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Virtual Research Environments: Overview and Activity

Michael Fraser provides an overview of the virtual research environment (VRE) and introduces three JISC-funded projects in which Oxford University is participating.

Introduction

Virtual research environments (VREs), as one hopes the name suggests, comprise digital infrastructure and services which enable research to take place. The idea of a VRE, which in this context includes cyberinfrastructure and e-infrastructure, arises from and remains intrinsically linked with, the development of e-science. The VRE helps to broaden the popular definition of e-science from grid-based distributed computing for scientists with huge amounts of data to the development of online tools, content, and middleware within a coherent framework for all disciplines and all types of research. This article highlights some of the issues relating to the development and deployment of VREs and introduces three VRE projects in which Oxford University is leading or playing a significant role.

The VRE as Currently Defined

A VRE is best viewed as a framework into which tools, services and resources can be plugged. VREs are part of infrastructure, albeit in digital form, rather than a free-standing product. It would be difficult for an institution or a research group to procure a VRE in quite the same way as VLEs have tended to be deployed. A VRE shares more in common with a Managed Learning Environment, that sum of services and systems which together support the learning and teaching processes within an institution. The VRE, for its part, is the result of joining together new and existing components to support as much of the research process as appropriate for any given activity or role. It is usually assumed that a large proportion of existing components will be distributed and heterogeneous. As with other virtual environments (e.g. an information environment) the emphasis is on architecture and standards rather than specific applications. The VRE as infrastructure or framework is a view shared by the JISC in its 'Roadmap for a UK VRE' [1] and by those who have reported on the needs and implications of cyberinfrastructure development in theUS [2]. For the most part, the terms VRE, cyber- or e-infrastructure are synonymous. If there is a difference between a VRE and cyber/e-infrastructure then it is this: the VRE presents a holistic view of the context in which research takes place whereas e-infrastructure focusses on the core, shared services over which the VRE is expected to operate. A VRE is more than mddleware and yet that function remains important (as discussed later).

A VRE will not be able to facilitate much research if is not integrated with existing research infrastructure and policies. Much of the existing research infrastructure already has a digital representation or replacement. For example:

- The Research Councils' Joint Electronic Submission (JE-S) system and institutions' own proposal costing and submission systems;
- The heterogeneous and distributed digital collections licensed or developed for the community by the JISC/Research Councils and institutions' own digital libraries and research repositories;
- The national Athens access management service, the planned implementation of Shibboleth and institutions' own single/multiple sign-on systems;
- The National Grid Service and institutions' own Campus Grid and super-computing facilities;
- National portals and institutions' own portals and VLEs;
- The Access Grid and institutions' own supported communication technologies;
- The Open Middleware Infrastructure Institute (OMII), the Open Source Software Advisory Service (OSS Watch) and institutions' own IPR and technology-transfer frameworks;
- The Digital Curation Centre and institutions' own emerging digital preservation and curation strategies, and storage networks.
- And so on...

Research-support also includes a university's research, contracts and technology transfer offices; IT support; archivists and curators. A VRE which stands isolated from existing infrastructure and the research way of life will not be a research *environment* but probably only another underused Web portal.

The JISC in its Roadmap notes that the VRE idea is still evolving (and will be informed by the various projects funded under the VRE Programme), but it is difficult to envisage a VRE sitting outside institutional structures even if the VRE belonged to a distributed research group. (This is particularly true within the context of sustainability and preservation.) In which case, the building blocks of a VRE will comprise a mixture of institutional, (inter)national and discipline-based systems and services. Given also the multiple roles which members of the research and research-support communities tend to have both within their own institutions and within multiple inter-institutional research activities, the convergence between local/national middleware, access management and VRE development activities is obvious.

The development of VREs is not only about the needs of 'big science' (in simplistic terms: large, often virtual, teams; high-performance distributed computing; huge amounts of data; and big budgets). Within a VRE framework access to grid-based computing resources may be one suite of services among others [3]. An institutional VRE, for example, with common infrastructure, shared services and specialised, but *sharable*, applications has the potential to encourage take-up or experimentation of grid-centric services by communities hitherto unsupported within e-science programmes. Likewise, while the social science community are well aware that their methodologies and research interests have much to inform the development and management of e-science, this is not necessarily the case in the arts and humanities (for some good reason) [4].

VREs are about enabling better collaboration. In much of the current literature the project team (whether distributed or not) tends to be accepted as the smallest unit served by the VRE. This may acknowledge that the so-called 'lone' scholar does not, and probably never has, existed. On the other hand, privileging the team or group may limit the VRE to a particular kind of research team with well-defined roles and boundaries and neglect more informal teams and collaborations which exist in other research contexts.

Multidisciplinary Focus

VREs have the potential to be profoundly multidisciplinary, both in their use and in their development. For the most part, it is expected that computer science will act in partnership with other disciplines to lay the foundations, integrating methods and knowledge from the relevant subject areas. Humanities scholars, for example, cannot necessarily be expected to apply tools and processes (initially developed for the e-science community) effectively to their own subjects. Better to articulate the challenges and methods and sit down with the computer scientists. This is not an alien idea for many in the humanities - there is a long history of such partnerships. Indeed, while the humanities and social sciences may not have the scale of data to contend with, they certainly have the variety and complexity of data to continue to provide interesting problems for computer science and engineering.

A common infrastructure for a VRE, even remaining at the level of agreed standards and policies, facilitates the sharing and reuse of tools, data and results. Tools created for one subject-based presentation of a VRE have the potential to be plugged in and available to other subject-based views. In addition, as part of the development of the common infrastructure, one would expect an enumeration of generic tools and services to take place. A number of these, especially collaboration and communication tools, may currently be a normal part of the research workflow within some subjects but not in others. Exposing such tools within a common framework provides the potential for experimentation within other disciplines. The same observation applies to the availability of more specialist tools, analogous to how different disciplines have appropriated methodologies from other subject areas in order to help address (or re-address) specific research questions. The AHDS, for example, has published a taxonomy of computation methods within the arts and humanities, many of which have their origin elsewhere [5].

User Requirements

The development and presentation of a VRE must be embedded and owned by the communities served and cannot realistically be developed for the research communities by others in isolation. Since the intention is to improve the research process and not simply to pilot technologies for their own sake, the research must drive the requirements. Undertaking a 'day in the life of your research' can be instructive and, if nothing else, will generally hammer home the point that the majority of the research community operate in a world which mixes the digital with the tangible, machines with people. In effect, the development of VREs should encourage research communities to be inward looking, reflecting on the types of research questions, the means to address them, and the acceptable ways of disseminating the answers. Understanding and articulating the research methods and culture of any given research area is key to developing a VRE.

The Building a VRE for the Humanities Project (BVREH), described below, is almost exclusively focussed on user requirements. The ISME Project, also funded under the VRE Programme, is led by an

end-user. ISME (Integration & Steering of Multi-site Experiments to Assemble Engineering Body Scans) aims to develop a prototype VRE to enable material scientists and engineers to collaborate on enquiry-based experiments (using multiple sources of archived data) [6].

Research Life Cycle

Advanced computing methods pervade many of the scientific disciplines (e.g. earth modelling systems, simulated ecosystems, DNA sequence analysis, 3D modelling of the human body, whole sky surveys, high energy physics at CERN etc - all noted by the US Blue Ribbon Advisory Panel on Cyberinfrastructure). Within the humanities the recently-funded Arts and Humanities Research Council (AHRC) Methods Network will promote the use of advanced ICT methods in the arts and humanities, drawing on and disseminating knowledge based within centres of expertise in the UK and elsewhere [7].

As well as facilitating multidisciplinary research, a VRE is intended to effect a transformation in how research is undertaken within a particular discipline. This effect may apply at various points in the research 'life cycle'. However, It is difficult to divide the research process into discrete elements. The research process is neither simply linear nor cyclical. Each element generalised below overlaps with others and may have its own identifiable life cycle. The research machine, so to speak, comprises cogs (and pistons and spindles) rather than a single wheel [8]. Having said that, the remainder of this section briefly comments on the role of a VRE with respect to some more general aspects of a research life cycle.

Research Administration and Project Management

A sometimes forgotten but clearly essential element of the research life cycle is the administration and management processes associated with research activities. Very few, if any, of the workpackages being undertaken by the projects funded under the JISC VRE Programme are investigating the role of the VRE in the initial search for funds, the research proposal itself, and the subsequent management operations associated with a project (including financial and reporting). Indeed, research administration (at least in the initial and final stages of a research project) is normally a well-established function within an institution. Research contracts offices and technology-transfer units presumably have a stake in the development of supporting tools and interoperability with existing systems within a VRE. The forthcoming RAE exercise will require the management of the institution's research record (and thus a link to the publishing element of the life cycle). The increasing emphasis on project management as a role distinct from the principle investigator and the impact of Full Economic Costing on research suggests that the e-administration aspect of VREs will be a key challenge to address in the near future.

Discovery, Collection, Analysis

A challenge common to many subjects is the creation of tools which enable intelligent searching of distributed heterogeneous databases. The connections made between data by a researcher can be quite different to the connections made by a software agent. Getting to a position whereby meaningful connections can begin to be analysed depends on having an understanding of the data sources in the first place. Gaining that understanding might not be particularly practical if the data is unstructured, inconsistent and plentiful. Even Google has not enabled federated searching across even its own indexes. What Google cannot do, and what many would like a VRE to do, is to facilitate the linking, integration and subsequent analysis of data.

Virtual worlds, modelling and simulation from large amounts of numerical or other forms of data are becoming increasingly common across the disciplines. The demand for the virtual construction of the past, for example, applies as much to climate prediction as it does to ancient theatres. Digital video is now a common tool for recording the present. The need to retrieve information from and analyse multiple video and audio sources is also an increasingly urgent challenge within the humanities and social sciences [9].

Since access to a VRE is not necessarily confined to desktop browser technologies, and given the improved wireless technologies (whether Bluetooth, 3G or 801.11x) data collection and analysis in the field has the potential to be both efficient and collaborative whether through time or space. The Silchester VRE Project, for example, is developing VRE-based components for online data collection, analysis and storage together with virtual seminars. Data can be collected and analysed remotely. This applies to both the operation of remote scientific apparatus and the collection of survey data online [10].

The sharing and reuse of tools assumes the implementation of agreed standards (as well as perhaps a careful separation of the tool from the data for which it was originally designed). In many subjects 'data'

comes with privacy, security, commercial or complex IPR issues that cannot be resolved by the researcher or research group alone.

Communications

Grid infrastructure includes the Access Grid, used for group-based video conferencing and collaborative working, whether from dedicated rooms, portable nodes, or the desktop. Relatively simple video conferencing technologies, readily accessible and inexpensive at the point of use, support the continued need to engage with fellow humans. The Memetic Project is extending the functionality of the Access Grid to enable better support for meetings together with a range of information management tools. The CSAGE Project, on the other hand, is investigating the use of an Access Grid enhanced with a stereoscopic module to permit the full-sized stereo viewing and recording of performances. The project has its basis in an experimental dance performance within a 3D virtual environment centre [11].

Scholarly Publishing

Common to all disciplines is the impetus to publish and for that process to include peer-review. The dissemination of research is frequently undertaken by third-party publishers. There is a growing emphasis on institutional repositories for research publications, an example of an e-infrastructure component with which a VRE must interoperate. The RCUK's recently released draft policy on open access to the outputs of research and other similar policies for publicly-funded research may, if properly funded, drive the implementation of institutional repositories as part of the core research infrastructure [12]. The forthcoming Research Assessment Exercise for 2008 and the vast amount of record management which accompanies it is likely to be another motivator [13]. Either way, research repositories providing deposit and access services for research outputs (whatever status) are a key component of an institution's e-infrastructure and thus a key set of services within a VRE.

The longer-term research repository is not just about eprints and research outputs, however. There is an increasingly urgent requirement for the long-term curation and preservation of not only research output but the data resulting from collection, creation and analysis. Indeed, preserving the 'project', comprising data, publications, workflows and the 'grey' material of reports, notebooks and other forms of more nebulous communications is important in a research environment where much of the material is born and raised digital. The development of today's research by tomorrow's scholars depends on it [14].

The VRE and the VLE

The BVREH Project, described below, makes the point that, in a research-led university, the relationship between the research and teaching environments is particularly important. This principle is relevant to any consideration of the place of the typical VLE within a VRE. There is certainly technical convergence between, for example, the service-oriented architecture approach taken by the JISC e-Learning Framework and the standards espoused by many of the VRE activities. Indeed, the e-Learning Framework is evolving into an e-framework for education and research which recognises that the learning, research and administration processes of the university utilise and depend on both common, shared infrastructure and resources as well as a series of domain-specific services [15]. The glue which binds together and enables interaction between the various components is an agreed set of open standards (especially relating to Web Services and metadata schema).

A VRE framework should be able to expose some combination of resources, data, and tools. The VLE should be able to consume and represent it as appropriate - a direct link in the virtual environment between research and learning. Conversely, in some contexts it may be possible to re-purpose the existing VLE as a presentation layer, if not the framework itself, for a VRE. The BVREH Project includes a task to survey existing use of the Bodington VLE at Oxford for supporting research activities.

The Sakai framework was designed as a collaborative learning environment and is now the focus of a number of JISC VRE projects. The History of Political Discourse Project, led by the University of East Anglia in partnership with the University of Hull, is piloting the use and development of Sakai as a VRE to support a taught MA programme together with the use of the Access Grid for collaborative research skills training. But, if necessary, the project will also consider the possibilities an existing VLE, such as Blackboard, might offer in place of Sakai [16]. The Integrative Biology (IB) VRE Project, described further below, envisages capturing workflows within the VRE, for example, for potential reuse within a learning environment. The IB Project feeds into the EPSRC-funded Life Sciences Interface Doctoral Training Centre, supported by the Bodington VLE [17]. The EVIE Project, led by the University of Leeds, is establishing an institutional VRE infrastructure which integrates the Bodington VLE with the

Leeds University Virtual Knowledge Park [18]. For both of these projects, integration with the VLE together with JSR 168 and/or Web Services is key to overall VRE development.

Developing VRE(s) at Oxford

Oxford University is participating in three VRE Projects funded under the JISC VRE Programme. Each of the three is briefly described below and each represents a different approach to the development of VREs. In common across the projects, however, are the twin pillars of user requirements and technical open standards as well as the institutional context in which all three operate. Further information about Oxford's involvement in the VRE programme is available [19].

Integrative Biology VRE

The Integrative Biology VRE Project arises from and is intended to address the specific requirements of a large international research consortium. Integrative Biology is an e-Science Pilot Project, led by Oxford University Computing Laboratory (OUCL) and distributed across seven UK universities, the University of Auckland and including a partnership with IBM. The project is developing Grid infrastructure to support computer simulation of whole bodily organs based on molecular and cellular models. The project addresses the needs of researchers studying cardiovascular disease and cancer in particular [20]. Thus, the IB Project is already, in a sense, building a virtual research environment which supports the research process from laboratory experimentation to mathematical model building and simulation, using distributed high-performance computing. The results of the in silico [21] experiments feed back to laboratory experimentation. Data capture, storage and analysis is an important component of this process.

Funding from the JISC VRE Programme effectively enables the IB Project to extend its support for the research environment beyond a service-oriented Grid architecture to acting as a testbed for a large-scale distributed, interdisciplinary research project. The requirements of a real and active research community is the central focus of the IB VRE Project. Under the IB Project itself a detailed user requirements analysis was carried out in order to inform the development of the system architecture. The IB VRE Project extends this requirements analysis to encompass the entire research process as well as the in silico experiment process. The IB VRE Project, with staff in both the OUCL and the Research Technologies Service (RTS), is deploying the Open Grid Computing Environment (OGCE) framework which, like Sakai, provides a standards-based approach to delivering tools to the user, in this case a core set of Grid portlets. Indeed, OGCE has migrated to compliance with the JSR 168 portlet specification which currently means implementers have a choice of deploying uPortal or Gridsphere as the containing framework. The convergence is obvious. uPortal, for example, is a popular choice for an institutional portal [22] and yet an institutional portal seems very far removed from the requirements of a specialised and highly advanced academic research team. Sakai is also moving towards standards-based communication with uPortal and there is on-going work to migrate OGCE tools to Sakai [23].

The IB VRE Project, like the Sakai VRE Project below, while ostensibly testing a particular framework, is committed to the development of portlets to conform with Web Services for Remote Portlets (WSRP) and, where Java-based, JSR 168. As already noted, the IB Project itself is already committed to this service-oriented approach for its Grid toolset. The IB VRE architecture includes support for presentation (from a Web page to a complex visualisation client); a series of front-end services to provide access to the core IB functionality required by the research community, including a workflow capture portlet; and a key set of underlying services which enable access to the computational and data resources, aggregation and presentation, and the overall management of the user's virtual research environment. The VRE will expose not only the computational and data resources currently part of the IB infrastructure but also other resources to support the research process, including peer-reviewed literature and project management tools.

If the IB Project succeeds, researchers will be able to access the VRE securely, consult their own task list and calendar, edit an existing workflow, set up a new experiment and initiate the job on a remote Grid-enabled computing resource while undertaking some combination of monitoring, visualisation, control and communication with colleagues. Given that the development and implementation is standards-based in addition to being requirements-led, then it is not a huge leap to generalise from a community-specific VRE to, for example, an institutional VRE with customised portlets and resources for particular disciplines and research projects.

Building a VRE for the Humanities

The Building a VRE for the Humanities (BVREH) Project further develops earlier work undertaken

within the Humanities Division at Oxford University to survey the existing use of digital technologies within research projects and to establish a set of priorities for the development of e-infrastructure to support humanities research. The BVREH Project, like the IB VRE Project, is firmly focussed on the user requirements of a reasonably well-defined research community. The BVREH Project, in arising from and primarily defining the needs of the Humanities Division at Oxford, has commonalities with the IB VRE Project (led by a specific research community) and the Sakai VRE Demonstrator Project (situated within institutional structures). Despite the Project's focus on a particular institution, the resulting scoping framework and demonstrator tools are designed to be reusable by humanities faculties and departments elsewhere.

The brief for the earlier survey undertaken within Oxford was to examine, among other things, the potential benefits of grid computing for humanities research, information retrieval from heterogeneous and distributed databases, communication technologies, data curation and reusable tools [24]. The results from the preliminary survey suggested that the overall priorities of most interviewees concerned central hosting and curation of the digital components of research projects; and potential for a VRE to facilitate communications. The latter included the dissemination of results from projects, event notification, registers of research interests, collaboration beyond institutional boundaries, and the promotion of humanities research at Oxford more generally. The cross-searching of distributed databases, project management tools, and directory services for hardware, software and other types of electronic resources were also noted as important requirements.

The BVREH Project therefore builds on this preliminary survey through a deeper analysis of the humanities research environment within Oxford and the mapping of existing research tools to specific components of the research life cycle. The results from these studies will inform the development of demonstrator VRE applications and their subsequent evaluation. Where possible the demonstrator tools will be developed or deployed as standards-compliant portlets both to gain added value from development work within other VRE projects (within and beyond Oxford) and to ensure sustainability and potential reuse beyond the project. Developing according to standards like JSR 168 and WSRP also provides the potential for re-purposing tools from elsewhere. However, technical development is not an aim in itself for this project and, should the technologies not prove available or satisfactory, simple Web-based walk-throughs would suffice as the means to the end: being the articulation of the priorities and benefits to be gained from deploying a VRE (in its widest sense) for the humanities research community, as well as an indication of those processes within the research life cycle which for the moment may be better served by more traditional tools and methods.

Sakai VRE Demonstrator

Oxford is a partner in the Sakai VRE Demonstrator Project [25] led by Lancaster University, with other partners being the CCLRC - e-Science Centre at the Daresbury Laboratories, and the University of Portsmouth. The Sakai VRE Project is not tied to any one subject area but rather is seeking to build a demonstrator VRE using the Sakai portal framework. Sakai, funded by the Mellon Foundation and with a large consortium of institutional partners, is intended as a virtual learning environment rather than a suite for the research community [26]. However, Sakai benefits from being developed with reference to key standards which encourage the reusability and sharing of tools developed within and without the Sakai framework. Sakai is also intended as a collaboration environment and collaboration is, of course, common to both learning and research environments.

The Sakai VRE Project will therefore retain the generic communication tools within Sakai but plug in and evaluate a number of research-led tools and services. The project takes advantage of the knowledge and expertise found within the partner sites. For example, Oxford, through the RTS, has particular responsibility for integrating a more effective access management service which builds on the experience of two Shibboleth-centred middleware projects (Spie and ESP-Grid) and integrates a Sakai instance with an institutional single sign-on system. In addition, Oxford is also investigating the integration of cross-searching tools based on Z39.50/SRW and delivered via WSRP/JSR 168 portlets.

A centrally mounted instance of Sakai is being maintained by Daresbury Laboratories which also have responsibility for developing an interface to enable access from within Sakai to user-selected Web Services. The Daresbury Laboratories, building on the related Growl Project, are also integrating a range of tools for Grid computing including data management and simple visualisation.

The University of Portsmouth is contributing to the integration of peer-to-peer tools together with portlet components which will enable interaction with external P2P systems. NaradaBrokering, for example, provides an overall messaging infrastructure which can support grid and Web services, P2P and video-conferencing [27]. Interaction with the NaradaBroker from within Sakai will enable access to core e-Science services. Portsmouth is also developing an advanced portal registry service within the context of the semantic web.

Lancaster University, the lead site for the Sakai VRE Project, is contributing to the overall Sakai infrastructure with a tool to simplify the creation of project workspaces. Lancaster also have ownership of a workpackage to provide a range of collaboration and communication tools, especially a distributed whiteboard, audio and video tools, wikis, and document management facilities.

The Sakai VRE Project neatly exposes the VRE construct as a combination of underlying framework and sharable tools. While the project may not be addressing the needs of a well-defined research community, the project's end-users are, in some sense, the institutional partners. If Sakai is to be seriously considered as a customisable institutional VRE, for example, then (among other things) it will have to prove itself to be not simply another Web-based portal framework but also a layer of enabling middleware with which other institutional systems can be integrated (from research costing applications to the VLE). As Sakai moves towards a Web Services approach, and in particular a WSRP producer, this scenario becomes more realistic. In the meantime, each of the partners in the project will implement and experiment with local instances of the Sakai framework. In Oxford, it is hoped that Sakai might provide an additional testbed for demonstrator tools from the BVREH Project and the sharing of tools from the Integrative Biology VRE Project.

Conclusion

The development of virtual research environments and the underlying e-infrastructure is mostly being driven by project funding. Technological change, including the supporting standards is, as usual, rapid. In parallel to the piloting, investigation and scoping of VREs there is convergence on multiple fronts whether it is the evolution to an all-encompassing e-framework, agreed portlet standards, integration between institutional portals, VLEs and emerging VREs, or more generally the gradual acceptance of open standards, open source software and open access.

However, users expectations have to be managed. There is always a risk inherent in the development of infrastructure through projects of attempting to deliver too much, too quickly. The complexity of both the technical development and the cultural change required has to be properly accounted for, if an early and prolonged trough of disillusionment is to be avoided. VREs within and beyond institutional environments are dependent on core e-infrastructure. Sustainable outcomes from projects require a strategic context and supporting policies. This requirement is especially apparent with regard to the future of institutional repositories, a key component in institutional e-infrastructure. Most eprint repositories, at least, have have been established within UK universities through support from projects such as SHERPA. Retaining a project-developed repository requires on-going funding for development, maintenance and awareness-raising. The deposit, curation, preservation and dissemination of research inputs and outputs requires institutional support: through strategy, funding and policy. The imminent arrival of Full Economic Costing (FEC) presents institutions with a hitherto unavailable opportunity to think through the real costs of providing the research e-infrastructure and ensuring, through formulaic costing, that it is priced appropriately in bids for research funding.

The strategic direction being taken by JISC with regard to recommending a specific set of standards for its e-framework, on the one hand, and the mandating of open access to publicly-funded research on the other, have to be appropriated by institutions if they are to have any practical and long-term realisation. Currently, it is the research councils which mandate deposit of research data and research results, often within services which lie outside the institutional structures and which themselves are dependent on the vagaries of short-term funding. A serious data migration and preservation strategy would operate over 1,000 years not three![28] Google harvests and indexes the Web without attempting to preserve it using approximately 30 clusters, each housing around 2,000 PCs [29]. How many distributed clusters are dedicated to the preservation of research data in the UK alone?

Finally, institutional support for the development of sustainable e-infrastructure requires recognition across all subjects that the creation of interoperable, sharable datasets and reusable tools within the context of a VRE is an important aspect of scholarship in the 21st Century, not merely unaccountable drudgery. The competences required within the disciplines and supporting services to support the development of a VRE along the lines described above are not common. Given the convergence between enterprise systems for education and research there is a pressing need to ensure appropriate recruitment criteria for new staff and adequate training for existing staff.

The UK Government's Science & Innovation Investment Framework 2004-2014, published in July 2004, makes it clear that HM Treasury, at least, believes that multidisciplinarity is the key to success in addressing the grand challenges of the next ten years and this includes the funding for infrastructure to support a multidisciplinary research environment. As part of this, the Government does "work with interested funders and stakeholders to consider the national e-infrastructure (hardware, networks, communications technology) necessary to deliver an effective system."[30] Future funding from JISC, the research councils, the third phase of the UK's e-Science Programme and, of course, institutions, should

help in addressing many of these priorities [31].

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