appropriate course of action, which often involves referral to technology developers, service providers or other professionals who have specialized knowledge and may be able to help.

‘They come and they ask questions and then they get answers hopefully, or they get told who will be best able to answer their questions depending on whether it’s an infrastructure problem or whether it’s an architectural problem or whether it’s a, you know, a coding problem. There are kind of different people for different jobs.’ (IT6)

The development of institutional investments in research-computing resources and support is inevitably linked to wider institutional agendas. Negotiations need to take place, in particular, about the necessary funding and service-level
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arrangements. Even where external funding is available, this is often time limited and other, more sustainable funding arrangements need to be developed.

‘So developing research is absolutely part of the University strategy, and [...] one of the statements in the research computing strategy is that as it would be implemented it will be done so to fit in with the University strategy [...] I’ve just been working with a college accountant to establish [a resource] as a small research facility so that it’s known to research councils and can be included on research grants, and also we have been in discussion with colleges that use of [a resource] by researchers who have not got a research grant in place that schools will pay what we call the baseline use of the service, and just in the last month schools have agreed that they will do that because they see it as an important facility for them.’ (IT11)

(b) Creating configurations and coalitions

As already mentioned above, e-Research tends to involve the creation of a working configuration of different components, both technical ones such as tools and infrastructure services but also social arrangements. For example, running a particular scientific code on a grid resource such as the UK’s National Grid Service (NGS) will often require more than the deployment of a binary file, but also involve the creation of various ‘wrapper scripts’ that ensure that the environment for the code is set up before execution starts,

‘We use NGS resources and White Rose grid resources to [to run a particular task] and that again was a computationally intensive and data intensive task [...] we’ve worked with [a local NGS support officer] and he’s written some staging stuff that allows us to use MPJ Express on these resources [...] he’s been a great help, and just to create this node list that we can use to fire up an MPJ Express environment [so] we can use the whole 128 nodes on a core site.’ (ES3)

In this case, the code makes use of a particular Message Passing Interface implementation that requires a list of nodes that the individual compute tasks are running on to establish communication. How this list is created will depend on the particular job submission mechanisms used and so may differ between different grid environments or even between different nodes within the same overall grid. The execution script plays a vital role in enabling the code to run in any given execution environment. It incorporates the knowledge required to execute this specific code in this specific environment and is therefore not an easily tradable artefact that could be turned into a generic component.

The code involved in the above example is relatively easy to parallelize as it can compute independent results for each of a large number of areas. Therefore, the execution on any high-throughput compute resource is relatively unproblematic. A different set of skills is required to make effective use of parallel processing in clusters and/or on multi-core architectures. The state of the art in developing software that makes effective use of multi-core and other parallel architectures is currently lagging behind the development of hardware and distributed computing platforms,

‘You know we’ve sat on the back of Moore’s Law for the last forty years and sort of expected [...] processors would get twice as fast every 18 months or so and that’s simply stopping, the approach of going down the multi-core route means that if you’re going to solve the computational problems of a decade’s time you’re not going to be able to do it on 100 or 1000 Phil. Trans. R. Soc. A (2010)
processors you’re going to be looking at 10,000 or 100,000 processors and frankly if you look at the code base they don’t scale so the numerical tools for example that we have today need a thorough overhaul and that’s an enormous task.’ (IT8)

Even where the problems involved are more modest, achieving a significant speed-up through the use of parallel architectures can require skills not easily available to researchers who are not traditional users of high-performance computing resources,

‘So, [our colleague] is working on a toy model at the moment for [a city] and so that’s about 1% of the country, and we’ve not managed to sort of parallelize it, so just working on the sort of basic, average PC of today.’ (ES3)

The problem with parallelizing application code is often as much technical as it is conceptual and therefore a solution cannot necessarily be found by applying a transformation of code from serial to parallel. Rather, an interaction is required between researchers and technical experts finding a way to re-draw the conceptual framing of a problem to enable it to be tackled using parallel architectures,

‘Difficult to parallelize, some parts of it, especially the migration component, because you are trying to work out how many people are moving from one region to go to another, but obviously there are constraints to how many people can move into that region.’ (ES3)

The day-to-day use of e-Infrastructures requires a set of skills and knowledge to be available. How these are passed on to new members of a research community is an important aspect for the wider uptake of e-Infrastructures and e-Research tools. Often, the traditional forms of teaching and supervision of research students does not lend itself to this task as senior academics, traditionally in charge of teaching and training, do not necessarily have day-to-day experience with e-Research technologies,

‘It does seem if I go along and I just want to download some map boundaries for [a city], then I have to download the map boundaries for the country and then cut them up. […] I had a student in my office who […] is doing a dissertation looking at a particular area of [a city], he got some indicators from the Office of National Statistics, I think, and he wanted to do some maps of them. So I say, ok, […] go to EDINA, […] so we ended up with some national level […] mid-level super output areas – loads of the things – all he wants to do is to map out 7 or 8 of them […] we had a little think about how we do that and you know after 30-40 minutes we gave up, basically, you know, because I couldn’t figure out there and then how to do it and he is a third year undergraduate student who doesn’t really have the expertise, it wasn’t that critical to him, so we literally said go and see what you can find on the ONS website, hassle somebody else maybe. You know […] I vaguely know my way around […] MapInfo […] there are times when I would have been able to do what we’ve been trying to do but only if it was kind of fresh in my mind. I am coming at it after a bit of [a] break, you know, I kind of just forget.’ (ES3)

The example above illustrates some of the intricacies of how practical knowledge around the use of e-Infrastructure services is traded. We see how a senior academic is struggling to provide advice on the manipulation of a dataset when asked, but how they also point to various ways in which the problem can be resolved. It is not that they lack the conceptual understanding of what is required...
but rather the practical experience with ‘working the technology’ and having this knowledge ‘ready to hand’. It is often more junior staff members or other research students who are referred to as potential sources of help.

‘If I wanted to get help I would access it locally, I’d go to one my colleagues, there is probably two or three people round here I would think, know the way around EDINA and the various GIS packages a lot better than I do [...] I mean to be honest, the postgrads are [a] pretty good source of information.’ (ES3)

Such peer-support practices are not uncommon and form an important part of what we mean by e-Infrastructures becoming ‘embedded’ in communities of practice. Consequently, research-computing support can help to facilitate social learning processes by bringing different user groups in contact with each other so that they may benefit from experiences already made, from configurations worked up as well as from continued collaboration,

‘That’s quite a common thing particularly if you know that you’ve got an application that one group is using, that another group is using, to point them and say well here’s an application that we think would be of benefit. If he comes along and says oh I’m trying to get this application working, can you give me some help on the cluster? We can say well actually why don’t you go and speak to this group because they’ve already got that application working and you can just use it from them and then that kind of cross-seeding seems to work quite well.’ (IT6)

The example above shows how intermediaries can often help not by providing support directly but by facilitating ‘learning by interacting’.

(c) Technology supply and use

We have already illustrated the interactions between users and local support staff and users with peers, and now wish to turn to how experience with the use of e-Research technologies can feed back into the development of technologies.

‘We were working [with] very large datasets, terabytes scale datasets, it was obvious to us that OGSA-DAI had not been tested on such large datasets so they were fundamental design and implementation problems that we had to resolve, so OGSA-DAI for us certainly didn’t work out of the box. We actually in the end have had to change OGSA-DAI quite a bit. In the end—we didn’t tailor make it specifically for our problem because we were trying to be general.’ (ST1)

The scale of the application discussed in this example is taxing the data-integration solution used as well as the underlying infrastructure. The respondent reported how making the data available on the NGS was a significant undertaking because of the size of the data involved. Once the data was in place, they found that the design of OGSA-DAI did not cope well with queries returning large amounts of data, which were quite frequent in their application,

‘What was happening was the memory was filling up, because they wrote the [data] to memory the machine would crash, so those [are the] sorts of design issues which we changed [...] clearly people were not expecting people to have queries to databases that returned gigabytes of data, but we routinely do that in physics and astronomy. That was one critical flaw in the design.’ (ST1)
We can see how the specific requirements of an application area are feeding back into technology supply and challenging some fundamental design decisions. In an ideal world, such lessons learned would be taken up and factored into new releases of the software but, as our respondent observed, resource constraints can lead to problems with factoring such innovation into successive versions of the technology,

‘The problem is if you ask them a question or you ask them for an enhancement, basically they don’t have the people to do it, so if you don’t [do] it no one would do it.’ (ST1)

Clearly, technology providers have to prioritize change requests and feedback from the community and they need to tread a fine line between the need to develop a generic product that can find wider uptake and the need to satisfy the needs of demanding users to drive technological development forward and satisfy those who are best placed to contribute to the ongoing development of the product.

4. Discussion

Research on the uptake of e-Research technologies has uncovered examples of successful adoption facilitated by social relations based on close proximity of developers and users (e.g. through ‘embedding’ the former in the latter’s work environment, see Hartswood et al. 2008), or personal contacts through membership in the e-Science community (Schroeder & Spencer 2009). Some of the findings reported above underline the usefulness of such relations and begin to unpack some of the issues involved in providing such support. Such direct interactions are clearly important enablers of the development of new e-Research approaches and should be fostered where possible. However, they do not provide us with a template for mechanisms to embed e-Research in the wider organization of research groups, departments and institutions. Not every researcher can be afforded the luxury of having access to technical expertise and support ready to hand.

We have seen how a range of mechanisms are now being deployed to address the problem of providing a suitable level of support to communities of researchers within the wider institutional setting. These range from liaison officers contacting researchers at important points in time to provide advice, the use of mailing lists and focus groups to maintain a level of ongoing communication and the provision of triage by local support services. We have also seen the role that peer support may play in providing the necessary specialized knowledge required to make effective use of services within a community of practice sharing similar kinds of concerns and needs.

Inevitably, the relationship between research-computing services and researchers is going to be influenced by the difference in size of these groups. We would argue that leveraging the kinds of peer support described above and effectively supporting the mechanisms that allow support staff to deal with the imbalance of potential needs and the availability of resources—such as triage mechanisms and hierarchical support and communication structures—is crucial if we wish the adoption of e-Infrastructures and e-Research tools to scale to wider communities.
Finally, we need to consider new ways to configure the user–designer relationships in the development of new e-Research technologies. Reporting on their experiences of developing new kinds of visualization tools for epidemiologists, Thew et al. (2009) emphasize the importance of an ongoing dialogue between researchers and technology developers about the mutual shaping of technologies and research practices. Not only are research practices constantly evolving—arguably more so than working practices in other areas—and requirements therefore ‘moving targets’, they are also embedded in social and organizational arrangements that are difficult to analyse, predict and control. Academic researchers tend to enjoy significant discretion in their choice of working practices and their technological choices, and they often have control of their own budgets. As a consequence, attempts to impose standardized solutions are likely to meet with resistance.

We would argue that the concepts of social learning, of domestication and the perspective on e-Research technologies as configurational technologies provides us with a conceptual underpinning for fostering social relations that will support the wider adoption of e-Research technologies and practices. This will enable us to look beyond the production of software artefacts in isolation and to look at the development of socio-technical configurations that feed back from the ‘implementation arena’ (Fleck 1988) into technological development, thus increasing the potential for innovation.

5. Conclusions

The e-Uptake study has provided valuable evidence of how HEIs are now seeking to adapt the services they provide in support for research in order to exploit new methodologies and the e-Infrastructure technologies that enable them. We have argued that by virtue of being a configurational technology, support for e-Infrastructure must draw on a diverse range of distributed knowledges, making for a particularly complex set of social relations that present HEIs with new challenges that must be tackled if their researchers are to benefit.

If the vision of e-Research being widely adopted is to succeed, the e-Research community must not only seek to create a technical infrastructure where access to resources is seamless and on-demand, it must also strive to create a human infrastructure capable of delivering support that is coordinated nationally, but is adapted to local needs, accessible to all and fit-for-purpose (Atkinson et al. 2009).

Our findings point to some promising ways forward of which providers of HEI research-support services should take note. In relation to the issues that we argue are important to the ongoing adoption, appropriation, domestication and use of technologies, we would make the following recommendations for future research-support models:

— Specific support structures are needed for specific types of research methods and tools. We know there are significant differences between different research disciplines (e.g. D. R. Spence, B. Beckles & L. Martinez 2010, unpublished report), but our data also show differences between research-intensive and less research-intensive institutions.
Experiences need to be gathered and disseminated on how research-computing services might engage with their users, how engagement is coordinated and managed, how support requirements are established and tracked, how well user engagement is perceived to work and how disciplinary cultures, institutional frameworks, policies and career structures influence the development of hybrid skills that make intermediaries so valuable. As the UK e-Science International Review Panel observed, people with hybrid skills ‘[…] require management and long-term organizational support that is atypical for universities.’ (Atkins et al. 2010, p. 25).

We will need to understand the merits and limitations (as perceived by stakeholders) of different support models. This will include perceptions of the cost/benefits of different models and their comparative effectiveness.

We need to leverage enablers and tackle barriers operating at various intra-institutional levels, for example, between: researchers and developers of specific tools; researchers and research computing and/or high-performance computing services; researchers and/or research-computing services and local or departmental information and communication technology services; local or departmental research-computing services and central research-computing services; and researchers and central research-computing services where local services or research-computing services do not exist.

Sustainable plans need to be put in place for research-computer support, including business models for sustaining a widening range of research resources and services, and further enhancing support services.

Knowledge needs to be collected on how to orient to and manage situations—of which we should expect there would be increasingly many if the e-Research vision becomes a reality—where research support spans administrative and funding boundaries.

Technology developers need to acknowledge the importance of the post-implementation phase, both for the effective adoption and use of their products, but also in order to make use of the innovative potential that lies in the experiences of researchers and support staff who encounter technologies in context.

The e-Uptake project has provided a basis for understanding the issues involved in fostering wider uptake of e-Infrastructure services. Inevitably, however, the space available in this paper has allowed us to present only a relatively small selection of the material we have collected, so we are making additional information available in a database of findings at http://www.researchconnect.org/findings. Nevertheless, even this material does not, in itself, provide an indication of the scope or the relative importance of the issues uncovered. Further work—e.g. larger scale surveys—will be needed to produce the evidence necessary to inform and prioritise research and funding policy options.

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