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The Development of Science Museum Websites: Case Studies

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Abstract

Science museums have embraced the technology of the web to present their resources online. The nature of the technology naturally fits with the ethos of science. This chapter surveys the history, development and features of a number of contrasting pioneering museum websites in the field of science that have been early adopters of the technology. This includes case studies of websites associated with the Natural History Museum of Los Angeles, the Museum of the History of Science in Oxford, the Science Museum in London and the completely virtual Alan Turing Home Page. The purpose is to demonstrate a diverse set of successful scientifically oriented websites related to science museums and the history of science, giving an insight into web developments in this area over the past decade.

Keywords: Accessibility; Database Searching; Digital Collections; E-Learning; Electronic Database; Electronic Resources; Information Access; Internet Access; Internet-Based Technologies; Learning Resources; Metadata Creation; Online Database; Online Public Access Catalog; Online Resources; Online Community; Search Engines; Virtual Community Building; Virtual Library; Virtual Organization; Web Resources; Web Surfing; Web-Based Learning; Web-Based Services

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INTRODUCTION

The idea of using computers for education is not new. Seymour Papert [www.papert.com], an Artificial Intelligence pioneer with Marvin Minski at the Massachusetts Institute of Technology (MIT), first mooted the idea of using computers for learning in the 1960s. For example, he held a symposium at MIT in 1970 entitled "Teaching Children Thinking," proposing that children could learn by teaching computers, developing the Logo programming language to help in this quest (Papert, 1993 & 1999). Of course it then took some years for computers to become widespread and cheap enough to make such ideas a reality in everyday life. Papert has continued his interest in learning in the context of the web. In 1996 he conducted a tour including locations such as the Smithsonian in Washington DC and the Boston Computer Museum to promote a book (Papert, 1996). He has also helped in the development of *MaMaMedia*, a website with over 4.5 million registered users that provides free activities for children to learn through the playful use of technology [www.mamamedia.com]. This is the type of well-funded e-learning resource with which museums are now in competition on their offerings on the web.

Science museums should, by their nature, be aware of technological developments and use these appropriately in a timely fashion. As an example, the Science Museum in London held two exhibitions on the *Challenge of the Chip* (Maynall, 1980) on microprocessors and *This is IT* on Information Technology in the early 1980s. In these exhibitions, the technology being presented was used to present itself. For example, the *Challenge of the Chip* included a PET microcomputer that illustrated the manufacture and workings of Field Effect Transistors (FET). This was among the earliest examples of using computers in museum displays, employing the animated computer screen in an educational context to augment the more traditional static displays. The use of a computer display meant that the operation of an FET could be illustrated in a dynamic and apt manner. The PET computer was itself also an appropriate exhibit in the context of the subject matter being presented. Nowadays, of course, such use of computers in museum galleries is commonplace, even expected, and is certainly far more sophisticated. In addition to in-gallery use, computers can now readily be connected via networks; access through the Internet, normally using the World Wide Web, is an expected mechanism for disseminating information resources available from museums in general, and perhaps especially so for science museums (Díaz & del Egido, 1999).

In this chapter we survey science museum websites in the context of e-learning. In particular, we give several personal accounts of specific websites and their development by people who have been involved directly. Finally, some general conclusions are drawn.

SURVEY OF WEBSITES

The annual *Best of the Web* competition at the *Museums and the Web* conference, established since 1997, includes an explicit section on the "*Best Museum Web Site Supporting Educational Use*", providing a snapshot of the start of the art each year. For example, in 2004, the Smithsonian National Zoological Park's online educational program, Conservation Central [nationalzoo.si.edu/Education/ConservationCentral],

was a finalist. This includes a number of multimedia interactive resources, including, for example, one that allows web visitors to design a panda habitat. Nowadays, relatively sophisticated animation is expected, within the confines of generally available Internet access speed, which is still limited by the quality of telephone lines for many.

The *Resources for Learning* section of the American Museum of Natural History website was among the *Best of the Web* finalists in 2003 [www.amnh.org/resources]. This is a collection of activities, curriculum materials, articles, exhibition materials, reference lists, etc., for educators, families, students and anyone with an interest in teaching or learning about science. It is possible to search for resources, browse by topic or explore special collections based around a particular theme. The material is explicitly aimed at different age levels that are selectable when searching (primary, upper elementary, middle school, high school and up). Different completions times, varying from less than a typical lesson period up to more than a week, can also be selected. In the previous year, 2002, the same museum was a finalist with its "Ology" website [www.ology.amnh.org]. This includes subject areas such as archeology, astronomy, biodiversity, Albert Einstein, genetics, marine biology and paleontology.

A search for "science museum education" under Google at the original time of writing produces a rather eclectic collection of links. For example, at the head of the list, the Franklin Institute in Philadelphia provides some "Educational Hotlists" in the form of an organized set of links to online resources under over thirty topic areas [www.fi.edu/tfi/hotlists]. *TryScience* provides a gateway to current science and technology using both online and offline interactive resources in conjunction with a large number of science centers around the world [www.tryscience.org]. It includes information for parents and teachers. The Science Museum of Minnesota has a Computer Education Center, established in 1983, that has its own website [comped.smm.org].

The Science Learning Network (SLN) links a number of science museums around the world [www.sln.org/museums], but the information available on the website appears to date from 1996. An important part of any online initiative is that it remains up to date, and this is especially true for children's resources that can very quickly appear dated if not maintained regularly. The San Francisco Exploratorium provides some excellent "tools for teaching" [www.exploratorium.edu/educate]. The website includes a list of "Ten Cool Sites" for science education, started in 1995, that seems to continue to be updated regularly, making the site dynamic and encouraging repeat visits [www.exploratorium.edu/learning_studio/sciencesites.html].

Accessibility issues are increasingly important for the museum sector, for both moral and legal reasons (Bowen, 2003; Bowen, 2004), to ensure resources are available to all, including the disabled. In the 2003 Jodi Mattes Access Award, the first year in the UK in which it was awarded for accessible museum websites, there were nine sites that were nominated. Only one site, the Australian Museum spiders website [www.amonline.net.au/spiders], was science-related. The site includes facilities to change the size of the text to be larger for partially sighted users at the click of a hyperlink, located at the bottom of each page.

The Association of Science-Technology Centers (ASTC) includes a "TEXT ONLY MENU" link at the top of its main web page [www.astc.org]. This is hidden as small white text against a white background for sighted people, but will be read immediately for blind people using text to audio software. The blind normally scan web pages sequentially and will find such a link quickly and easily. ASTC also provide online advice on accessibility for science centers and museums [www.astc.org/resource/access].

The Museum of Science & Industry in Manchester, UK have a "Text Only" link as part of their standard set of navigation links at the top of each page [www.msim.org.uk]. Thus this can be found easily even by users entering the site but pages other than the main home page (e.g., via a search engine). In 2004, the Science Museum in London had a similar a "Text Only (Beta)" link in operation (the "Beta" indicating that this facility was under test), available under an "options >" link [www.sciencemuseum.org.uk]. On this site, the text-only versions of pages also include a link back to the graphics versions at any time, thus giving good flexibility of navigation.

Later in this chapter we consider some personal views of individual science-oriented websites, both associated with real science museums and of a completely virtual nature, written by people directly involved with their development. In each case, a brief history is given, together with some of the more interesting features of the site, especially with respect to e-learning aspects. Here we briefly look at a couple of examples, one associated with the leading science center in France and the other providing a well-established completely virtual resource on the history of computing.

La Cité des Science et de l'Industrie

The first version of the *La Cité des Science et de l'Industrie*'s website [www.cite-sciences.fr] was developed in 1994 and consisted of a very few pages presenting general information on the museum. It was nothing more than an online brochure (sometimes dubbed "brochureware"), updated by the Communication Department as needed. In 1998 it had around 300,000 visits per year. The second version, which is still online today, was introduced in 1999; it was inspired by a "mediation approach" rather than simple communication/ transmission of information and content.

The progressive growth of the renewed site in terms of content (temporary exhibitions, learning material) and services (*Visite+*, educational tools, etc) in the past four years has contributed to creating a rich and varied offering, which attracts a significant number of visitors. In 2003, for example, the museum counted 3,161,000 visits, that is to say a 122% increase in comparison to the previous year. The next reorganization of the site is scheduled for 2005. The idea is to continue the mediation approach. This implies taking visitors into consideration as much as possible and creating online services for them, especially when it comes to the more pedagogical aspects of the site (Cité des Savoirs). For example, the different sections of the existing website are not conceived from the visitor's point of view; that will change in favor of a much clearer segmentation approach and solutions that include more semantic navigation.

From an educational viewpoint, the site already offers many different types of services and tools for the general public, as well as for teachers and students/children. An explicitly educational website is available [education.cite-sciences.fr]. Educational material such as reading matter, interactive facilities, quizzes and animations are available, relating to both temporary and permanent exhibitions. An entire section of the website, the scientific lab, is dedicated to manipulation and interactivity with games and quizzes for all ages. For professionals and more expert visitors, text, video and audio versions of conferences and presentations that take place in the museum auditorium are available online, as well as a section dedicated to the latest news and developments in science and research, with articles, dossiers and even a specialized online journal on astronomy and space.

Special sections of the site are also dedicated to teachers (Cité des Enseignants) and children or students (Site pour les elèves). In the "Cité des Enseignants", information is available on general and specific activities for groups and schools as well as tools and material to prepare for the visit, while in the student section, direct access to manipulation games and quizzes targeted for specific age groups is provided. There is also access to web pages that have been created by students and children technical workshops ("ateliers"), normally held at La Cité. In spite of the already conspicuous material and tools available on the site, the idea is to move further and create a real educational platform ("platforme educative") that will be used by teachers and students to download material for the visit or use in the classroom. This will enable the museum to create a community of users that will use the site as a proper working tool and that might be able to exchange opinions and comments through a series of forum activities (Beler *et al.*, 2004).

Virtual Museum of Computing

Virtual museums, without a physical counterpart, are by their very nature a relatively new phenomenon whose form is still developing (Schweibenz *et al.*, 2004). As a fairly early example, the Virtual Museum of Computing (VMoC) [vmoc.museophile.org] was originally set up on a whim one Monday morning in 1994 when the founder and subsequent maintainer was a computer science researcher at the Oxford University Computing Laboratory. This grew out of an early online museum directory, the Virtual Library museums pages (VLmp) that also started shortly before this in 1994 (Bowen, 2002) and was subsequently adopted by the International Council of Museums (ICOM) [icom.museum/vlmp]. In those days (and even now) it was relatively easy to set up a website in an academic environment, with few bureaucratic or technical barriers to those determined to do so. The initial website provided a small number of links to history of computing resources then available on the web. By the end of the first week the site was already receiving around a hundred visitors each day. It quickly gained international prominence online (Bowen, 1996) and has continued to form a nucleus of online computing history information ever since. An important aspect of success is stability and continued maintenance of educational resources online, as in this case.

The VMoC website consists of an eclectic collection of links to online history of computing resources, categorized in a number of broad types, together with a selection of local virtual galleries. For example, there is a resource presenting *A Brief*

History of Algebra and Computing, based on an article (Bowen, 1995), together with additional external hyperlinks and visual material from the MacTutor History of Mathematics archive [www-groups.dcs.st-and.ac.uk/~history]. This is specifically linked from and recommended by a number of educational websites. Despites its simplicity, quality of content is of prime importance in e-learning resources.

VMoC also includes links to important computer pioneers. One of the major "virtual galleries" is a resource on the computing pioneer, Alan Turing, maintained by Andrew Hodges, Turing's definitive biographer (Hodges, 1983). More detailed information on this resource can be found later in this chapter.

Case Studies

In the rest of this chapter we present a number of example website case studies associated with both real museums and in one case a virtual museum. The first, the Natural History Museum of Los Angeles County, was one of the first museums to start a major website, as is demonstrated by its enviable web address [www.nhm.org] that is no doubt coveted by other natural history museums around the world. Secondly, the Museum of the History of Science in Oxford is located in one of the earliest purpose-built museum buildings in the world (originally for the Ashmolean Museum). It was also able to initiate a website relatively early because of the advantageous networking facilities and expertise available in a university environment. Thirdly, the Science Museum in London is one of the major science museums in the world. Again it was able to establish an early web presence partly due to the proximity of Imperial College, but also spurred on by the fact that the Natural History Museum next door actual established the first dedicated museum web server in the United Kingdom just before them. Finally, a completely virtual website is presented, again established relatively early due to the support of a university environment and the enthusiasm of an individual for the project. Since this website, is a personal project, in contrast to the others that are associated with actual museums, the section describing it is written by the originator in the first person.

All the websites described in these case studies are early pioneers in the field in different ways. Thus it is apt that their various histories should now be reflected upon in this chapter. It is hoped that other later adopters can learn from some of the lessons illustrated here.

NATURAL HISTORY MUSEUM OF LOS ANGELES COUNTY

The story of the Natural History Museum of Los Angeles County's website [www.nhm.org] is in many ways the story of the web itself (Angus, 2000). It is a journey of discovery that starts before the advent of the web at a time when only universities and governments were using the Internet. It is a story of the particular needs of an organization and how the Internet and later the web provided answers. It is a journey that continues to this day as the medium itself evolves and adapts to the community's needs and aspirations.

Super Science, Kiosks, Gophers and the Web: The Genesis of One of the First Museum Websites

In 1991, the museum sought to establish a comparative genetics laboratory that would enable museum researchers to more easily determine evolutionary relationships between different species of plants and animals. By 1991, the Internet was highly utilized by the academic community enabling a degree of collaboration that would lead to a rapid increase in the pace of scientific discovery. Genetic sequence repositories, established on the Internet, were key resources to help researchers determine evolutionary relationships.

The need to access these repositories drove the museum to seek funding from the National Science Foundation (NSF). The museum's application was successful and with the NSF's help they established a direct connection to what was then known as NSFnet. This always "on" connection operated at speeds of 56 kb/sec, the speed of a standard PC modem today. This connection was the first building block in a foundation that would place the museum in a position to rapidly deploy a website at a time when the web was new and audiences were demanding substantial content.

The second block was provided by the museum's educational outreach program. The museum held an annual open house for members, who were interested in the comparative genetics laboratory, but the lab was understaffed. The museum turned to multi-media, another relatively new innovation, to address the issue. Several animated presentations were developed and installed on laboratory computers. These presentations substituted for docent led explanations and established the necessary expertise to later develop web-based presentations.

The third block was set down when the museum developed software for informational kiosks that were to be placed in local businesses, most notably airports. The programming included all the basic facts about the museum and its programs and mirrored what would be needed in a basic website.

In 1993, the museum began to investigate the possibility of developing a "Gopher" site to provide a presence on the Internet. Gopher, a precursor to the web, offered a text-based interface with an innovation: hyperlinks. But already, this technology was old. A newer application called the World Wide Web was gaining popularity. It offered the same text-based interface and hyperlinks, but included an exciting option: the ability to link to pictures. There was only one experimental browser available and that browser could not display the images directly. Text could only be crudely formatted and position control of various page elements was minimal. But by the end of 1993, the museum had launched one of the first museum websites, using material that had been developed for the informational kiosks. The first "online" exhibit consisted of educational presentations derived from the multi-media developed by the genetics lab for the annual members' open house. The University of Southern California hosted this site and it is still operational, though transformed [www.usc.edu/lacmnh].

Building Audiences: From Tricks to Substance

By 1995, the enormous potential of the web was becoming clear to a number of people. The University of California Berkeley Museum of Paleontology had launched a major website and a content starved community came to the site and kept coming. Because there is no "home page" for the World Wide Web, no "site map", the location of a website was passed by word of mouth, or more accurately, by email. So two graduate students from a San Francisco Bay Area university (Stanford) came up with an idea, why not build a directory for Internet websites? And the brainchild that would eventually become "*Yahoo!*" was born. People quickly discovered the directory and came back again and again. Any site that was listed was certain to get visitors.

Museums understand the need for audiences. Exhibits and educational programs both build and reach out to audiences. The trick was for museums to do the same on the web. Clearly the key to building an audience was to have content and to be listed in a directory. The question was how to open that door. The museum decided to host a directory of cultural sites called "*The Guide to Museums and Cultural Resources*." It was structured along the lines of the Stanford site but focused on the cultural sector. The museum actively collected links to cultural resources through a reciprocal exchange with the managers of other directories and by setting up a system where community members could add listings to *The Guide* using a simple web-based application. In a very short time, *The Guide* had links to thousands of new sites worldwide and more importantly, had tens of thousands of links back to *The Guide*. And each of those visitors to *The Guide* was able to easily click over to the museum's website.

The museum also recognized the importance of a *name*. In 1996, the museum moved to secure "naturalhistorymuseum.org", "nhm.org" and the ".com" variations. So in addition to referrals from *The Guide* and other Internet directories, any time a person entered "natural history museum" into one of the new search engines, the museum's site was likely to come up, if not first, then within the first half dozen listings.

Within a short time, the museum was getting tens then hundreds of thousands of hits per month to their website. However, aside from a few simple online exhibits, substance was seriously lacking. This changed in 1996 when the museum received funding from the National Science Foundation to produce an exhibit on the natural history of cats. Because of the success of the museum's website, at least in terms of hits, it was easy to convince museum administrators to invest the resources to develop an online version of the exhibition. The *Cats! Wild to Mild* website [www.nhm.org/cats] was born and the museum committed itself to producing a series of online exhibits [www.nhm.org/exhibitions/online.html] that included fully developed lesson plans, classroom activities and other curricula for schools. A balance between content and directory referrals was achieved.

The success of the *Cats!* exhibit was not assured. The museum made an effort to actively involve the wider cat research community in the production of the website. Draft pages were offered up for review to a variety of Internet-based email distribution lists and ideas were solicited. This resulted in "buy-in" from these

communities even before the launch of the website and with the launch, immediately resulted in links that referred more visitors to the website (Angus, 1998).

In 1997, the museum's website was voted "Best Educational Use" at the first international *Museums and the Web* conference held in Los Angeles. This firmly established the success of the museum's website in the minds of the museum's administrators and the wider community.

Building Audiences: *Make Their Websites Accessible*

The museum fell upon hard times. Several scandals rocked the Los Angeles cultural community and helped to dry up sources of funding for the museum. The budget for the website, never generous, took a beating. With available resources, the museum would not be able to compete for new visitors against other, better-funded organizations. Nor would the museum be able to invest in any of the promising new technologies that could help leverage and re-purpose existing web-based content. How could the museum maintain its lead with limited funds? The key was discovered while attending an *American Association of Museums* annual meeting in 1998. A visually impaired woman suggested to a panelist (the author of this case study) that museums could reach out to another audience if they would make their websites accessible to persons with disabilities. *Make their websites accessible.* This comment resonated and inspired the museum to move forward in a direction that was both on the leading edge of web development and was ethically sound. Another benefit was that it would keep the museum's website in the spot light for several years to come. The museum led the way in accessible web design and sought to promote the use of standards that would provide equal access to all audiences, including those with disabilities (Angus, 2001; Bowen, 2003; Bowen, 2004).

A Single Content Repository: Multiple Audiences, Multiple Devices and Multiple Uses

During the course of seven years of growth, the Natural History Museum's website grew until it consisted of over 10,000 files. How could all that content be managed? How could it be updated as technology changed? How could it be used to reach new audiences via new devices? Simply put, how could be used over and over in new ways?

The web grew explosively because it was technically easy to write web pages in HTML (HyperText Markup Language), the "language" of the web. Everyone knows that your friend's 16-year-old son or daughter can have a web page up and running in an hour or two. However, HTML has a hidden and fatal flaw. It blends *content* and *presentation*. How can material be presented in a new context if the format, the style and the association with other pieces of content cannot be separated? A new language of the web, a new standard is required, and that standard is XML (eXtensible Markup Language), XSL (eXtensible Stylesheet Language) and XSLT (XSL Transformations) [www.w3c.org].

Information or *content* can be placed in a single location, a *content repository*. That information can be marked with XML so that a computer "knows" what that piece of content is and how it relates to other content. For example, information about a

painting can be marked so that a computer knows what part is the name of the painting, its description and the artist's name, and it will know much about the object's relationship to other paintings. Other standards allow web developers to access specific pieces of content and present them with a particular "look and feel" or a particular *context*. The information itself remains untouched within the content repository and is available to be reused in different ways. This allows visitors to request specific kinds of information and have it returned in the context of the request. Many organizations are using these standards to leverage their content, to repurpose the collective efforts of hundreds of staff, to reach the public with educational materials that can provide a teacher with new options and in many instances change a student's life.

The separation of presentation and content can also allow the museum to reach new audiences. The museum's content can be presented using more than one *presentation template*. A template can be designed for the "typical" Internet user, a template that easily meets the marketing goals of the museum. A second template can be created for individuals who are blind. The information can be presented in a format that allows a visually impaired person to use assistive technology that will read the page out loud. A third template can be created and used to serve information to visitors using hand-held portable devices. *The same content that is on the website can be used to guide visitors within the museum.*

The volume of electronic content continues to grow and museums must find ways to manage the content. Software that allows museums to manage web content is available. Many of these systems use the new standards that allow the separation of presentation and content. Although the software is expensive, in the long term the museum will find that it is able to better serve the public with accurate and up-to-date information. For example, the name and telephone number of the museum's outreach coordinator may appear in as many as 20 places on a website or within a variety of electronic documents. A single edit within the content repository will update the information wherever it appears. This saves staff time and ensures that the museum remains an authoritative source of information.

Metadata is information about information. For example, metadata can be used to identify a particular piece of content as being of interest to a particular audience, perhaps middle school children. This allows the museum to design a website where visitors can personalize the site so that the content they most wish to view is presented first.

The web has changed a great deal since its inception and it will continue to grow and change, depending upon the community's needs and aspirations. Museums need to change as well, to adapt to the new world of instant access and wireless connectivity. Although the technology of the web provides instant access to a museum's information, it is the content that is important, not the technology. Museums need to adopt standards and technologies that will allow them to preserve, manage and leverage that content into the future. If they do not, then the richness and educational value of our scientific heritage may be lost in an electronic sea of information.

MUSEUM OF THE HISTORY OF SCIENCE, OXFORD

The Museum of the History of Science is a small, university museum with an outstanding collection in a specialist area, namely early scientific instruments. It is a department of the University of Oxford, and as such is expected to contribute to the research and teaching agenda of the University. Its most prominent contribution to teaching is a Master of Science course that is conducted entirely within the Museum – taught by the curatorial staff and to a large extent shaped by the collection of instruments and the working environment of a museum. As well as its academic presence in research and teaching, the Museum also aims to be fully public – open six days a week and with a program of exhibitions, lectures, gallery talks and other events that provide a distinctive educational opportunity for visitors. We expect our position within a university to contribute to this distinctiveness, since research and scholarship can contribute to the richness of the visitor's experience. Linked to this is the fact that our collection of objects is very strong in early material, so we tend to be more object-focused that many other museums of science. Our use of the web for education reflects these characteristics and has helped to resolve some of the tensions of being a scholarly museum with a strong public program.

The museum launched its website [www.mhs.ox.ac.uk] in 1995, principally as a vehicle for virtual versions of its special exhibitions (Bowen, Bennett & Johnson, 1998a & 1998b). A series of exhibitions was begun in that year, and the first, *The Measurers: a Flemish Image of Mathematics in the Sixteenth Century*, was offered simultaneously in the gallery, on a gallery computer, and via the Internet. The web version is still available today. This established a pattern for web activity for several years, as each exhibition was placed on the web, and maintained indefinitely. Each exhibition was essentially the full text of the catalog, with all the advantages of navigation and image management that an electronic edition can offer. We have no evidence that this availability was detrimental either to visitor numbers or to catalog sales, and anecdotal evidence suggested the reverse.

While it remains the museum's ambition to maintain this link between the exhibition program and the website, in recent years it has proved difficult to do so. Our early exhibitions helped make the case for a major grant from the UK Heritage Lottery Fund, and the Museum closed for a comprehensive project of extension and refurbishment. Equipped with new facilities, not least a dedicated gallery for special exhibitions, we have been coming to terms with a much more ambitious public program and the virtual exhibition work has not yet been re-established. This may be a local problem, rather than a common experience, but we have found that as the Museum has expanded its work – an expansion that was itself fostered and promoted by improving web resources – it has proved difficult to maintain development on all fronts, and the web-based work has slipped back. Clearly resource limitations are part of the problem, at a time when museum funding has not grown to meet either staff ambitions or visitor expectations. Nonetheless, a parallel gallery and web exhibition program is too valuable to lose without a struggle and we hope to be able to revive it before long.

If the virtual exhibition program has stalled for the present, other web work has flourished and some of this has been in line with achievements or ambitions elsewhere. Both our collections database (with images) and our library catalog are now online, as is an image library of 8,500 items – not massive but large in relation to the size of the Museum and its collection. Where our contribution may have been more distinctive has been in going beyond the presentation of our own material and towards connecting or combining distant collections.

Museums that are physically separate, even those in different countries or different continents, hold objects that are intimately related to each other in history. They may have been made by the same hand, or in the same workshop, or commissioned by the same patron, or used together in the same laboratory. They may represent closely related stages in design development. In extreme cases they may even be separated parts of what was once a single piece. Whether or not the objects have this level of intimacy, it is often enlightening to take a broad view, since a review of evidence across a number of collections may well modify or enrich one confined to a single source. In early periods of instrument making the culture of design and manufacture had aspects that were local and derived from certain traditions of production in a city or region, but there were also developments that were European in scope and depended on an economy of learning that was thoroughly international.

We have offered two, very different responses. In one case a relative small, natural population of prestigious objects was strongly represented in a few very fine collections. These objects were closely related to each other in intellectual, economic and social respects, but the small size of the population meant that they could be considered – individually and as a group – in great detail and with a wealth of supporting material. In the second example, by contrast, we have a potentially unlimited population, and the aim here is to provide a tool for the researcher, a large database that does not itself hold detailed information on individual objects but which can be searched for unknown instances of the objects under study and for impressions of their frequency and distribution.

In the first project, four museums have combined records of their European instruments up to the year 1600 to create the *Epact* database [www.mhs.ox.ac.uk/epact]. The museums are the Museo di Storia della Scienza in Florence, Italy, the Museum Boerhaave in Leiden, The Netherlands, the British Museum in London, UK, and the Museum of the History of Science in Oxford.

Here is an example of a population of objects that has a strong internal coherence and because of the richness of the four collections involved, the result also has the advantage of presenting a fair proportion of the instruments from the period now in captivity in public museums. A terminus of the year 1600 created a relatively small and manageable group of 520 instruments, and each has at least one image at three sizes. The intention was to provide as high-resolution images as was feasible, so that researchers could use the largest images to examine the instruments in detail. The user has a choice also as regards the accompanying text, for two descriptions are offered for each entry. On overview gives such systematic information as the maker, date, place, materials and dimensions, followed by some general remarks and comments on the instrument. These are intended to draw attention to points of interest and not to require any technical background. The second level of text is a detailed and technical

description that seeks to reach the standards of a scholarly catalog. This is one approach to the problem of having to satisfy different audiences with different needs.

Users are offered other assistance as well, such as biographies for all the makers, information on the locations where they worked, explanations of the different types of instrument, and a glossary of technical terms. Links are provided for direct reference to this supporting information, and a range of ways of ordering the material is at the command of the user, who can also choose whether to browse by text heading or by thumbnail image. The standard facilities of a web database have made this a catalog that is more versatile than any printed equivalent could have been, but perhaps its greatest advantage comes from the combination of collections that allows comparisons and inferences that would not be possible in a single source.

Epact was an attempt to produce the finest product that could be managed, to the best standards of scholarship and presentation. It required a great deal of effort, and twelve people from the various museums were involved in different ways. Several years of work – not, of course, full-time – and a number of meetings were needed. The result is attractive and has been well received, so that there have been suggestions that it be extended, either by involving other institutions or extending the date limit. So far, those involved have not felt inclined to reopen and extend the project they have completed, because they are well aware of what would be involved. It was a challenge to keep us all working to the same conventions and to standardize our product. But one thing that might be useful to others is that the conventions and standards we agreed on and sought to implement have been published online with the database [www.mhs.ox.ac.uk/epact/conventions.asp].

The second project, the *Online Register of Scientific Instruments* [www.isin.org], presents a complete contrast to Epact. The Register comprises a much larger population, spread over a much broader range of types and dates, has no restrictions on participating collections, and it could expand indefinitely. But the more profound differences are in ethos: where Epact aimed to be closed, complete and conforming exactly to established standards, conventions and limiting conditions, the Register is an open-ended experiment, whose future is, at least to a large extent, in the hands of its contributors and users. The conventions are minimal and its future direction and development unclear and undecided.

There would clearly be an advantage to researchers to be able to consult a single database, instead of having to keep up with the many initiatives by individual institutions. One the other hand, grand and comprehensive schemes do not work in the long term: they are unwieldy, they soon outgrow the resources and the enthusiasm of their originators, and they trespass on the legitimate interests of the keepers of collections. Collection holders rightly want to control their output. They do not want to hand over to others their responsibilities for making information available on their collections, but at the same time they want to be part of some central vehicle for making their work known and for attracting interested users. The Register seeks to answer this need: to provide the minimal facilities that will be of service to users and collection holders alike, while responsibility for information and its dissemination stays where it belongs, namely with the individuals and institutions who care for the collections.

So one principle of the Register is that collection holders contribute the information on their objects. They can include as many of their objects as they wish, and in each case they complete as many as they wish of the fields of information (there are only a few) offered by the Register. They can return to their entries whenever they like, to correct them, modify them, improve them, delete them or add to them.

The Register is like a library catalog which tells you about the existence of a book and how to find it; it does not contain detailed descriptions or histories or images: for these the user contacts the collection holder, either through a direct link to an online database where the collection holder has provided this, or by email or post. At present there are 17 contributing collections, the largest being the Science Museum in London with 2,273 entries.

The disadvantage, of course, with placing all responsibility for content with contributors is that it leads to inconsistency. With Epact we had enough difficulty imposing consistency on ourselves in a relatively small group of workers dealing with a relatively coherent group of instruments. Given the scope of the Register, this would be impracticable with the slight resources at its disposal. It might not even be wholly desirable in any case, again given the ethos the Register has adopted: contributors do not relinquish responsibility and centralization is minimal.

The Register does not control or vet contributions in any way. There has been no attempt at a thesaurus of allowed terms and entries, and no particular language is required. There are no preferred forms for names of people or places. Where inconsistencies, or mistakes, appear in the indexes, it is hoped that the contributors will notice these and make correcting submissions: again it is the contributors who are responsible. In practice nothing else would be possible; the resources for a thorough vetting and correcting procedure does not exist. But in any case, there is a virtue in placing this responsibilities with contributors: the interest and responsibility is collective, and the Register will develop or not depending on the extent to which contributors and users find it valuable and want it to work. It is intended to be an opportunity, rather than a finished product. It also has to be said that the lack of success of grander projects for agreed terminology is not encouraging. The indexes generated by the Register could become vehicles for agreement and convergence, as contributors notice consensus emerging on certain terms and names, and adjust their entries accordingly.

It is in this democratic spirit of self-help, allied to the conviction that a central index of this sort could be of great use to institutions and researchers, that the Scientific Instrument Commission of the International Union of the History and Philosophy of Science has sponsored the Register. The original designer, Giles Hudson, presented the project to a Symposium of the Commission in 1998 and Jessica Ratcliff has since developed the site with the support of the Museum. The Register is a challenging and imaginative experiment, whose future rests with the community of users. For that reason, although it was launched and is managed by the Museum, it appears at a different URL [www.isin.org] from the museum's website [www.mhs.ox.ac.uk], where the Epact database can be found.

While the educational value of our virtual exhibitions is evident, the projects presented in more detail here, namely Epact and the Register, may seem more like

tools for research, and to a certain extent that is true. Neither offers class or individual lessons tailored specifically to target groups of e-learners. Until very recently the Museum has not had the professional educational staff necessary to ensure that such material is really useful and relevant. However both projects have such potential, and Epact in particular can readily be used as an information and image resource with a great deal of supporting material for the user. Its subject matter may at first seem relatively distant from school learning, but because mathematics in the Renaissance was often closely related to practical matters, it is not difficult to apply the Epact material to social history.

Time, for example, forms the basis of many school projects, and the single most common instrument in Epact is the sundial. Many lessons can be learnt from the dials on view; the importance of time telling, for example, is seen from the number, variety and quality of the pocket dials, while the arbitrary nature of our division of the day into hours is demonstrated by the numerous alternatives in use in the past. Many of the instruments relate to warfare, while others illustrate the importance of religion or astrology in daily life. At present, students may have to do some exploration to tease out what they want to use, but the various directories and glossaries ensure that the information is there, and learning to explore has its own value.

SCIENCE MUSEUM, LONDON

The Science Museum (London, UK) is part of the National Museum of Science & Industry (NMSI), which further comprises the National Railway Museum (York), and the National Museum of Photography, Film & Television (Bradford). The Science Museum has its origins with the Great Exhibition of 1851, and has resided in its present building in South Kensington since 1928. Today, the Science Museum exists to promote public understanding of the history and contemporary practice of science, medicine, technology and industry.

In regard to the online presence of the Science Museum [www.sciencemuseum.org.uk], the development of its website has been organic, at least for the first four years of its existence. The website itself was launched shortly after the Natural History Museum (NHM) [www.nhm.ac.uk] set up its own pages in 1994. It should be noted that the Natural History Museum was the first UK museum to have its own website presence. Both the Natural History Museum and the Science Museum benefited from the close physical co-location with Imperial College, where the relatively high-speed JANET academic network was already well established with good network connections to other UK universities and the rest of the world.

The early Science Museum site quickly developed a broad and deep hierarchy with many cross-listings. In addition to visitor information, there were approximately 12 navigation sections, a quick search and featured highlights. The sections largely represented organizational activities and to some extent, the main divisional areas of the Museum itself. These included Exhibitions, Education, Collections, Research, Commercial and Services.

Exhibitions Online

Of note at this time were the featured highlights. The Science Box series appeared under this section – a series of small, temporary exhibitions. In 1995, The Information Superhighway was one of the Science Box events that appeared on the web and which coincided with a set of seminars and a touring exhibition component that provided outreach to the public in the area of new communication technology.

In the latter half of 1998 saw the appearance of "Exhiblets", the first exclusively virtual exhibition that did not reference a physical space or exhibition in the actual museum [www.sciencemuseum.org.uk/collections/exhiblets]. The name "Exhiblet" was derived from a combination of the terms "exhibition" and "Java Applet". Exhiblets represented a set of online information resources that used a specific object or collection to explain events, discoveries and personalities. Each Exhiblet is comprised of a narrative, object list and bibliography. The resources were a form of pro-active approach to enquiries in popular areas, such as the personality of Marie Curie, and to highlight collections within a historical context. The success of the medium can, perhaps, be gleaned from the web statistics of December 1999, which shows that "Marie Curie" was a top search phrase that led visitors to the site, only exceeded by the term "science museum."

Exhiblets were a relatively low-tech addition to the website and were intended to be easily viewed by different browsers and printed-out as a resource for the enquiring public and school students. This complemented the availability of activity sheets that the Education Department had placed online for printing and downloading for teachers and schools.

More interactive applications were developed for specific featured objects and exhibitions in the Museum galleries. One of the earliest features to use a form of VR was the online exhibition for the Apollo 10 Command Module, which incorporated an activity entitled "Design your own rocket" [www.sciencemuseum.org.uk/on-line/apollo10].

The use of web tools to provide interactivity and participation was encouraged under the STEM initiative. The STEM Project (Students' and Teachers' Educational Materials) was an Internet competition held by the Science Museum and sponsored by TOSHIBA and begun in 1997. STEM encouraged school visitors to create a website based on a particular gallery, exhibit or online exhibition. The purpose of the project was to result in the creation of a database of resources created by students and teachers for students and teachers. In this way, the project extended the interrelationship between the museum and school curriculum. Over 1,000 resources are now archived on the site [www.sciencemuseum.org.uk/learning/sheets/sheets/sheetintro.asp]. Note that STEM ended in 2003.

Web redesign

During this active period of online development and features added to the website, namely between 1997 and 1999, the Museum began to review its online presence and sought to provide more integration to existing content. Importantly, it looked to provide a more interactive and community based web experience, and to provide multiple entries to website content through a variety of navigation methods.

Following meetings during the summer of 1998, it was determined that there was a need to revise the existing navigation of the website and to provide multiple audiences with multiple information structures. One of the methods was determined to be via offering a subject-based navigation.

In an evaluation conducted by the Visitor Research team in 1999 (Steiner et al, 1999), recommendations indicated the need to reduce the number of highlights on the front page and the number of options for the initial navigation. Some of the section headings also came under review. For instance, whereas it was clear that the Education section contained information to the educational community, especially schools, there was also the expectation for continuing learning to be located there. Similarly the heading "Online Features" was another area of confusion for visitors who anticipated "information" about physical exhibitions. Some of the heading changes thus resulted in Education becoming "Learn & Teach" and Online Features changing to "Exhibitions Online."

These changes reveal a move toward usability in terms of language and design for a growing web savvy audience, and possibly emphasized the variations in the needs and expectations of virtual audiences versus the physical visitor to the Museum.

Wellcome Wing

This reorganization of content and web restructuring coincided with the development of the new, Intel sponsored, website for the Wellcome Wing building of the Science Museum [www.sciencemuseum.org.uk/on-line/wellcome-wing]. The Wellcome Wing, opened in June 2000, and focuses on contemporary science and technology, with a particular emphasis on biomedicine.

The website for the Wellcome Wing was the largest "microsite" at this point accessible via the museum's pages. The site was developed to support both the interactive nature of the new building and the look and feel. It contains interactives similar to those in the gallery (for example the "Pattern Wall" which can be downloaded as a Flash game or played within the Museum itself). Also of note is the VRML (Virtual Reality Modeling Language) 3D clickable walkthrough of the Wing that gives users the chance to engage with the space itself as well as providing alternative ways into the content. The building and the website represented a move away from more "object-oriented" and historical rich spaces.

At the same time as the launch of the Wellcome Wing, Antenna was developed [www.sciencemuseum.org.uk/antenna], "a world first – a constantly updated exhibition devoted exclusively to science and technology news…" This exhibition brings rapidly changing exhibitions and CIPs (Computer Information Points) into both the virtual and real spaces. As time went on, the CIP development was levered into XML which means that content developed for the gallery kiosks can be re-deployed within minutes to the wider website audience. Antenna is a conscious response to the information-seeking behavior of younger audiences who are informed by and exposed to rapid news and media-led events.

InTouch [www.sciencemuseumintouch.org.uk] went a stage further in linking the real and virtual by allowing gallery visitors to create their own web pages when they visited the gallery spaces of the Wellcome Wing. Various interactives are connected to the web space and all are activated on-gallery using a retina scan and online using a user name sign-in system. To date, roughly 170,000 personal web pages have been created. InTouch is also an example of *personalization* (Bowen & Filippini-Fantoni, 2004) driven design whereby the experiences offered by the interactives are user-led. The sustainability of InTouch continues to be reviewed and has provided an important foundation in this area for subsequent projects, especially in convergence (physical and virtual interdependent spaces).

Dana Centre

The Dana Centre [www.danacentre.org.uk], launched in the winter of 2003, "…marks a new direction in science communication: to challenge public perception and tackle contemporary science head on. This dynamic events space will bring the hottest themes in modern science to adults-only audiences through a program of bold and innovative events."

Similar to the Wellcome Wing, the Centre is linked to the experience of a physical building, but striking differences lie in the use of new media channels for information delivery, omission of gallery/object-oriented spaces, and its focus on adults as the key audience. The Centre itself is a highly wired building, with facilities including OB (Outside Broadcast), webcast, webcam, wireless, kiosk, projection, moveable stages and rigging, wired rooms etc. The direction in which it has influenced the web most, however, is again in the connection between the virtual and real spaces. Not only is the program and other key information displayed on the Dana Centre website, but dialogue is fostered through online discussion boards (Bernier & Bowen, 2004) – and permeates the real space via the live web kiosks and projections. There are other less obvious connections as well: the program of events, for example, is updated once online and an XML feed then powers the "what's on" projection in the building itself. There is also a projection feed of images from the NMSI Picture Library website [www.sciencemuseum.org.uk/piclib], chosen at random from the database.

In this community-driven space, the "4thRoom" represents another complementary innovation developed during the website build – a flash interactive which acts as a "skin" on the online discussion. Each person's point of view on a particular thread is displayed within this interactive as an avatar figure. Shortly the interactive will be available as a screensaver with the discussion fed remotely by the website. One consideration in the set up of the 4th room and debate areas of the Centre is the need for moderation and the introduction of "House Rules." The latter was undertaken specifically for the Centre and in light of its provocative content.

To support community-centric activity, and particular to a technologically aware target audience, development into the future includes an innovative 3d chat event, use of SMS (Short Message Service) and MMS (Multimedia Messaging Service) during and after debates, "klip" technology that will provide users with live, desktop notifications of the latest discussions and events and further building of key areas of the site.

The Ingenious Project

Ingenious [www.ingenious.org.uk], funded by the NOF-digitise program (a lottery funded initiative), represents the largest scale object-based Internet project to date undertaken by the Science Museum and NMSI (to launch in the Spring of 2004). The project aim is to make publicly accessible 30,000 digitized images and accompanying records, 10,000 library records, and 10,000 object records sourced from the Science Museum (including the Science and Society Picture Library), and its sister sites: the National Railway Museum in York and the National Museum of Photography, Film & Television in Bradford (Borda & Beler, 2003).

In addition, this material is to be contextualized by several hundred pages of circa 40 topical stories aimed at life-long learners (the widest potential audience of the "microsite" projects). These topics use the primary material "to weave connections between the people, innovations and ideas that have changed our lives and the way we see the world, from the industrial revolution to the present day" (extracted from the *Vision statement*). Through these connections, users have the further opportunity to find meaning for themselves by being presented with tools to "create" and to contribute to subject-driven debates (Borda & Bud, 2002). As an example, the Ingenious website allows users to custom-build their own user experience by adding resources to a "save image" clipboard, and self-market the site by passing on e-cards, personal pages and links to their friends and colleagues.

A highlight among the toolkits is the "webgallery" function that will enable users to add text and captions to images of objects, to arrange them, and to save other types of resources, as well as email the end product. This creative building process provides an individualized means of making learning resources of direct significance to the user.

On a community level (Beler *et al.*, 2004), debates permit users to contribute and join conversations focused around contemporary issues. There are also plans to cross-link debates with the Dana Centre to build on existing tools and streamline the user experience (and moderation efforts). Due to the nature of the sharing activities and depth of authored content (especially for the topics), one issue similar to the Dana Centre is the need for libel coverage and for Ingenious to have its own set of House Rules as the Museum engages more in the area of user contributions online.

Other than the STEM project, Ingenious tools will be unique to be drawing from a comprehensive knowledge base for self-publishing and sharing, and general content syndication (Borda & Beler, 2003). Watermarking is an issue currently being discussed so that ownership and, viral marketing, can be realized. There are plans to do an extensive summative evaluation on the whole site once it becomes public. This will likely inform the development and tweaking of the tools to optimize usability first and foremost.

Science, Invention and Nature

Expanding the community-focus online, the Science Museum is leading a consortium project (again funded by the NOF-digi program) called *Science, Invention and Nature* (SIN) [www.sinergies.org.uk]. SIN is an interdisciplinary web portal that combines information from four institutional websites and their respective NOF-funded projects

exploring aspects of the natural and man-made worlds. The four partner websites linked to the portal thus far are:

- Science Museum [www.sciencemuseum.org.uk]
  – *Ingenious* [www.ingenious.org.uk]
- Natural History Museum [www.nhm.ac.uk]
  – *Nature Navigator* [www.nhm.ac.uk/naturenavigator]
- Wildscreen Trust [www.wildscreen.org.uk]
  – *Arkive* [www.arkive.org]
- Y Touring [www.ytouring.org.uk]
  – *Genetic Futures* [www.geneticfutures.com]

Internet users entering the SIN website can browse through different themes (also known as SINergies) and click on related links which will also take the user to content on the four sites. The SIN website's main task is to collate select content from each of the sites into these broad editorially driven SINergies. One example of such a theme on the SIN portal is "Food." The SIN portal will hold an introductory text on this theme, as well as food-relevant links to the other four websites.

There is a possibility for the user to "drill" the other way as well. The four websites will each hold a SINergy button icon on different pages where theme relevant content will take the user to the SIN portal. For example, a page on "Eating disorders" on the *Y Touring* website will hold that SINergy button, when a users clicks it, s/he will be taken to the SIN portal and the theme on "Food." The theme will then lead to further content on the topic "Food" through links and relevant keyword search (pre-defined based on subject page on which the button resides). This concept follows the idea of a "web-ring" in which a group of websites with a common theme, configured in a loop, allows the user easy access in the ring by clicking on links. Significantly, throughout this learning experience, the user is kept within a contained group of authoritative and subject-focused set of sites.

To support the concept of an "enclosure" of subject specific resources, the other principle component of the SIN web portal is a sophisticated search engine. One of the main purposes of the portal is to provide users the possibility to search for content for relevant topics and provide them with a "complete" result across all underlying partner sites via search algorithms and metadata. The user can also search by resource "type" (e.g., image, PDF, HTML page). To achieve optimum results, the SIN portal has been designed to crawl the four websites (other sites may be added later) in order to create an indexed database that will be used for efficient and targeted searches. The search is a particularly key component because SIN represents a resource almost entirely comprised of *born digital* resources (i.e., website materials), and the site itself has minimal content –the SINergies really acting as jumping off points and a means to provide examples of the range of interdisciplinary content.

In summary, the idea behind the overall concept is to offer users something more targeted than a Google result set – here the users are provided with well-known and branded knowledge organizations from which to search across and access

authoritative learning materials. The SIN site is due to launch in Spring 2004 and will then be re-evaluated.

Future Directions

Future projects are beginning to approach website technology, content and delivery in a more holistic way, not least the need to "join-up" both on resource and practical levels. This will mean the development of a central content management system, including industry standard storage and systems, as well as unifying many of the tasks carried out today into re-useable "toolkits". These will provide each project with an increasing array of technical solutions already in place. Effort on projects will therefore be released to focus on innovation of design and content (i.e., the user experience) rather than technology. We envisage therefore that as time goes on, the technology will become increasingly invisible to users and builders of sites within the Science Museum and the NMSI family.

Continuing efforts are being made to improve accessibility (Bowen, 2003; Bowen, 2004) and interoperability across all sites, and we expect delivery to multiple platforms to begin to become an important part of what we do both online and offline, and to extend the learning/engagement channels to multiple users and audience profiles of the website.

ALAN TURING HOME PAGE

The Alan Turing Home Page, now the index page to a large website dedicated to the life and work of the mathematician, computer scientist and codebreaker Alan Turing (1912–1954), first appeared on the World Wide Web in September 1995. At first it was hosted in my own user space on the web server of Wadham College, Oxford University. In 1996–97 there were mirror sites in San Francisco and Chicago. But in 1997 I started paying for my own domain names and web hosting and since then the site has been solely under its own dedicated domain name [www.turing.org.uk]. It currently has between 1,000 and 2,000 visitors a day.

The background to these early developments was, of course, the very rapid expansion and growing sophistication of the web. I was a slow starter on the Internet (for an academic), and it was not until 1995 that I appreciated how important it was going to be. Matthew Westby, one of my students at Wadham College (where I am Lecturer in mathematics) showed me HTML, and thanks to him I began life as a web-author just at the exciting point when the web was transforming itself from a club for enthusiasts to a universal medium for global information and communication. My initial motivation for the Alan Turing Home Page was simply that on looking up "Alan Turing" on the search engines that then existed, I was aghast to discover pages of inaccurate offerings, plagiarized from obsolete texts or the result of poorly informed student projects. I had an alarming vision, which has never left me, that all my work in the 1980s, in particular my large-scale biography *Alan Turing: the Enigma* (Hodges 1983) might as well never have existed as far as web-users were concerned! More positive feelings very rapidly superseded this anxiety, because my first web-pages were noticed and appreciated at once (in particular by Jonathan Bowen, already a

pioneer with his Virtual Museum of Computing), and these new contacts gave me a delight in the value of co-operative linking which, likewise, has never left me.

The website was started to complement that biography of Alan Turing, and its spirit has remained similar to that of the book, which I started as a multi-faceted, multi-level work back in 1977. Now as then, I work as an individual researcher and author. But there are obvious differences between writing a printed text, and authoring for the web, which struck me right from the beginning. One is the immediacy of web-publication, both in the sense of being able to publish without the glacial timetable of book publishers, and in the sense of being unmediated by their no less icy and static conventions – to publish direct from author to reader and inviting personal response. The dynamic quality of the web also allows correction and expansion of material to be done at any time. This means, of course, that unless fairly elaborate schemes for archiving and dating are in place, one cannot expect web pages to play the role of printed publications in establishing definitiveness and priority. For this reason I do not write for web pages in the same style as for a printed publication, and I am mildly surprised when other people cite ephemeral web pages as academic references. Another difference is economic: without elaborate registration and payment schemes, impractical in my case, there is no royalty payment to the author. The economic rationale of this work has had to rest on the hope of improved book sales and a small amount from Amazon.com commissions: neither would justify the time I have spent. The shoestring finances have also dictated that the technical work must remain as it began – by doing it myself. This means that the design does not meet the standard expected by those using professional graphic design elements optimized for all platforms and screen sizes. Still less could I undertake advanced dynamic "personalization" features (Bowen & Filippini-Fantoni, 2004). However, it is tolerable.

In web authoring I am influenced by the fact that my written style make much use of allusion – "only connect" was one of the mottos of Hodges (1983) – and so the principle of hyperlinking seemed natural to me as soon as I saw it. In the first few days of the site, I decided on a format that has remained good ever since. There is a formal textual biography, based on my entry on Turing for the (British) *Dictionary of National Biography*. This allows for straight linear reading without the distraction of links. Parallel to it, there is a web page "Scrapbook", visually designed to look like entries and pictures pasted into a book, which has all the links. This choice of design meant that when new ventures such as the Turing Digital Archive [www.turingarchive.org] came online, the browser could move into them seamlessly through hyperlinks. The Scrapbook is probably the most interesting part of the website as it is intended for hyperlinked "browsing" in a way that only the web can offer. My policy for the Scrapbook has been from the beginning to give *annotated* hyperlinks to other sources. Web authors tend either to provide sites which are either totally self-contained, without using external links, or else to give uncritical listings of links to other pages, expressly without any responsibility or judgment of any kind regarding their content. I have never felt happy with either extreme, and try to update the links and associated commentary. The downside is, of course, that it is hard to maintain working links and compose suitable remarks. I am always aware of a large stack of tasks confronting me through the volume of relevant material on the Web. It is very different now from 1995, when there were only a few items on the web for the

Scrapbook pages to point to. All truly web-based material is always "under construction."

After 1997 I added further sections, reflecting the new research, talks and publications that had stimulated by the existence of the website. In particular, a "Philosophy" section has been built round the short printed text that appeared in the *Great Philosophers* series (Hodges, 1997), and my online entry in the Stanford Encyclopedia of Philosophy [plato.stanford.edu]. This more advanced material attracts about 100 users a day, many of them degree-level students from around the world. Inevitably, sometimes paragraphs from my writing must be copied, undigested, into students' work: as all lecturers know, the web lends itself to crude cribbing. But I try to counter this tendency in the Scrapbook section by annotations that show students (and indeed anyone else) how there are many differences of view and sometimes-fierce arguments among leading current thinkers. This relates particularly to the significance of Church's Thesis, to the question of how the electronic computer came into being; and to the prospects for Artificial Intelligence. Here I encourage users to follow external hyperlinks to see these different views for themselves, and discourage mindless copying.

It also becomes apparent from enquiries that the website is being used by school students. Indeed, the UK National Grid for Learning references it. I am inclined to say, however, that the questions being "researched" by school students, judging from the demands for "information" that I receive, often seem to reflect the fact that they are attempting to answer questions which are far, far too difficult. There is nothing on my website specifically intended for school students, and on the whole my motto would be that computability is an adult subject. Of course some exceptional school students will discover my site with relish, like my book, but I make no claim that it would be of general value for education below degree level. However, this could change: the new A-level in the ethics and history and philosophy of science might make it a very worthwhile course element.

From these remarks it should be apparent that I am critical of the too-frequent assumption that web material is, just by its nature and its availability, a learning resource of value to students of all kinds. The web is poor in its provision of structured course learning, and is not convenient for the experience of serious reading. My site does not pretend to supply anything of what students should be getting from textbooks of computer science and computability. It can complement, but not substitute for, my own printed work. I can offer specific technical benefits – like a JavaScript Turing machine demonstration, which does much better than the static printed explanation in my book. I can give technical details that it would not be economic to print. And I can give an illustrated taste, an overall browsing experience, which can usefully excite the imagination, and be accessible to people all over the world. These seem to me the main benefits of web material in general.

Looking into the future, I would expect to develop those features of web material further, and especially those areas where I can give something unique that no one else would do. One of these lies in creating a "Book Update": supplementing my printed text with new and corrected material of all kinds. If, one day, publishers let Hodges (1983) go out of print – i.e., it loses its economic viability on printed paper – then the website could extend into providing an e-book alternative. There is certainly room for

me to enlarge and improve the role of technical design and illustration, but really it is the content that matters. Probably the area where I could best take advantage of my own particular knowledge and development, is to expand the Philosophy section into a much larger discussion of physics, computation and the human mind, for instance in relating Turing's ideas to those of Penrose (1989).

This may sound a very dry and abstruse conclusion, but actually it is a very personal one. I am in an unusual position as having come to study the development of computer science from a background of working with Penrose in relativity and quantum mechanics, and from a strong personal and political interest in Turing's individual life. Publishers, like academic departments, are very wary of cross-genre, multi-purpose work, and enforce the *either/or* mentality. The web, with its low marginal costs and its natural interlinking, allows a *both/and* principle which suits me better, and allows me to express what I want, in the way that I choose. Although I have expressed a skeptical view about the value of web material for traditional structured learning, readers' responses teach me that there seem to be no obvious limits to the effect that web authoring can have on readers of all kinds and all backgrounds, and it is the response of these readers that has been the non-economic reward to this author.

Lastly, after the preceding text was completed, and just before the final editorial deadline, there was an unexpected development. I was offered, and have now accepted, a commercial arrangement with the online retailer Kelkoo [www.kelkoo.co.uk], under which I am paid for displaying links to it throughout the site. This new arrangement may, of course, be as short-lived as the famous dot-com bubble of 1999–2000, depending as it does on the marketing concepts of a multinational company, but for the time being it offers a rather better economic basis than the state of affairs that I outlined above for maintaining and augmenting the site. It also illustrates the dynamic nature of online publishing, where one has to be prepared for changes from day to day. You are now reading a printed text that captures the state of affairs as they stood in early 2004, but time will not stand still in cyberspace.

The business of a physical museum is a strange amalgam of detailed and obsessive long-term scholarship, the exploitation of graphic and advertising techniques, the pressure of unpredictable demands from the general public, and the necessity of negotiating financial sponsorship. Being the curator of the branch of a "virtual museum" is, albeit in microcosm, not so different. Experience shows that communication of all kinds is more like the hopeful floating of bottled messages into the oceans, than the direct linear inculcation of facts and logical deductions. Electronic publication and e-learning is no exception. One can only carry on in the hope that this new symbiosis of text and image, enhanced by the global glow of the computer screen, will spark in some readers that magic response that goes beyond "information" to real excitement and involvement.

CONCLUSION

In this chapter we have explored a number of case studies of science museums and their associated websites, as well as completely a virtual website concerning the history of science, in the context of e-learning. The case studies have all been

pioneering in their own way and have taken very different approaches in their development and presentation of e-learning material.

Of course the web is constantly developing with new issues and technologies. Any e-learning facility must try to keep up with these changes or it will inevitably start to look dated. For example, personalization is an increasingly important technique that allows websites to provide a more relevant experience based on individual requirements. Although there is considerable scope for development, major science museums such as the Science Museum in London and La Cité des Science et de l'Industrie in Paris are now exploiting this approach in their latest website developments (Bowen & Filippini-Fantoni, 2004).

Widening access is also an important concern, with legislation now making this a legal requirement in many countries (Bowen, 2003; Bowen, 2004). Online, it is possible to make educational resources in a form suitable for many types of user, whether they are school children, the general public or advanced researchers (Bowen *et al.*, 2001), even if they are disabled (e.g., through blindness or partial sightedness for example). The Natural History Museum of Los Angeles County was an early museum pioneer in this respect [www.ed-resources.net/universalaccess]. With the ever-increasing number of technologies available on the web, it is important that museums understand the accessibility issues when including a particular technology on their website (e.g., to improve the interactivity or multimedia presentation of an e-learning resource). Presenting material in multiple ways (e.g., textually, visually and aurally) is often beneficial for many end users, if suitable resources are available.

For the future, successful museums should use their websites to augment their educational facilities in appropriate and cost-effective ways. For example, it is an ideal medium to make material available for teachers cheaply, avoiding postage costs associated with traditional physical delivery, and for providing widely available interactive facilities while avoiding the installation of expensive hardware. It is possible to provide good facilities even when the budget is limited, as in many virtual museums. It may be feasible to leverage volunteer effort in the development of e-learning material, through liaison with universities, for example.

Overall, there is no one route to success, but the area where museums reign supreme over many other organizations is the availability of real objects and associated unique content. Using and combining these resources in novel ways can help to inspire those using museum websites for educational purposes in a distinctive way that is not possible for other organizations.

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Biographies

Jonathan P. Bowen, London South Bank University

Jonathan Bowen [www.jpbowen.com] is Professor of Computing at London South Bank University, where he is Deputy Director of the Institute for Computing Research. Previously he was at the University of Reading, the Oxford University Computing Laboratory and Imperial College. He has been involved with the field of computing in both industry and academia since 1977. As well as computer science, his interests also extend to online museums. Bowen established the Virtual Library museums pages (VLmp) in 1994, a web-based directory of museum websites worldwide that has since been adopted by the International Council of Museums (ICOM). He was Honorary Chair at the first *Museums and the Web* conference in 1997 and has given presentations at each conference since then. He guest edited two special issues of the *Museums International* journal concerning online museums. In 2002, Bowen founded Museophile Limited [www.museophile.com], a spinout company from London South Bank University with the aim to help museums online, especially in the areas of accessibility, discussion forums and collaborative e-commerce. Bowen is a Fellow of the Royal Society for the Arts and holds an MA degree in Engineering Science from Oxford University.

Jim Angus, National Institutes of Health

Jim Angus joined the National Institutes of Health in 2001 as web project manager. He has a diverse background with undergraduate degrees in Biology and Geology, and graduate training in Immunology and Molecular Biology. His prior employment was at the Natural History Museum of Los Angeles County where he established and managed the Museum's Molecular Systematics Laboratory. In 1992 he became interested in information technology as applied to scientific research and assisted in the development of the Museum's IT infrastructure. In 1994 he produced one of the first museum websites, which was subsequently named "best educational use" at the 1997 *Best of the Web* Awards sponsored by Archives and Museum Informatics. He currently serves on the board of directors of several professional organizations including the *Museum Education Roundtable* and frequently speaks on web design and accessibility of websites.

Jim Bennett, Museum of the History of Science

Dr. Jim Bennett is the Director of the Museum of the History of Science, University of Oxford, which has a strong commitment to making its exhibitions and collections available on the Web. He also directs the Masters course offered by the Museum. Previously Jim was at the Whipple Museum of the History of Science, University of Cambridge. He is attached to Linacre College and the Faculty
of Modern History at the University of Oxford. His research work is on the history of practical mathematics from the sixteenth to the eighteenth century, the history of scientific instruments and the history of astronomy.

Ann Borda, The Science Museum

Dr. Ann Borda has held strategic and operational roles in academic and cultural organizations and recently held the position of Head of Multimedia Collections at the Science Museum, London. Among the projects in which Ann has been involved are Fathom.com, an e-learning collaboration led by Columbia University, and a large-

scale web initiative to bring cultural collections on-line across several national organizations in the UK. Ann received her PhD at the University of London in Information Science (1999) and has published in the areas of e-learning, informatics, metadata applications and content delivery. Ann is the Chair of the CIDOC Multimedia Group and assistant editor of the journal *Multimedia and Information Technology* (MmIT) [www.mmit.org.uk]. Currently she is a Visiting Research Fellow at the Institute for Computing Research, London South Bank University.

Andrew Hodges, University of Oxford

Dr. Andrew Hodges was born in London in 1949 and studied mathematics at the University of Cambridge. His postgraduate and postdoctoral work was with Sir Roger Penrose in the development of twistor theory, applicable to problems in fundamental physics. He is now attached to the Mathematical Institute at the University of Oxford and is a Lecturer at Wadham College, Oxford. His interest in the computing pioneer Alan Turing developed partly through mathematics and partly through his participation in the gay liberation movement. His *magnum opus* is the definitive biography entitled *Alan Turing: the Enigma*.

Silvia Filippini-Fantoni, University of Paris I, Sorbonne

Silvia Filippini Fantoni is a research student at the Sorbonne University in Paris, where she is working on her PhD about *Personalisation through IT in museums*. She graduated in contemporary history from the University of Milan and has experience in working as a researcher at the European Centre for Digital Communication (Heerlen, Netherlands), the McLuhan Institute (Maastricht, Netherlands) and the Louvre Museum (Paris, France), where she focused on developing personalization applications for the new website. The results of work carried out so far have been presented at international conferences and seminars (EVA, ICHIM, Museums and the Web), where positive contributions towards the hypothesis have already been received and have led to interesting collaborations with Dédale on a European Union study about *Cultural Institutions as New Learning Environments*, La Cité des Sciences et de l'Industrie in Paris and the Canadian Heritage Information Network (CHIN).

Alpay Beler, The Science Museum

Alpay Beler is an Information Systems Architect and digital technologies/new media strategist. He has over 10 years experience of development and management experience in the educational and heritage sectors, with particular knowledge of digitization technologies, e-commerce, R&D, cross platform networks and web product design. Alpay has recently completed a major web infrastructure at the Science Museum (London, UK), managing the development of a £1.2m government-funded website that draws on the resources of three national museums and which offers personalized activities and community building tools. He was also a key team member of a pilot project for educational content delivery to mobile phones, consulted on the JPEG2000 standard for the British Standards Institution, and currently is responsible for the implementation of an online student information system at Birkbeck College.