Systematics as Cyberscience: the role of ICTs in the working practices of taxonomy

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Introduction

Information and communications technologies have been a highly persuasive means of imagining our future. Most, if not all, areas of social life have been the site of speculation over the implications which information and communication technologies (ICTs) may have for their transformation, and ICTs are probably the most popular vehicle for the expression of hopes and fears in recent times. In many of these areas we are seeing these hopes and fears being worked through with outcomes which, although not trivial, are largely not those predicted at the outset. In use, the technologies that we have developed turn out not to have the wholesale transformative effects that some proposed. Instead, as so often with technologies, we find variation, contradiction, and locally specific innovation. At the same time it seems clear that ICTs have indeed provided potent sites for cultural expression and for the development of new social formations. ICTs are both culturally embedded artefacts and cultural sites in their own right. In this paper, and in an ongoing programme of work, I look at one field of social endeavour, science, and its engagement with ICTs. The aim of this research is to look at ICTs in science as a site for the expression of hopes, expectations and fears, to examine the drivers of change and the areas of resistance and constraint, and to work through the practices and identities that result from the increasing incorporation of ICTs into scientific work. Scientific knowledge being a central feature of contemporary society, it seems important to examine to what extent ICTs are involved in transformations of the processes of science and its outcomes. How far new forms of knowledge are shaped by the application of ICTs, and how far we see distinctive forms of cyberscience emerging, are questions for detailed sociological examination.

ICTs for science have been high profile recently. In the UK context, an initiative by the Office of Science and Technology has invested over £100 million pounds in the development of computing technologies and demonstration projects for e-science, involving all of the research councils together with a core programme. The vision, as articulated by the Economic and Social Research Council (ESRC) in its call for demonstration projects in e-social science, is as follows:

> The E-Science vision is of a globally connected scholarly community made up of virtual co-laboratories aimed at promoting the highest quality scientific research. Underpinning this vision is the development of an IT infrastructure that will

> support research collaborations through the shared use of very large computing resources, enormous data collections, remote access to specialised facilities and visualisation technologies.
>
> The 'Grid' is a developing technical architecture that will make possible such a vision for E-Science. It aims to provide an infrastructure that enables flexible, secure, co-ordinated resource sharing among dynamic collections of individuals, institutions and resources. This includes computational systems and data storage and specialised experimental facilities.(ESRC 2003)

The vision, then, depends on intensive use of advanced computing facilities, used in order to realize both new scientific knowledge outcomes and a new social organization for scientific practice. These "dynamic collections of individuals, institutions and resources" will produce "the highest quality scientific research". Of course, this is the kind of visioning that has become familiar when we talk of ICTs, remarkable in this case mainly in that it survives the bursting of the dot com bubble, which rendered ICT-vision-talk unfashionable in so many fields. It is easy to sneer at the naivety of a vision: visionaries always risk becoming the object of ridicule, since extreme versions of the future can so easily be shown to be mistaken. It is not sufficient, however, simply to write off such talk as overblown, and to do so would be to miss out on a fascinating opportunity. Science does remain a highly important area of contemporary social life, and whether the vision turns out to be overblown or not, the fact remains that practices and knowledge outcomes inevitably will change in some ways with the increasing use of ICTs. Faced with an investment of £100 million in high profile intensive computing applications alone, not to mention to continuing investment in mundane, everyday computing applications and Internet communications within science, it seems reasonable to invest a small amount of sociological effort in examining the consequences.

This paper begins the exploration of a potential cyberscience in the making. It is essential to look at a case study in action if we are to get close to ways in which working practices and outcomes are changed with the advent of new technologies. Without looking at the details of a case study, we are stuck with the competing grand pronouncements on what science is like and what ICTs can do that prove ultimately unsatisfying as a description of the experience of any of those involved. By looking at a particular area of science as it has grappled with use of ICTs, we can start to see how blanket statements about what ICTs can do for science miss out on so much that is important. We can also begin to see that ICTs have not merely parachuted in to scientific disciplines as agents of change. These technologies have histories, they have advocates and opponents, and they have cultural meaning for those involved. While ICTs may provide an opportunity to make science more efficient, and may provide the chance to carry out different kinds of science altogether, the analysis presented in this paper suggests that these opportunities will be enacted in ways quite specific to particular disciplines. A historical perspective allows us to see how both the concerns of the discipline and the corresponding ICT solutions develop over time.

The area of science chosen for this study is biological systematics, or taxonomy[i]. This field, arguably one of the oldest sciences, has the remit of classifying and naming biological organisms and studying evolutionary relationships between them. This is a far from trivial task. Estimates of the number of species on earth vary wildly, but always produce a total that is vast in relation to the numbers of taxonomists available to describe and name them. Modern systems of nomenclature date from the work of Linnaeus as published in the 18th century, and working taxonomists now have to grapple with complex synonymies built up by superceded and discredited classifications since that time. Increasingly systematists work with DNA sequence data to add to more tradntional techniques. While there are complex rules on the process of naming and the steps which must be gone through for a name to be considered valid, there is no final arbitration on whether a classification, and the names that depend upon it, are accepted. Acceptance is a matter of emergent consensus. In so far as the rest of biology requires names for the organisms that it studies and needs some guidance on their similarities and evolutionary relationships, biology as a whole is dependent on taxonomy. It has long been argued by taxonomists that they are as a group inadequately funded to complete this task, and that the rest of biology does not understand their work and does not respect them for it.

There have been enduring concerns about the image of taxonomy. As this paper will demonstrate, taxonomists have been concerned that other biologists do not respect or appreciate them, and that users outside biology have little regard for them. The proposed solutions to this image problem have frequently involved the use of ICTs (Hine 1995). Biological systematics, or taxonomy, has undergone major transformations in recent years, thanks both to the advent of new methods and to a new political prominence due to interest in biodiversity. The application of ICTs has served these transformations rather than driving them, and while taxonomists have been involved in new organizational forms through large scale database initiatives, basic working practices for the majority have remained largely unchanged. In other parts of this ongoing work, I will record a history of information technology in systematics, looking at the ways in which the uses of the technology have changed along with the hopes and fears of the discipline. I will also be examining specific instances of ICT use in systematics in terms of their implications for working practices and outcomes. As a starting point, however, it seems useful to look at where we are right now, and, quite fortuitously, a recent report gives a perfect set of materials with which to consider the state of contemporary systematic biology as expressed by the most interested parties. The set of themes which emerge form the basis for analysis of the recent history and current practices of ICTs in systematics developed elsewhere.

In 2002 a report was published strongly recommending that systematic biology should take steps to become a web-based science. Species descriptions and interactive identification keys should be published on the web, and increased funding should be made available to digitise collections of specimens and make taxonomic information available to people all over the world. The proposals are for a radical re-shaping of practice to incorporate ICTs into every stage of taxonomic communication. This advice, if followed, would surely turn systematic biology into some kind of cyberscience[ii]. Unusually, these calls did not come from within the community of systematic biologists. Instead, they were contained in a report of the House of Lords Select Committee on Science and Technology. This groups of peers (Lords Flowers, Haskel, Lewis of

Newnham, McColl of Dulwich, Patel Quirk, Rea, Soulsby of Swaffham Prior and Turnberg, the Earl of Selborne and Baroness Walmsley) state in their report: "We highlight the importance of digitising the systematic biology collections, which will both increase accessibility of these data and help to update the archaic image of systematic biology. We also suggest that the systematic biology community should consider exploring new ways of presenting taxonomic information, in particular through increasing the amount of information available in digital form via the world-wide web, and should consider updating the system of naming previously undocumented species." (Select Committee on Science and Technology 2002a: 5). If, in the first place, it is unusual for the House of Lords to take such a detailed interest in the workings of a scientific discipline, it seems even more strange that their recommendation should so clearly point to a technological solution to the problems identified. This paper examines how systematics came to the point of receiving such high profile attention, and how ICTs came to be seen as the solution to its problems. An analysis of the report, including the evidence offered by a wide range of parties interested in the development of UK systematics, provides a set of themes which are examined in detail in other parts of this work.

What on Earth? The Select Committee Report

The background to the existence of the Select Committee report lies in the new spotlight placed on biological systematics by increasing political interest in biodiversity and conservation. High profile events such as the Rio Earth Summit in 1992 and the Johannesburg World Summit on Sustainable Development in 2002 turned the conservation of wildlife into a matter of international politics. At the Rio Summit, the Convention on Biological Diversity was signed. This agreement committed its signatories to undertake a variety of activities to safeguard the preservation of biodiversity, both in their own territories and by assisting developing countries. Among these activities was the need to survey and document the extent of biodiversity. It was recognised that for conservation to be effective, and to be monitored effectively, there was a need to know what species were present, and that in turn this relied upon the work of taxonomists. The Rio Summit, and the Convention on Biological Diversity, thus meant that some 157 countries publicly committed themselves to supporting the work of taxonomists. It is hard to imagine another branch of science, outside medicine, gaining quite such widespread approval.

While the Rio summit gave taxonomy a high profile, this is not to suggest that all has been easy for taxonomy since Rio. The 2002 report was an update on a 1992 Select Committee report on the state of systematics in the UK. The 2002 update found that 1992 recommendations for funding of taxonomy had not broadly been met: indeed, the increased political focus had some felt imposed new demands upon systematists without increasing funding to match. By becoming politically high profile, taxonomy has also been forced to make public its concerns and to justify what it does with the funding it receives. In the report, then, and the contributions made to its deliberations by written and oral evidence, we have a remarkable set of data in which a scientific discipline is cross-examined about its goals, its practices and its organizational and funding regimes. In the rest of this paper I examine this data set for themes which emerge in the representation of information and communications technologies and their role in contemporary systematics.

Evidence to the Select Committee: a thematic analysis of taxonomy and IT
An open invitation was issued to give evidence to the committee. The call invited evidence on the following questions:

> "How has the organisation of and funding for systematic biology in the United Kingdom changed since 1992?
>
> What, if any, are the changes required in this area to enable the United Kingdom to meet its policy aims on biodiversity?" (Select Committee on Science and Technology 2002a) : 29

Evidence was offered by a set of institutions and organizations who represent key positions in British taxonomy. Learned societies, museums and botanic gardens, government departments, funding councils and academic departments were represented, together with prominent individuals in the field, and the occasional less prominent individual responding to the open call. A selected few were invited to give evidence in person to the committee. In addition, a seminar was organised at the Natural History Museum in London to introduce the current state of biological systematics, and the committee also visited Kew Gardens for an introduction to the work of its herbarium, library and Jodrell Laboratory. The written evidence and transcripts of oral evidence are available to accompany the final report. Also available in the public domain are the transcripts of a House of Lords debate on the report, the government's response to the report and a set of memoranda from interested parties commenting on the government response, plus the Select Committee's commentary on that response. Without attempting to summarise the full content of the arguments made, this section looks at the places where references to information and communications technologies occur in this evidence, and what qualities are attributed to these technologies in terms of their abilities to solve (or occasion) problems. The analysis is presented as a set of broad themes which arise repeatedly in evidence and which locate particularly problematic or contested issues in the application of ICTs within systematics.

Material and virtual: the adequacy of digital specimens and the audiences for availability
Probably the key concept running through the report, as far as ICTs are concerned, is the need for digitisation. Repeatedly in the main report and in individual pieces of written and oral evidence, it is stressed that systematics holds a wealth of valuable information in its collections of specimens and its literature, which simply must be digitised and made available. The coming of the Internet, and particularly the World Wide Web, is seen as mounting a challenge to which taxonomy must respond: the availability of the technical means providing the imperative to make use of it. The main problem identified is that museums and herbaria hold vast collections of specimens which need to be digitised in order to be made available, and that this will require funding and effort.

In the evidence given to the Select Committee, it is stressed over and over again that collections of specimens need to be made available in digital form. In its material form, the specimen is held to be relatively unavailable. The idea of digital data as available data runs through the report. The equation of digitisation with availability did, however, gain a closer examination in some of the oral evidence. First, the ability of users to distinguish reliable information from rubbish was questioned, and second the ability of users to ask the right questions was doubted. When asked if digitised information was available to users in universities, the representative of the Joint Nature Conservancy Council replied:

> Yes. There is a much wider access to these data in universities and other educational institutes. The problem is that there are insufficient course modules to enable people to start asking the right questions and to begin the process of understanding how systematic biology operates. (Select Committee on Science and Technology 2002b):110

A distinction was here made between simple availability and meaningful use. In other cases, it is argued that, rather than the general digitization of data, taxonomists need to develop particular products, aimed at specific audiences, and place these on the Internet. This distinction was, however, rare. In the majority of cases digitization, or placing databases on the web, was represented as making taxonomic research and data globally available (more in the next section on the political connotations of global availability).

The digital specimen then appears to be the ideal specimen – instantly available to a wide range of audiences, and the only sticking point is the need for funding to carry out the "one-off" task of digitisation. Another advantage of digitisation, as far as the collection holders are concerned, may be that pressure is taken off the systems for loan of specimens. Where a digital representation can be portrayed as adequate, there would be no need to send off the material specimen to a distant researcher. The collection holders are, however, at pains to point out that the digital representation does not render the material collection redundant (possibly foreseeing the need to head off suggestions that the costs of ongoing curation of material specimens could be saved). Written evidence from the Department of Plant Sciences, University of Oxford, made this point:

> However, computers do not make the collections themselves redundant. Whilst one can digitize an image of a herbarium specimen and make it and the associated specimen label data easily accessible to a wide range of users on the World Wide Web, research that involves approaches such as anatomy or molecular analysis must still rely on the physical specimen. (Select Committee on Science and Technology 2002b):57

The importance of physical specimens in this perspective lies in the impossibility of predicting in advance, and thus capturing in digital form, all the qualities of a specimen that might interest future taxonomists. A particular category of specimen, the type specimen, holds a particular importance in taxonomy. When one describes and names a new species, one nominates a particular physical specimen as the type, to which the name is formally attached. In any future revision of the definition and boundaries of this species, the original species name stays with the type specimen. This almost guarantees that a future taxonomist re-examining the definition of a species will need to see the type specimen in physical, rather than virtual form. Physical specimens are seen as carriers of potential future information, as yet unrecognisable, in a way that digital specimens are not.

The evidence therefore enacts a complex dance in representing digital specimens as both universally available and at the same time not adequate in themselves for all systematic purposes. The self-evidence of the need for digitisation is taken as a point of leverage for more funds, since it augments rather than replacing the traditional activities of curating specimens. Holders of collections stress that digitisation, while essential, lies outside the activities for which they have traditionally been responsible and been funded. The report as a whole, in equating digitisation with availability and in taking as self-evident that availability is a good thing, makes that case for increased funding appear incontrovertible (although this turns out not to be the case in the government's response to the report).

The equation of digitisation with availability also takes on additional significance when we consider the audiences for availability. Systematics has been deeply concerned not just with its direct audiences, i.e. those who make use of its information, but also with the broader audience for its work as a discipline. Systematics, and in particular taxonomy, feels itself to have an image problem. This problem was the focus of considerable attention by the Select Committee. It was felt that while the poor image represented a misunderstanding of the importance of systematics, and led the discipline to receive less respect and less funding than it deserved, this image was also to some extent the fault of the discipline, and therefore some responsibility for rectifying the situation lay with the discipline. One of the committee's nine recommendations was as follows:

> We recommend that the systematic biology community, especially via the Systematics Association and the Linnean Society, should continue to increase efforts to demonstrate the relevance and importance of systematic biology. This should have the effect both of improving its profile to funding bodies and of making it more attractive to potential professional taxonomists and volunteers. We also hope that systematic biologists who are members of learned societies, such as the Institute of Biology and the Royal Society, will use their influence to promote the discipline.(Select Committee on Science and Technology 2002a): 6

That the image of systematics was indeed a problem ran through the committee's deliberations: some time was given in the oral evidence to discussion of whether archaic or arcane were the more correct term to describe taxonomy's current practices. Baroness Walmsley, in her presentation of the report to the House of Lords, suggested that the discipline "suffered from an image of anorak-clad scientists poring over disintegrating specimens in dusty archives." (Lords Hansard text for 12 Jul 2002: Column 922). In this context, the use of information and communications technologies figured as an image of modernity that could help to correct taxonomy's poor image, and be seen to bring it up to date. The audience for digitisation explicitly included not just direct users of information, but also a broader imagined audience alert to the technologies that the discipline was using and astute to the meanings carried by those technologies. Repeatedly in the written and oral evidence systematics was urged to make use of modern technologies in order to improve its image. Plantlife, a wild plant conservation charity, suggested that use of information technology would appeal to the young in particular:

> We need a web-based resource where any group's taxonomy is placed on the web and then future revisions or additions would also take place on the web. The implications of this move would obviously be great, but would surely change the image of the discipline and make it a more attractive career prospect for young scientists. (Select Committee on Science and Technology 2002b): 55

This perception of technology use as affecting disciplinary image was clearly influential for the Select Committee. In the summary of their report, two functions of the digitisation of data were given equal prominence:

> We highlight the importance of digitizing the systematic biology collections, which will both increase accessibility of these data and help to update the archaic image of systematic biology. (Select Committee on Science and Technology 2002b):5

Already, then, we have some insight into the complex arena into which information and communications technologies are inserted. What these technologies can do is worked out on a highly charged and contested field, upon which funding regimes, institutional and disciplinary images, and sets of rights and responsibilities can depend. Systematics has also, however, become a much more explicitly political domain, and this too impacts upon discussions of ICT use, as the next section demonstrates.

The complex political geographies of systematics

The history of taxonomy is to a large extent a colonial history. In the past, nations with colonies in other parts of the world would exploit the natural biodiversity resources of those countries as unquestioningly as they might draw upon their people and their mineral wealth. The history of the major taxonomic institutions is tied up with traditions of travel and collecting in far flung parts of the world. Viewed from the present day, this situation is highly problematic. The politics of biodiversity involve clear inequalities. Both specimens and the expertise to study and interpret them tend to be located in the richer nations, whilst the economically poorer nations are often rich in biodiversity but lacking in both expertise and the raw material, in terms of a heritage of physical specimens, to take charge of their own natural resource. It is into this context that current thinking on biodiversity information is inserted.

The recent history of systematics is heavily influenced by the Rio Earth Summit in 1992. At this meeting, the question of biodiversity and the need to conserve species and habitats entered onto the world political stage in an unprecedented fashion. At the summit, the Convention on Biological Diversity was signed by 157 countries. By signing, and later ratifying the convention, the UK committed itself to a range of activities in support of biodiversity conservation on a global scale. The politics of biodiversity were explicitly written into the convention, in that it attempted to redress the imbalances between richer nations which were so often the holders of expertise, and the poorer nations which were biodiversity rich. Taxonomy was recognised as underpinning attempts to conserve biodiversity. Indeed, the convention enshrined the notion of a "taxonomic impediment" to biodiversity conservation, caused by lack of basic taxonomic data and lack of access to what data there was. Signatories to the convention were explicitly required to share what taxonomic information and expertise they had. The notion of "data repatriation" is used to stand in for meeting this requirement and is cited often in the Select Committee report, both in the summary report and in written evidence by interested parties. By digitising collection information, and placing the results on the Internet, it is considered that the requirement to share taxonomic information is met. The possibility of sending physical taxonomic specimens, other than on temporary loan, does not arise.

The requirement for sharing of taxonomic expertise has, according to the report, largely been met by projects carried out under the Darwin Initiative. This scheme, developed in 1992 and administered for the UK Government by by the Department for Environment, Food and Rural Affairs, has allocated approximately £3 million per year through a range of activities aimed fulfilling obligations under the Convention on Biological Diversity. Projects funded under this initiative were praised in this report for their activities in sharing information and expertise. An exemplary project cited in the report is described thus:

> The Natural History Museum, the Plymouth Marine Laboratory and the Kasetsart University in Bangkok and the Ministry of Fisheries, Thailand collaborated to explore the potential of the world-wide-web as a tool for exchange of taxonomic information between biodiversity researchers. The project has enabled researchers to share information about polychaete worms, in order to determine whether specimens found in various places are the same or different species. Polychaetes are segmented worms and are very common marine organisms. Taxonomic information on them is used to monitor environmental quality. This Darwin Inititiative project has contributed to developing a high quality base of taxonomic information for use by marine conservationists. (Select Committee on Science and Technology 2002a):15

The project is presented as exemplary in its focus on an environmentally important group of organisms, in its internationally collaborative organization, its aim of sharing information, and its use of the World Wide Web. The Darwin Initiative, then, through the notion of "data repatriation", draws on information and communications technologies as a way of meeting the UK's obligations under the Convention on Biological Diversity. Projects to develop Internet-based resources, particularly where they also involve training programmes with economically poor but biodiversity rich nations, are favoured in a funding climate where money for any kind of systematics research is seen to be extremely scarce. The value of this source of funding is stressed in the report as of general benefit in the goal of digitising collections, in addition to any role in redressing the colonial legacy of systematics.

A further dimension of the complex political geography of systematics is provided by the Global Biodiversity Information Facility (GBIF). This initiative of the OECD Megascience Forum Working Group, supported by the parties to the Convention on Biological Diversity, has the remit of producing interfaces to biodiversity databases, including taxonomic databases, which will allow for relatively seamless searches across different sources of data (in GBIF terms, "an interoperable network of biodiversity databases and information technology tools"). This initiative, and the UK systematics community's involvement in it, were frequently used in submissions to the Select Committee to stand in as evidence for the willingness to embrace modern methods and make information available. Membership was therefore both globally important, in terms of meeting requirements as a signatory to the Convention on Biological Diversity, and locally important in terms of demonstrating, within the UK funding context, a willingness to be modern, to undergo change, and to embrace up-to-date technologies. Conscious of the UK funding context, many of the authors of written evidence to the committee were at pains to point out that while they were willing collaborators with GBIF, it tended to deal only with existing databases and did not fund nor address the question of basic data input of information from taxonomic collections. In rendering participation in GBIF a self-evident good thing and national obligation, holders of collections reiterated the case for increased funding to digitize their own collections.

Automation and expertise, ease and difficulty

The previous section laid out the extent to which initiatives to create taxonomic databases and to place systematic information on the Internet within the UK take place within a complex political geography and funding regimes are skewed towards activities significant on an international international stage. Local taxonomic practices, including the use of information technology, are played out on a global stage. These local practices are also, however, historically situated, in that the technologies both that the discipline uses and is willing to use are shaped by ideas of what it has done in the past, what is easy and what is difficult, what is routine and what is innovative. As we have seen, there is considerable purchase for systematics in being seen to be innovative in its use of technologies. Some pieces of evidence to the committee pointed out instances of technology use which were already in place, and could be considered to show how far the discipline had already moved. That the use of computers for calculating potential evolutionary relationships was established practice was pointed out by a representative from the Natural History Museum:

> Many taxonomists today are primarily interested in relationships (phylogeny) of groups, and in estimating phylogeny using computer programmes based on character data. Major sources of characters in today's systematics are DNA sequences.(Select Committee on Science and Technology 2002b): 34

Acceptance of computerized methods could also be used in support of the idea that left to conventional scientific practices, innovation could happen in systematics:

> Systematists and evolutionary biologists increasingly agree on accepted methods, available as computer applications for estimating systematic relationships from

> gene sequence or morphological data; David Swofford's PAUP is now the almost universally accepted route for estimating the tree of life from genbank. It is important to grasp the significance of now having accepted international protocols based on sound science. Evidence from Professor Paul Harvey FRS. (Select Committee on Science and Technology 2002b): 26

Paradoxically, in demonstrating that they already use computers in their work in a routine fashion, systematists at the same time demonstrate that they are up-to-date and yet push the boundaries of what they can be expected to do. If use of computers is already routine in this area, then one might ask why it cannot progress still further. These strategies of highlighting existing computer use are therefore somewhat risky in a context where one is arguing for extra funds.

The distinction between routine work and innovative work was played out in representations of funding regimes. While no clear sources of funding for the work of entering taxonomic information into databases were identified, it was suggested that money for developing innovative technologies was available: referred to by a representative from the Biotechnology and Biological Sciences Research Council as funding for "software and data bases; generic technical development" (Select Committee on Science and Technology 2002b): 164. The Royal Society, in its submission, suggested that the focus had been too much on innovation in technology:

> The funding for electronic databases has been mainly technology driven and the information to populate these databases is sparse.(Select Committee on Science and Technology 2002b): 140

Identifying what is innovative and what is routine is therefore perceived to be of significance in negotiating a way through funding regimes. It is also, of course, important in representing the discipline as highly skilled and valued. To be seen as consisting wholly of routine work is problematic for the status of a discipline, and certainly problematic where routine work is also likely to be seen as ripe for automation.

Some future possibilities for automation were presented in evidence to the Select Committee. The Royal Botanic Gardens Edinburgh suggested that automating routine identification of diatoms would help to overcome the "taxonomic impediment" to conservation of biodiversity. The Linnean Society approved of the idea of "automatic and on-line identification systems that enable non-specialists to make identifications"(Select Committee on Science and Technology 2002b): 126. More extreme versions of automation were produced by non-systematists: notably the representative of the Office of Science and Technology suggested that this kind of project would have a strong fundability:

> So the whole question of taxonomic research today is in development where exciting things can happen, where visionaries could take it forward using modern biology methods, molecular biology as a basis, using modern instrumentation and, above all, using modern IT techniques, so instead of sitting examining with a

> microscope every specimen that comes your way and determining in fine detail what the structure is before its taxonomy is discovered, would it not be smart to develop techniques that could automate that process? I believe that the research councils would respond properly within their tensioning [sic] process to such proposals. So individual scientists are required as visionaries to come forward and take the field ahead. (Select Committee on Science and Technology 2002b): 149

Where the possibility of automating various tasks associated with taxonomy, such as “routine” identification was suggested, systematists offering evidence to the committee were often careful to point out that this did not remove the need for trained taxonomic experts. A University of Cambridge representative made a distinction between expert taxonomic work and the “service role” that could be automated:

> In not very many years from now, the preferred way of identifying specimens of “difficult” groups will be by obtaining a short DNA sequence. This is already beginning to happen for some groups of applied significance (eg fly larvae in forensic cases). To make this more widely possibly, our long term aim must by to establish databases that correlate a DNA sequence tag with each classically described species. Once this has been done, specimens can be attributed to “existing species”, or recognized as new to science, without huge taxonomic expertise. Of course, precise definition of species boundaries, the formal description of new species, taxonomic revision, and the generation of keys, will still require expert taxonomists who look at the animals- but the service role of such taxonomists will surely be replaced by automated sample analysis over the next 20 years.(Select Committee on Science and Technology 2002): 3

In arguing for the value of their discipline and its continued funding, systematists are therefore representing their work and its relationship with technology on a public stage, and are involved in local and global politics. The demarcations they draw between routine and expert work, between physical and virtual specimens, between the various audiences for taxonomy and between new and old technologies are highly consequential. Whether, and in what ways taxonomy moves towards and is seen to move towards cyberscience, will be played out on a highly politically charged and complex field. One feature with particular influence in shaping the recommendations of the Select Committee that taxonomy should strive to become a web-based science was the work of one Professor Charles Godfray. Godfray, not himself a taxonomist, had published a paper in the newsletter of the Royal Entomological Society, recommending wholesale change in taxonomic working practices(Godfray 2002). His suggestions, framed as ways that systematics might become more attractive to funders (including sponsors from the commercial sector) involved the intensive use of ICTs to revamp the process of assigning and communicating taxonomic nomenclature. This paper explicitly recommended the use of these technologies to improve the usability of taxonomic information and its image to non-taxonomists. Godfray aimed his recommendations not simply at databases to communicate taxonomic results, but at transforming the basic practices of taxonomic work itself, at least in so far as rules for assigning nomenclature were concerned. This paper was attracting attention in the systematic community and beyond at the very time most of those concerned were preparing their responses to the Select Committee's call for evidence. Thanks to its timing, this vision of taxonomic future then had a far greater impact than even its author would probably have expected. There have been many calls for the revamping of taxonomy through use of information and communications technologies over the years (Hine 1995), each time focusing on the perceived problems of the discipline at the time and finding appropriate solutions in technology. Few, if any, have achieved this kind of public prominence. Godfray's paper provided a packaged "vision" of a future web-based systematics at just the time when the Select Committee were seeking to find a way through the complex territory mapped by the evidence submitted to them.

Conclusion

This paper presents only a small section of an ongoing project, and the "conclusions" are therefore more correctly pointers to areas of investigation for other parts of the research. The first major point to note is that ICTs in systematics turn out to be entering a highly charged territory. Talking about these technologies, in the context of the 2002 Select Committee inquiry, involves shaping identities of technologies, people and organizations in sets of moral relationships, giving roles, rights and responsibilities. In talk like this the stakes are high, and all of those involved appear to be conscious of the fact. Contributions are carefully crafted to make the best impression. Systematics institutions are bidding for the future of their institutions and their discipline, while government departments, funding bodies and learned societies all have past decisions to defend and future priorities to protect. The status of this evidence as a reflection of practices of information and communication technology use in systematics therefore needs to be understood with some caution. This is not a neutral portrayal of how systematics is using ICTs. The themes that emerged in the analysis need to be followed through in other arenas in order to assess their wider currency.

Three thematic areas emerged from the report. The first, focusing on the relationship between physical specimens and virtual information, demonstrated that the capacities of technologies to achieve particular functions for taxonomy are contingent, open to debate and interpretation. The second theme, the complex political geographies of taxonomy, showed that the adequacy of virtual taxonomy is played out on a global stage, in which local initiatives can be influenced by and consequential for international relations of responsibility and dependency. Finally, the third theme showed that representations of what the technology can and cannot do are tied up with representations of the the need for and qualities of human expertise, and that such representations again take place in a highly charged territory where funding decisions can depend on appearing to be suitably innovative and yet not replaceable by innovative use of technology.

In other parts of this research I examine the use of mailing lists by taxonomists, both in terms of the extent to which the themes described above arise in discussions, and as an alternative context in which taxonomists engage in reflection on their discipline. I also undertake ethnographic research, both face-to-face and online into the development of a taxonomic database and into the digitization of specimen collections. By looking at ICTs in systematics across these different contexts we can see that, as the themes described above suggest, ICTs are embedded into systematics in very specific ways. Far from a unidirectional transformation of a discipline and its working practices, we find culturally specific embedding of technologies into particular contexts. This is not, then, an instance of cyberscience transforming the practices of knowledge, but rather a case of the shaping of a cyberscience. At the same time, however, ICTs provide a cultural field for the playing out of systematics, and this field enables both the development of new practices and the opportunity for reflection on these practices. I suggest, in the broader work of which this paper forms a part, that one of the key strengths of ICTs in science (whether that be natural or social sciences) can be in the reflexive opportunities they provide. Scientific disciplines can capitalize on the introduction of new technologies to examine and reinvigorate old practices. Wholesale change is by no means a necessary outcome, but considered and conscious change is a real possibility.

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[i] Systematics is generally used as the overarching term, to denote the study of the relationships between organisms. Taxonomy lies within this field as the practice of classifying and naming organisms. In this paper the two are used interchangeably.

[ii] As Beaulieu suggests, "cyberscience" (Wouters, 2000) may prove to represent "a novel, technologically-supported organization of knowledge-production, in which the digital format and electronic transmission of data figure prominently". This definition carefully focuses on new forms of organization, leaving open whether new forms of knowledge might result.