Chapter III

Imagining E-Science beyond Computation

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Abstract

This chapter problematizes the relation between the varied modes of knowledge production in the sciences and humanities, and the assumptions underlying the design of current e-science initiatives. Using the notion of "epistemic culture" to analyze various areas of scientific research practices, we show that current conceptions of e-science are firmly rooted in, and shaped by, computer science. This specificity limits the circulation of e-science approaches in other fields. We illustrate this using the case of women's studies, a contrasting epistemic culture. A view of e-science through the analytic lens of epistemic cultures therefore illustrates the limitations of e-science and its potential to be reinvented.

Introduction

The promise of technology and the dreams of what a tool might be good for are important in shaping its development and adoption. The futures of new technologies such as the Grid are not determined by the extrapolation of its technical possibilities. It is not even enough to postulate complex interactions between the social and the technical domain as the determinants of e-science. Rather, the future of e-science is, at least partly, created at this very moment, namely in the expectations with which the e-science enabling technologies are inscribed. The way proponents of e-science configure their dream can be analyzed as a "future script" (Brown & Michael, 2003). This script carries assumptions and presumptions that create boundaries between users and nonusers of the Grid and other e-science technologies. Moreover, the writing of the script itself already foreshadows these processes of social inclusion and exclusion by inviting some actors to coauthor the script and effectively excluding other voices. In this light, our chapter examines current concepts of e-science with the aim to uncover the foregrounding of certain future practices, and the backgrounding of others in this "practice of promise."

E-science is a particularly interesting case for the sociology of expectations because the creation of promise is a central feature of its current practice. The writing process of the future script includes the design of e-science web sites, the drafting of funding proposals and national programs as well as the creation of demonstrators and pilot projects. It is a very practical affair. And an open one—the nature of e-science as a dream about the future is not hidden but made quite explicit by its protagonists:

> *. . . whereas the Web is a service for sharing information over the Internet, the Grid is a service for sharing computer power and data storage capacity over the Internet. The Grid goes well beyond simple communication between computers and aims ultimately to turn the global network of computers into one vast computational resource. That is the dream. But the reality is that today, the Grid is a "work in progress", with the underlying technology still in a prototype phase, and being developed by hundreds of researchers and software engineers around the world.* (CERN, 2005)

The dominant discourse about e-science is one of revolutionary changes in the way research will be conducted. In the words of the Grid Cafe: "The Grid is attracting a lot of interest because its future, even if still uncertain, is potentially revolutionary" (CERN, 2005). This dream hinges upon the difference between the web and the Grid. Whereas information-sharing is the core of the web, the sharing of computer power is the linchpin of the Grid. As is fitting for a dream, the exact features of e-science are not pinned down. What it means to practice e-science is not defined in any strict way. Rather, the proponents of e-science indicate what e-science will be by pointing to individual examples and case studies, usually in the form of pilot projects. This seems to be common to all e-science dreams, and generates a creative tension. We think that this tension is formative of the nature of e-science and should receive more attention from analysts and builders of this challenging new enterprise in the world of science and scholarship. We are interested in how this tension shapes the aspirations of e-science, both in the discourse about e-science and in research practices. Not least because it will determine whether important aspects of e-science infrastructures may become relevant to research and scholarship across the board or, alternatively, will be restricted to areas of computational research in the sciences and humanities.

We pose the following questions: To what extent is the dream of e-science constrained by the disciplinary background of e-scientists? What is the focus of current e-science projects? Is e-science truly a dream for everybody and a generic set of tools for all styles of scientific and scholarly research? And, last but not least, what would a non-computational e-science practice look like?

We discuss these questions by zooming in on the tension between generic description and specific embodiment of what e-science might be. We use the notion of epistemic cultures to highlight the different contexts of knowledge production. In the next section, we will define the analytical categories to investigate epistemic cultures in research in general and e-science in particular, drawing from the work of Knorr-Cetina (1999). We will then analyze the main e-science projects in the UK to find out whether e-science is indeed mostly about computation. The last two sections will make the case for the potential of non-computational e-science by using materials from fieldwork in women's studies with respect to e-science, and by bringing this together with a discussion of specific features of e-research in humanities.

Using Epistemic Cultures to Understand E-Science

Epistemic culture is an analytic framework, elaborated in the field of science and technology studies (STS) by Karin Knorr-Cetina (1999). This approach takes as a starting point that science is not a homogeneous set of practices but rather a patchwork of different ways of life. According to this framework, epistemic cultures can be characterized in terms of the objects being produced, the types

of experiments conducted and the relations between units in a field. While developed to study experimental science, we are currently exploring the possibilities of adapting it to analyze knowledge production in other forms (Beaulieu et al., 2005; Wouters 2004; Wouters, et al., 2007 in preparation). This framework may therefore be a useful approach to study research across science, social science and humanities.

In this approach to science as culture, culture is defined as a shared set of recognizable patterned activities. Science is therefore analyzed not only in terms of material, organizational and praxiological aspects of knowledge production, but also in terms of symbolic and meaningful elements (Knorr-Cetina, 1999, p. 10). The notion of culture also highlights the development of researchers, and the way they maintain and adapt a particular culture that distinguishes them from other researchers. Each of the elements of an epistemic culture (its object, experiments and social relations) can help guide analysis of practices and of the way these change, for example, when there is an increased use of ICT. These elements are also useful in analyzing how ICTs are shaped by the cultures in which they are observed. Each element is briefly explained and illustrated below.

Objects

Every epistemic culture has a particular relation to the empirical. The ways in which an object of study is constituted therefore characterize an epistemic culture. For example, botanists constitute their object by collecting specimens in the field. In sociology, answers to surveys that give indications about behaviors may constitute the object of research. In each area of science, there are accepted ways of constituting objects and of manipulating them. These are situated practices, and not necessarily equivalent to textbook methodologies taught to undergraduates. They may also change. For example, in literary studies, the relation of researchers to their objects changes as texts are digitized. Whereas the traditional approach encounters a text in a relatively linear way, once digitized and tagged, the elements of a text can be mechanically recalled whenever the researcher wants. In other words, the relations to the empirical shifts as elements of the text are removed from the "field." In searching a data file, the elements of texts are removed from the book as the field where they occur. It is as though the encounter with the text is lifted out of the phenomenological encounter with the text in the act of reading, and replaced by an encounter with the text based on searching or other such manipulation. This kind of computer-based literary study constitutes the text as a new kind of object that can be studied in the "lab" of the analysis programs.

Experiments

A second analytic category of epistemic cultures is the way the object is interrogated, manipulated and made to yield interesting and unexpected results. To illustrate this with practices in literary studies, an example of an experimental strategy is the comparison of texts to determine authorship. Expertise for such comparisons might come from years of reading to familiarize oneself with a canon, with its boundaries and with the history of literary analysis of this canon. The analysis of texts then builds on the embodied knowledge of the reader, who interrogates the text based on this understanding. In a context where digitized texts form the empirical object, the interrogation of literary texts can take on a different form. For example, comparisons of vocabularies or structures may be based on the retrieval of similarities and differences based on automated search functions or on running the text through parsing software.

Relations between Units

Finally, the relations between units within a field are a key aspect of epistemic cultures. This can be seen as the "social organization" of a culture. The unit can be a research group but also an individual scholar. In literary studies, the "units" of this culture may in fact tend to be individuals, several of whom may be organized in relation to a common resource (collection, library, archive, national canon). In cases where special tools are being developed, scholars may be working in collaboration with other specialists and form research teams. This level of analysis addresses institutional issues in the production of knowledge (specialization, resource distribution) and other questions that have traditionally been addressed in the sociology of science (such as the economy of credit for work done, patterns of publication and recognition such as authorship, and the development of career paths).

The perspective of epistemic cultures, as an approach to understanding knowledge production, keeps sight of the fact that science is pursued not only by individuals or collections of individuals. Knowledge-making must be understood in terms of the material and symbolic dimensions needed to run experiments and communicate with others in the field. This notion helps to maintain an analytic stance that avoids technological determinism (the idea that technology determines social relations), that keeps sight of the contents and specificities of different types of work and that doesn't overly focus on the technical requirements of new tools.

A cultural approach to technology enables, moreover, a focus on meaning, on the locally elaborated practices around artifacts. It draws attention to the specific

(as opposed to the taken-for-granted and unquestionable) ways in which technology can *become* significant, and maintains as a starting point that technologies are underdetermined. Given what we have said above about notions of promise of technologies as formative of practice, the epistemic cultures approach enables us to analyze the interaction of current and potential practices. We now turn to e-science initiatives and consider them in terms of the epistemic cultures from which they arise.

A Computational Dream

A common rhetorical strategy in documents and on web sites about e-science is to oppose the future Grid to the existing internet. In this way, a contrast is set up between a network of independent computers on the one hand (the internet) and a network working as one computer (the Grid). It is a computational dream:

> *It is practically impossible, nowadays, to do science without computers. Scientists are facing increasingly complicated problems which require much more than a blackboard! Often, a single computer, a cluster of standard computers or even a special-purpose supercomputer, is not enough for the calculations scientists really want to do. That's the way scientists are—always pushing the limits. Of course, computers are improving incredibly fast: processor power doubles every 18 months or so, a phenomenon often referred to as Moore's law. Still, they do not keep up with what scientists demand of them. As a result, scientists are often faced with situations where they "hit the wall", and which make it very difficult, very expensive, and sometimes downright impossible to achieve certain scientific goals with current computer technology. So some scientists started dreaming. They dreamt of a way to surmount these obstacles. They dreamt of having nearly infinite storage space so they would never have to worry where to put the data. They dreamt of having nearly infinite computing power available for their institution, whenever they need it. They dreamt of being able to collaborate with distant colleagues easily and efficiently, safely sharing with them resources, data, procedures and results. And, being always worried about their research grants, they dreamt of doing all this very cheaply—maybe even for free! (Dreaming costs nothing.)* (CERN, 2005)

Note that the Grid is not only about computing, but also about data storage and distant collaboration. Nevertheless, computation is central as the key intellectual challenge driving the wish for e-science. Two ingredients are designated as the grounds for the need for more computational power: more complex problems on the one hand, and more data on the other. These two problems are intimately linked to the increased social scale of research: the need to coordinate resources for mega-projects across all continents. They emerge as central "motivators" for the Grid in most Whig histories (Butterfield, 1931) of the e-science communities[1]. However, the initial dynamics that generated the field of Grid computing, the core of present e-science initiatives, were quite different. To understand this, we need to delve into the history of the Grid.

It is a history of forward-looking documents and pilot projects in computer science that link to each other and build on each ancestor. The histories we have are mainly Whig histories: introductions or "historical" chapters in volumes aimed at promoting e-science and the Grid. Puzzles in computer science were the initial triggers of e-science. The first modern Grid emerged in 1995 with the I-WAY project. At a conference on supercomputing, researchers aggregated a national distributed test bed with over 17 sites networked together by a computer network, the vBNS. "Over 60 applications were developed for the conference and deployed over on the I-WAY, as well as a rudimentary Grid software structure to provide access, enforce security, coordinate resources and other activities" (Berman, Fox, & Hey, 2003 p. 13). Developing infrastructure and applications for the I-WAY seems to have been a transforming experience for the first generation of modern Grid researchers because they had to rethink their ideas about computer networks. "Whereas distributed computing generally focuses on addressing the problems of geographical separation, Grid research focuses on addressing the problems of integration and management of software" (Berman et al., 2003 p. 13). Thus, creating a global Grid was in fact the response to a local problem within a particular field in computer science, in other words, within the terms of a very specific epistemic culture.

Computer science is not the only driver, however. According to e-science proponents, a number of fields have been confronted with barriers in tackling complex computational problems and/or masses of data that threatened to swamp their computational resources. This is the case in astronomy, medical and cognitive science using digital imaging technologies and in many areas of the life sciences. But how far has this dream of e-science actually progressed? To what extent are researchers from specialties outside of computer science already involved in the construction of e-science practices? To answer this question, we analyzed the UK e-science program[2]. The UK program is one of the biggest e-science programs in the world. To be sure, the U.S. cyberinfrastructures programs organized by NSF predate the UK initiative. Nevertheless, the ambition to speak to scientific communities other than natural scientists has not developed until very recently. In the words of Stephen M. Griffin, a program director in the Division of Information, and Intelligent Systems at the National Science Foundation (NSF):

> *Historically, the USA Federal funding agencies have used narrow and restricted definitions of information/knowledge infrastructure—primarily focusing on computing and communications hardware systems, and more recently, networking middleware and scientific databases. Digital libraries research has reframed perspectives and dramatically broadened the IT applications spectrum. Innovative interdisciplinary applications in non-science, content-rich domains such as the arts, humanities and cultural heritage informatics are proving to pose altogether new and greater challenges for IT research and cyberinfrastructure development than have been encountered in computational science applications.* (Griffin, 2005)

The UK program has taken the initiative to spread the gospel of e-science to the social sciences[3]. The first international conference on e-social science, for example, has been held in June 2005 in Manchester. Therefore, if e-science has evolved outside of its original context into other fields of academic research, this evolution should be visible in the UK e-science program[4].

The UK e-science program is run by a steering committee supported by a user group and a technical advisory group. The latter group is composed of 14 researchers with a background in computing and one bioinformatics expert. Computer science and physics are the dominant fields in the Steering Committee. The User Group is more diverse: its seven members are spread over six fields. Table 1 gives the composition of the Steering Committee and the User Group in

Table 1. Composition of committees UK e-science program

Steering Committee	
Field	**Number of members**
Computing	7
Physics	4
Bioinformatics	1
Neuroscience	1
Environmental science	1
Gerontology	1
DTI representative	1
Rolls Royce R&D	1
User Group	
Field	**Number of members**
Computational chemistry	2
Bioinformatics	1
Medical statistics	1
Physics	1
Meteorology	1
Astronomy	1

more detail. We must conclude that the e-science program is being run by experts from computational research fields only.

We also analyzed the projects running under the UK e-science program as of January 30, 2005. We looked at the project goal, the description of the actual research that the project entailed and the discipline to which the project contributed[5]. Interestingly, the three dimensions pointed to both the generic and field-specific features of e-science, the generic ones emphasizing the potential of e-science as a general enabling infrastructure and technology, the field-specific features underlining the local nature of technological and scientific puzzles. The project goal descriptions were most diversified and ranged from building the nuts and bolts of the Grid architecture to the design of racing yachts and new forms of publishing. This underlines that the e-science program is relevant to a wide variety of research projects[6]. If we look in more detail at the type of research actually foreseen, however, the picture changes. The development of data management and analytical tools is the largest cluster: One quarter of the research is devoted to data. Table 2 gives the types of research work that are most frequent[7].

The UK e-science research is mostly about data, data formats, data sharing and data analysis. In terms of the concept of epistemic culture: E-science seems especially relevant for the construction of the object. We also see that the infrastructure for research is strongly represented: Middleware, grid services and resource scheduling belong to the more frequently mentioned research activities. This refers to the relationships between units in the field. Visualization, distributed computing, and simulation are more directly linked to new research practices and may be interpreted as bearing upon forms of experimentation. Often they go together with the development of new data tools and these projects are almost exclusively devoted to quantitative research. This does not hold for the last type of research mentioned in the table: collaborative tools. These projects aim to build tools that in principle could be used in a variety of fields, although the fields in which they are tested in the first instance are mostly quantitative in nature. Forms of research that seem most relevant to non-computational research do appear, but they are scarce. For example, the creation of tools for textual analysis is mentioned three times, fieldwork support twice and browser development once.

Table 2. Main research work in UK e-science projects

Type of research	Number of projects
Data tool development	62
Middleware	22
Visualization	20
Grid services	19
Distributed/shared computing	17
Simulation and modelling	16
Resource sharing scheduling/ brokering hosting	15
Collaborative tools	15

Table 3. Scientific fields figuring in UK e-science projects

Fields	Number of Projects
Computer science	93
Bioinformatics	36
Medical	21
Engineering	9
Environmental research	8
Bioscience	5
Physics	5
Chemistry	4
Astronomy	4
Social science	2
Neuroscience	1
Mathematics	1
Electromagnetics	1
Anthropology	1

This dominance of computational work is underlined by the relevance of the UK e-science projects to different scientific fields. Computer science is here clearly dominant, followed by bioinformatics. Table 3 gives the different fields to which the UK program aims to contribute in its projects.

As we can see, almost all fields are computational. Social science appears only twice, anthropology once and these projects may very well be mostly quantitative in nature. Of course, this in itself does not mean that e-science is being "colonized" by computational researchers. The dominance of computer science can easily be justified by the need to build sophisticated computer infrastructures that also pose new puzzles to computer science and engineering. With respect to infrastructure, the UK program is mainly focused on design. The relatively high number of projects that contribute to medical sciences is mainly due to projects that are creating new tools for clinical practice, such as fieldwork support and remote access to patient data. These same tools could arguably be relevant to, for example, the digital analysis of medieval manuscripts or the observational study of cultural behavior. In other words, there seems to be potential for e-science technologies as enabling technologies for a wide variety of fields.

Nevertheless, this potential is not yet instantiated as concrete possibilities. We can draw three conclusions from the analysis of the U.K. e-science program. First, most research in the e-science program aims to construct an infrastructure that is supposed to support all forms of e-science in the future. Second, the building of this infrastructure is related to and informed mainly by computationally-oriented research. The input from humanities has so far been virtually nonexistent and input from the social sciences scarce[8]. Third, this infrastructure-in-the-making has moved closer to actual research practices, which explains the dominance of data-oriented projects. Apparently, the basic computer infrastructure has developed far enough to be able to overlay this structure with data structures and middleware tools that should connect substantive research projects to the e-science infrastructure. This distinction between form and content is, we think, an interesting observation in itself. The conceptual move to create middleware that is at an intermediate level of specification with respect to the general information infrastructure on the one hand, and particular research practices on the other hand, points to a potential steering influence of e-science infrastructures. It is too early to tell whether and to what extent this standardizing potential will be actualized. Nevertheless, it seems worthwhile to follow its development. Furthermore, the ambitions of e-science projects underscore the importance of questioning the assumptions "black boxed" in digital infrastructure and tools.

Women's Studies

Epistemic culture as an analytic framework has mostly been applied to natural and life sciences. An important element that undergirds Knorr-Cetina's approach is the notion of experimental science, and its concomitant investment in the laboratory. While the configurations of object, experiment and relations may seem radically different in the humanities and social sciences, the framework of epistemic cultures can also be used to reflect on the practices in these fields—and to explore the limitations of the epistemic cultures framework.

For Knorr-Cetina, the laboratory is important in that it is the site where experiments and objects come together. The laboratory is therefore the place where an epistemic advantage can be gained, since the object does not have to be accommodated when and where it happens, in its environment. This element distinguishes, first of all, experimental science from "field" or observational science. As such, it would not seem to include practices in qualitative/phenomenological analysis, or many interpretative practices that are core activities of the humanities. Yet, western epistemology still has fairly directive requirements—disciplines must make their objects.[9] This always implies some removal from the field, even though a spatial configuration such as a laboratory may not always be the characteristic of such a removal.

Indeed, this broader view of what it means to draw on the empirical, to do experiments, provides insight into the way the promise of e-science might be received in certain epistemic cultures. It suggests which new scripts might be elaborated from these epistemic cultures in relation to e-science. In this discussion, we follow the road from promise to practice in opposite directions, and begin with practice in a specific epistemic culture. The material presented here is drawn from an ongoing project on a university-based women's studies

group in a humanities faculty in the Netherlands. While the analysis is still in an early stage, some of our observations are used here to suggest how e-science might be dreamed otherwise.

Objects

In the women's studies group, the object of study is always highly contextual and reflexive. Scholars strive to understand their object in relation to its cultural provenance, and in relation to the theoretical and analytical tools used to examine this object. As stated in the dual research questions presented on their web site:

> *What representations of gender and ethnicity are currently being produced in theory, history, oral narrative, literature, television, cyberspace and film? What feminist methods, gender tools and analytic frameworks in relation to the power of dominant discourse are currently being produced as a form of resistance?* (Women's Studies, 2005)

The object is therefore a cultural formation, in all its complexity, levels, variation and contexts (including that of interpretation). When encountering the web for example, it becomes an object of interest insofar as "cyberspace" provides the possibility of new forms of gendered representations, or new ways of interrogating them.

If the way women's studies constitutes its object were to be served by e-science tools, the following elements would be important to link practices and possible applications. Women's studies researchers would not tend to recognize their object as "data," which can be retrieved. Rather, the object to be accommodated by new technologically-supported practices would be the cultural representations of interest to women's studies. The possibility of recording, of displaying these cultural representations, would be more in line with the epistemic aspirations of women's studies. Furthermore, the possibility of showing and demonstrating digital and electronic settings would be valuable. An analogy with what e-science could do for women's studies might be the way the VCR was integrated into research practices. What is studied is not the videotape itself, but how the VCR does allow for capture, demonstration, close study and teaching of representations and cultural formations of interest to women's studies that may be present on television or in the cinema theatres. A similar way of "showing" the web or other ICT-mediated settings would likely be of interest.

Experiments

How can we speak of experiments on such objects? While experiments in the sense of "physical manipulation" are not particularly relevant, this notion can still be helpful to think about the ways in which objects of knowledge are constituted and interrogated. The representations analyzed are not solely a specific instantiation of a cultural form in a medium, but also the conditions that make this possible. The relations and conditions that support that instantiation are the object, and the discovery, analysis and expression of these constitute the process of knowledge-making in women's studies.

We are not talking, in the case of women's studies, about "digitization of empirical sources," at least not in the technical sense. The representations that are selected as objects of study may be in the realm of the digital, but they matter as "culturally" digital. This digitality is considered to be made up of many layers of practices, meanings and institutions, rather than solely as the expression of a bit of code on a particular type of hardware. To understand this object therefore requires an understanding of how it is created, valued and sustained.

Knorr-Cetina's classic example of the signal in high energy physics is perhaps not so different from the way women's studies make and understand their objects. In order to understand the signal, the accelerator must be understood in relation to all other events taking place in the experimental infrastructure. Similarly, women's studies tries to understand the context in which representations are made. In high-energy physics, the apparatus and context are highly technological (the infrastructure of the accelerator). The relation between the signal and the infrastructure is examined via complex mathematical models and calculations. In contrast, in women's studies it is the analyst herself who serves to "detect" the object of interest. The relations between the analyst and her object, as well as the context of this relation, are examined via sophisticated philosophical categories and reflexive processes. Working on an object in women's studies therefore means being aware of what is being made visible, of the role of the analytic framework for constituting and interrogating an object. The process of writing constitutes the main manipulation, the experimental setting where theoretical framework, object and interpretation come together through representation of the analysis in the shape of a text.

The analysis of "experiments," construed as the manipulation of objects by women's studies researchers, also highlights particular practices that have implications for what might be of value to researchers. Women's studies scholars highlight the importance of writing as a key knowledge-making activity, rather than as a way of "reporting" findings or disseminating results. Writing in women's studies involves maintaining an awareness of multi-layeredness of objects/interpretations/representations. Tools that support such activities might

be imagined, beyond current office automation and word processing tools currently available. To elaborate a very simple example, when asked what would make her life easier, one researcher told of her need to keep track of what she has written. What she would like is an ICT application that enables her to keep track, not of her notes, nor of digitized archival material, but of the work she has done on a particular topic. This would enable her to answer the question: What have I said about such and such a historical figure? The idea here is to track meaningful passages, across a variety of texts. Currently, this can be solved by rereading one's work. This is not the same as managing data, because the context of the text within which this finds itself is important. This is one small way in which digitization must NOT mean removal from context, if it is to offer a meaningful function for scholars in this epistemic culture.

Social Relations between Units in a Field

As a philosophically and literary studies-oriented group, it might be expected that very individualistic modes of operation would be privileged. Indeed, if one looks at elements such as publications, there are rarely coauthored works.

In order to maintain an institutional space where this work can proceed, however, strong social relations are needed. In the case of this particular group, there is an important interaction between the use of e-mail and web-based communications, the notion of "internationalization," and the securing of a space for the pursuit of women's studies in the university. Women's studies practitioners were already attuned to the international scene, often explaining that women's studies could not be viable in terms of the national context of their original discipline. Very briefly, the notion of internationalization is significant because in the past decade, it has become an important criterion of scientific quality in the specific national context. E-mail communications therefore are a way of maintaining and expanding this international connection, while web sites can serve to display this international orientation to local administrators in the university, for example.

In this particular fieldwork to date, the activity most mentioned (and usually mentioned first) in relation to ICTs is sustaining of networks. Contacts with faraway colleagues and groups sustained by individual e-mail, mailing lists and web sites are considered crucial to the success and activities of the group. This plays out in a number of registers. For example, contacts serve to develop work and ideas for members of a community that is very small in the national context. Awareness of conferences, workshop and publishing opportunities also happens via e-mail and mailing lists. Making contacts that are essential for the organization of group or bilateral activities and for obtaining grants also happens via e-mail. This network enables obtaining funding, or holding events (PhD summer schools) that would not be available or feasible on a national scale. Related to this networking activity, the "international" dimension functions as a mode of legitimation in the national context where this fieldwork is taking place. Having international links is considered a criterion of excellence, one which researchers in this group have been able to fulfil very effectively. As a consequence, the display of international contacts as forms of legitimation, in the face of university administrators, other departments in the university or other scholars from the mother discipline is also performed via web pages. Therefore, while a lot of the work of these scholars is solitary, networks have a very important function in sustaining this work, and ICTs are thoroughly enmeshed with this practice. It is not so difficult to dream of ways in which the maintenance and display of network relations might be enhanced via new applications.

Conclusion: Toward a Non-Computational E-Science

We have shown that there is an intriguing tension between the ambition to make e-science the new paradigm of knowledge creation and the actual research practices that are built into the new knowledge infrastructures. E-science, at least as it is embodied in the UK e-science program, is about building a particular type of infrastructure for research. This infrastructure has been shaped in the context of a very specific epistemic culture which originated in the world of high-energy physics and was subsequently modified in computer science and bioinformatics contexts. Nearly all tools that are being built are related to computational research. The problem of whether or not this may constrain the future potential of e-science as an infrastructure conducive to all sorts of academic scholarly work is usually not raised in the e-science community. The spread of e-science is more frequently framed as a problem of awareness raising or of diffusion of ideas and technologies. In other words, there may be a serious problem of misalignment between the emerging e-science community and other scholarly communities. We have conceptualized this as a misalignment between the script that underlies the present massive investments in e-science projects on the one hand and the practices in other epistemic cultures, taking women's studies as an example.

In other words, this tension between the undefined generic ambition of the e-science dream and the particular pilot projects that embody the dream is not an accidental phenomenon but is the very consequence of the way e-science is constructed as a future mode of scientific research. As a result, the *general* description of e-science has an all-encompassing nature. There seems to be no field of research to which e-science might *not* be relevant.

On the other hand, if we look at the *concrete* embodiment of e-science in demonstrator projects, computational research seems to be dominant to the point that it is hardly about anything else than the design of infrastructures for large-scale data and computation. These projects therefore predominantly highlight the Grid as a potential technology for large-scale data management and computational analysis. Another application on which e-science attention is focused is data visualization in modeling and simulation research projects. E-science is therefore strongly associated with computational research (Brockman, 2001; Chien, Foster, & Goddette, 2002; Hey & Trefethen, 2002). The potential for non-computational uses of e-science tools may be mentioned but usually only in passing. In other words, the *promise* is the opening up of venues undreamt of for researchers, irrespective of their specialization. The *practice* is one of building e-science infrastructures by computer scientists in close cooperation with scientists in computational research in physics, life sciences, materials science and social and behavioral sciences.

The various aspects of epistemic cultures analyzed in the section on women's studies can shed light on what a "non-computational e-science" might become. Without wanting to claim that such an analysis would provide guarantees of providing useful tools, such a starting point does highlight other possible directions for e-science. Thinking about epistemic cultures in relation to tools also highlights the decisions that have already been incorporated into current e-science projects.

It is important to note that the three features of epistemic cultures (objects, experiments and relations between units in the field) are interrelated, and that e-science will not simply "answer needs," but also reconfigure practices. If ICTs seem most present in the social/organizational aspect of this epistemic culture, there may be new practices developing that affect objects and their manipulation. To give one final example from women's studies: Members of a network are aiming to pursue a task online, in a distributed manner. The goal is to bind the network, through the creation of a novel object (a database in this case), the manipulation of which will in turn require adjustments to current practices around objects. Such initiatives require expertise, support and tools, which might be elaborated within e-science initiatives.

Finally, if epistemic cultures can speak to e-science, the methods and concepts of this analytic frame must also be questioned. If this approach has the advantage of interrogating the meaning given to technology, it does, however, potentially reify the notion of culture, and may therefore blind us to some of the novel social relations being enacted through technological networks. The setting of e-science may cause us to revisit the notions of epistemic object and technical object, which are key to the notions of laboratory and experiment in the cultural approach to science. These and other issues surrounding epistemic cultures are discussed by Wouters et al. (2007, in preparation).

We have noted above the rise of new analytical puzzles. New methods may also be needed for science and technology scholars who study epistemic cultures in highly-mediated settings. Knorr-Cetina suggests that ethnographic work might be scaled up to study distributed organizations, such as high-energy physics collaboration. E-mail might be used by the analyst, in the same way that physicists also link up to this network (Knorr-Cetina, 1999, p. 23). E-science tools might also be imagined for this kind of research practice (Beaulieu & Park, 2003; Hine, 2002, 2005; Ratto & Beaulieu, 2003; Wouters et al., 2007 in preparation).

We are not arguing that e-science is a promise that will never be realized, and that we are setting out to debunk it. Nor do we want to argue that we are better off looking into the crystal ball and predicting what researchers will need or will want in terms of concrete technologies. Dreams and promises are a necessary part of change. And only a very close collaboration with researchers can hope to have concretely useable tools as an outcome. Rather, we have tried to show in this chapter that the promises of generic tools are not neutral at all, but rather represent the "culture of no culture" (Traweek, 1988) that physicists and computer scientists, as originators of the Grid promise, have been shown to have. Second, we have argued that there is already a strong tendency for e-science to generate a specific kind of application, towards computationally-oriented tools. We have sketched how ICTs are present in fields such as women's studies, which, while neither computationally-oriented nor involved in large scale digitization projects, are still very concerned with digital media and electronic networks. The presence, extension and development of new ICTs may be imagined from an analysis of epistemic cultures, and lead to forms of e-science that have not yet been elaborated—possibly avoiding "top-down" dynamics which are especially likely to rebuff researchers.

In short, if e-science is to be a dream then the question, "Whose dream is it, anyway?" is a pertinent one.

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Endnotes

1 See for a discussion of the notion of Whig history: Wikipedia (2005).

2 We downloaded all documents from the official Web site of the UK e-science program that contained the descriptions of 195 projects (National e-Science Centre, 2005). We also analyzed the disciplinary background of the scientific committees by looking up the personal home pages of the researchers listed as members.

3 The Dutch have taken new initiatives which focus on the humanities and qualitative social sciences (Wouters, 2004).

4 Business has also discovered e-science as a novel opportunity, of course, but this is strongly focused to data management and computational problems and on selling e-science software and hardware. A discussion of the impact of e-science on business is outside the scope of this article. IBM is particularly active in the promotion of e-science and Grid computing (http://www-1.ibm.com/grid/).

5 Each project can only have one goal, but may contribute to more than one field or may contain more than one type of research. Therefore, the total numbers of the three lists differ.

6 The complete list is given in the appendix.

7 The complete list is given in the appendix.

8 We do not mean to belittle, of course, the study of e-science practices by social scientists from the perspective of the social shaping of technology, social informatics, or science and technology studies. This book is itself a result of these research efforts. Until now, however, insights from social science have not been taken up in conversations underlying the creation of e-science or cyberinfrastucture programs in the UK or elsewhere, and the building of e-research infrastructures. It is the very purpose of our chapter to point to some important factors contributing to this state of affairs.

9 See for a recent treatment of this question Boumans and Beaulieu (2004).

Appendix

Table 4. Project goals of UK e-science program

UK E-SCIENCE PROJECTS	
Topic	**Nr of instances**
grid architecture	14
visualization	10
genomics	9
virtual organization	8
data	6
hospital Grid	6
Grid services	5
astronomy grid	4
biodiversity	
resource sharing	
security	
climate prediction	3
neuroscience	
physics grid	
proteomics	
networks	
ontology	
aircraft	2
archiving storage curation	
biochemical networks	
complex systems	
computational electromagnetics	
data access	
database integration	
desktop environment	
education	
engineering data	
environmental e-science	
high throughput informatics	
information services	
medical images	
middleware	
ocean diagnostics	
peer to peer	
portal	
vessel design	

Appendix (cont.)

Table 4. (cont.)

One instance each:
aging
anatomy
anthropology
authorization
bacteria models
bandwidth
biomolecular simulation
brain atlas
breast cancer
cancer management
cardiovascular
chemical structure
chemicals design
chemistry Grid
complex materials
computing
computational resources
condensed matter
crystallography
debugging
data mining
disease data
earth system
e-science center
e-science experiences
evaluation,
fluid dynamics
geochemistry
Grid hosting

Appendix (cont.)

Table 4. (cont.)

One instance each:
insulin[e] resistance
integrative biology
Java code
lubrication,
mammography
mathematics
medical devices,
medical diagnosis
messaging
microarrays
military grid
mobile resources
molecular informatics
MS.net software
mouse atlas,
multipart jobs
problem solving environm(
protein crystallography
publishing
racing yachts
radiation risk
remote microscopy
search engines
semantic Grid
sharing information
simulation
social science
source querying
streaming
SUN grid
system biology
teleconferencing
television, text mining
trust
university grid

Appendix (cont.)

Table 5. Type of research in UK e-science projects

Type of research	Nr of instances
data tool development	62
Middleware	22
Visualisation	20
grid services	19
distributed/shared computing	17
simulation and modelling	16
resource sharing scheduling brokering hosting	15
collaborative tools	15
grid infrastructure	3
network analysis	
ontology	
software demonstration	
text analysis	
centre of excellence	2
course	
fieldwork support	
performance prediction	
security tool development	
standards	
broadcasting	1
browser development	
building of design environments	
decision support	
experience sharing	
image analysis	
incomplete information management	
information retrieval	
multicasting	
patient care remote access	
quality control information	
repository	
selfmanaging systems	
service quality	
surgery	