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Epistemic Infrastructure in the Rise of the Knowledge Economy[1]

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Introduction

The *epistemic infrastructure* of the knowledge economy arose from libraries, archives, museums, galleries, zoos, aquaria, and other systematic collections that enable individuals and societies to know what they know and to do what they do.[3] The assembling, safe keeping, organizing, representing and displaying of archival documents, plants and animals, common and rare objects, works of art, and so on is the heart of knowledge generation, learning, sense making, and commerce. This is an ancient art: as long ago as 5,000 years, collections of clay tablets, papyri, and inscriptions on stone kept track of laws and decrees, administrative and financial transactions, ownership and control over property, and reminded citizens and subjects of their the duties and obligations.[4] These collections were stored and maintained in centers such as the great Library of Alexandria, as well as in similar libraries at Ephesus, Pergamum, Athens, Ur. Ancient libraries can be found as well in sites from Macedonia to the Persian Gulf, and from China and India to southeastern Asia.

Even though elements of epistemic infrastructure have been with us for five millennia, there is no inherent reason for any particular collection or collecting institution to persist. In fact, we have to contend with the fact that the Alexandrian Library was destroyed, and that no library of Greek or Roman antiquity survived intact due to a combination of natural disasters, intentional destruction, and a decline in the relevance of their collections for new political regimes, ideologies, and epistemic cultures. The decline and rebuilding of collections and the amassing of new ones both signals and serves as a trigger for significant transformations in the creation, dissemination, and exploitation of knowledge.

The “Dark Ages" of Europe followed closely upon the purposeful destruction and dissipation of the ancient libraries of Greek and Roman antiquity in the 4th century. Had the learning captured in those collections not been preserved by Islamic scholars of the Middle East and North Africa, it might have been lost forever. That learning was restored to the West beginning with the Islamic conquest of Iberia in the 8th century. The Christian retaking of Iberia in the late 11th century captured some of what had been preserved in these precious Islamic libraries, and portions of the collections were subsequently translated into Latin and disseminated. Christian Europe, awakening from centuries of intellectual impoverishment, began to evolve institutional mechanisms of

knowledge creation and sharing that contributed directly to the Renaissance, the Scientific Revolution, and the Enlightenment. We attribute the persistence of collections in part to the adaptability of collecting practices and collecting institutions. As collections grew in size and scope, their custodians developed methods for organizing and managing larger collections and new types of material. In time, ancient collections and their new counterparts were transformed from cloistered secrets or private treasures to public goods that played vital service for science, education, and entertainment.

This brief essay cannot cover completely the story of epistemic infrastructure. Rather, it pulls into the foreground attributes whereby epistemic infrastructure forms an essential foundation for the knowledge economy, and suggests how and why epistemic infrastructure is as critical today as it has been in the past.

The Rise and Role of Epistemic Infrastructure

Modern epistemic infrastructure has been built on a vast array of collections, as well as the systems of practice that have shaped their contents, organization, accessibility, and use. To illustrate the rise and role of epistemic infrastructure, we focus on collections of objects and texts in two classes of institutions, museums and archives/libraries. The modern versions of these institutions arose from a revolution in thinking in early 17th century Europe that replaced the traditions of scholasticism with principles of rationality and empirical investigation. Slowly, the haphazard gathering of oddities evolved into a deliberate practice of collecting similar and dissimilar things, and imposing upon them a systematic order that reflected a new way of thinking that became the foundation of the modern world.[5]

We begin with the Ashmolean Museum of Oxford University, which is among the oldest surviving museums in the world.[6] The Ashmolean was never conceived of as a museum in the modern sense. It arose from rather informal collecting habits by two gardeners, a father and son team named John Tredescant Sr. and Jr., between 1610 and 1662. Tradescant Sr. began collecting plants, but expanded his collection to include shells, stuffed animals, works of art, and artifacts from afar.[7] He eventually established a residence in South Lambeth, across the Thames from London at Westminster, and put his collection on display under the name, The Ark. Tradescant Jr. became the keeper of the collection and expanded it after his father's death. In 1650 he met Elias Ashmole, a successful lawyer who had studied at Oxford, and who recognized the importance of the collection. Ashmole and a colleague, Thomas Wharton, produced a catalog of the collection titled *Musaeum Tradescantianum* in 1656. Following Tradescant Jr.'s death in 1662, Ashmole took control of the collection and donated it to Oxford University in 1683.

This was not a unique occurrence. From the middle of the 16th century onward, many such collections were created.[8] By the 18th century, Paris alone had at least 723 of these Cabinets of Curiosities, or *Wunderkammern* as they were commonly known.[9] Such collections eventually found their way into institutionalized arrangements in universities, scholarly societies, and as self-standing museums that afforded greater stability and

allowed for scholarly interrogation. This paralleled the rise of the distributed "invisible college" of scholars, collaborating through meetings and correspondence under the auspices of organizations such as the Royal Society of Great Britain.[10] The Royal Society set out in 1669 to construct a universal taxonomy of natural objects, and although the effort failed, it established a goal of systematic collecting in the natural sciences that continues to this day.

Wunderkammern, and their later instantiation as museums, played a critical role in the rise of modern science and scholarship. Collecting became a form of inquiry: a means of creating a didactic resource that initially made sense only to the collector, but with organization and codification, was transformed into a resource that could be shared among collectors and with inquisitive people to create a common knowledge.[11] This institutionalized clarification and correction of earlier evidence constituted a vital step in the rise of modern scholarly and scientific inquiry. When the skeleton of the dinosaur *Iguanadon*, discovered in 1822 in southern England, went on public display, visitors asked where such a thing came from. The public debate over the fossil record and the implicit arguments by visual metaphors that specimen collections presented, paved the way for both easy acceptance of and widespread alarm at the publication of Darwin's *Origin of Species* in 1859. Science came into the political sphere, and remains there still. *Wunderkammern* also aided the rise of systematic method in the sciences by facilitating careful, repeated observation. Large collections permitted careful comparison of morphology among the specimens, and sparked early efforts at taxonomy and classification that became the foundation of the life sciences.

Documentation, in the form of written and printed catalogs and paintings of *Wunderkammern,* allowed representations of the collections to circulate.[12] This made it possible to export knowledge from centers to the periphery, and to import knowledge into the centers from the far-flung places in an emerging global network of trade and commerce. Scholars on the periphery could compare local collections with representations of other collections, raising questions that led to further discussion and examination via the invisible college.[13] At the same time, new specimens and objects were imported from China, India, Africa, and the Americas into European commercial centers like Venice, Seville, Lisbon, and Amsterdam, enabling what Burke calls "discovery in a global context."[14] This emerging epistemic infrastructure laid the groundwork for Carl von Linné (Linnaeus) to construct his *Systema Naturae* in 1738, upon which all subsequent biological taxonomy was built.

Wunderkammern sparked scholarly and scientific collaboration that formed the foundation of the scientific and industrial revolutions. In a short time, major institutionalized collections were formed. The nucleus of the French National Museum of Natural History was formed in 1749, and that of the British Museum in 1753. Their success led to a golden age of museum expansion and stabilization in the 19th century. Philadelphia's Academy of Natural Sciences opened in 1812. The Peale Museum opened in Baltimore in 1814. The National Museum of Denmark was established in 1816. The ethnographic museum of the Academy of Sciences in Petrograd opened in 1836. The Smithsonian Institution got going in 1846. The British Great Exhibition of 1851 had a

major influence on the relationship between display of collections and emerging industrial enterprise. Harvard University established museums for botany, zoology, and anthropology between 1858 and 1866. Museums became both forces for development and common fixtures in developed countries.

Modern libraries and archives also emerged during the Scientific Revolution and the Enlightenment. The invention of printing with movable type around 1450, based upon earlier woodblock printing and papermaking technologies from China and the Islamic world, interjected a powerful new technology into the epistemic infrastructure [15]. Historians of writing and literacy find many connections between the introduction of printing, the Scientific Revolution, and the spread of Enlightenment thought. For one, the technology of printing made it possible to reproduce manuscripts as books and greatly reduced the labor required to create multiple copies. The vast majority of early printed books were published editions of classical and religious texts that had been preserved in Islamic societies or salvaged thorough repeated copying and translation in the monasteries of Catholic Western Europe.[16] Yet by the 16th century, printers were publishing a wide variety of new compilations of facts, drawings, and other data. These compendia of laws, astronomical charts, botanical drawings, maps, and the like created the initial constructs for analyzing abstract representations of the world, much like the early collectors of museum objects created a common language for analyzing objects of nature.[17]

Multiple copies of stable printed works created an opportunity for scholars, intellectuals, and the clergy to compare different texts and to discover similarities and anomalies among different representations of similar things, and among different interpretations of similar phenomena. The circulation of printed works fundamentally altered the transfer of knowledge between religious and secular cultures, from expert to novice, from academy to academy, from scientist to artisan, and across generations. The power to reproduce texts and circulate them on a larger scale than every before possible allowed scientists, philosophers, and the theologians to mobilize and convince others to see the world the same way they did. [18] The circulation of published works also created new discourse about secular society, religion, science, philosophy, and geography that eventually resulted in distinctions between science and magic, evidence and faith, and near and distant, which characterize the Scientific Revolution and Enlightenment thought. Printing texts in vernacular languages, with accompanying dictionaries, grammars and spelling books, helped to consolidate local dialects into national languages, giving European languages their modern forms by the 17th century. This process hastened the differentiation of people from people and state from state on the basis of a shared linguistic and cultural identity.[19]

Like museums, libraries and archives grew hand-in-hand with private publishing and the book trade, the emergence of the modern university, the maturation of scholarly societies, and the rationalization of the administrative apparatus of modern states. These forces worked together to further accelerate the production of books, administrative documents, maps, journals, reports, and the like, and to foster the collection of books, maps,

drawings, and documents that flowed into private and public collections. Between the 16th and 18th centuries, many collections of texts were gradually appropriated from the Church and the nobility and transformed into sources of information that the nascent disciplines of philosophy and science used to create new epistemic cultures. Private collectors gradually opened their collections for viewing by privileged elites and for research by qualified scientists, or they donated them to libraries and archives in universities, major municipalities, and provincial towns. Progressive monarchs donated their private libraries to the citizens, forming the early instances of national libraries. This effort was aided by the advent of mandatory legal deposit. France established in 1537 that every printer must deposit a copy of each title printed in the King's castle, and similar laws were soon enacted throughout Europe. This greatly facilitated the creation of major libraries such as Oxford's Bodelian Library, which grew out of an arrangement between Sir Thomas Bodley and the Stationer's Company to place into the Oxford University library copies of everything the Company published. The first copyright act, Britian's Statute of Anne in 1709, provided fixed term of protection for published works, and required deposit of nine copies in libraries through the country. During the French Revolution, the Bibliothèque du Roi, at that time the largest collection of books in Europe, was seized and transformed into the Bibliothèque nationale de France. By 1800, national libraries existed in 20 countries, including the United States, which passed legislation that year establishing the Library of Congress.

Archives also grew in number and scope during this period to meet the demands of administrators in the Church, the State, and the commercial sector for organized records to keep track of land, facilities, production, extraction, and subjects in their growing domains of domination. A major breakthrough in the organization of archives occurred shortly after the French Revolution, when scholars of paleography and diplomatics at the Ecole des Chartes established the principle of provenance. When faced with the task of organizing massive collections of books, archives, and manuscripts from pre-revolutionary institutions that had been seized by the new state, archivists introduced the concept of *respect des fonds*. Under this principle, archivists maintain the original arrangement of collections that was established by the person or entity that produced the records. This helped overcome the confusion of earlier classification schemes for archives that were built on arbitrary criteria such as time period, subject matter, strict chronology, author, location, size, and even shape or color, in favor of classifying similar documents on the basis of their common origins or provenance.[20] The use of archives to write history of the French nation, based on documentary evidence rather than determinism or romanticism started a transition that made archives valuable not only as instruments of administration, but also as resources for learning from the past.[21]

The evolution of archives and libraries into instruments of knowledge acquisition and organization was not accidental. As the collections in libraries and archives grew, haphazard methods of storing and organizing collections became inadequate for locating material on particular topics. Efforts by collectors, scholars, and librarians to impose order on collections through organizational and classification schemes began in the 17th century. Early proposals for arranging books and catalogs, such as Naude's *Advice on Building up a Library* (1627), de Aráoz's *How to Arrange a Library* (1631), or Leibnitz's

Plan for Arranging a Library (1679), reflected competing views of how best to divide knowledge into useful categories.[22] Use of the term *bibliothéque* (library) was not limited to the physical places where books were organized and housed. *Bibliothéque* also denoted catalogs and inventories of all known books by a particular author, on a particular subject, or in a particular language, regardless of their physical location.[23] Managing the proliferation of books required increasing specialization of libraries by subject, language, origin, and types of works. This created a need not only for universal classification schemes to organize the ideal universal library, but also for increasingly specialized vocabularies and cataloging methods aligned with particular topics or specialties, much like the emergence of systematic classification in museums and the scientific disciplines that they supported.

We opened this discussion with the rise of the Ashmolean Museum from a Cabinet of Curiosity, created for the pleasure of its collector and used as a form of public entertainment, to an organized museum at the end of the 17th century. We conclude this section with the Library of Congress as an example of how far the epistemic infrastructure had evolved by the beginning of the 19th century. The copyright provision in the U.S. Constitution already reflected the progressive goals of the new republic. Unlike earlier copyright laws, which were intended either as a means to censor unorthodox ideas or to protect the intellectual property of authors, the copyright provisions in the U.S. Constitution had the intention of promoting "the progress of science and the useful arts." In 1802, President John Adams approved an appropriation of $5,000 to purchase "such books as may be necessary for the use of Congress." The first books arrived from London in 1801 and were stored in the U.S. Capitol. After the Capitol burned during the War of 1812, Thomas Jefferson reestablished the Library by selling his own personal collection of 6,487 volumes to Congress in 1815. When Jefferson sold his multifaceted, multilingual collection to Congress, he felt the need to defend its diversity by stating that there was "no subject to which a Member of Congress might not have occasion to refer."[24] The establishment and rebuilding of the Library of Congress illustrates a number of aspects of the development of epistemic infrastructure. By the early 19th century, Enlightenment thinkers, founding a new nation on the periphery, considered a national library essential for informed governance and for the "progress of science and the useful arts." Jefferson's private library, which reflected his own broad and cosmopolitan interests, became the core of a national resource. Science and the useful arts would serve as the engine for economic development, long before the concept of a "knowledge economy" came into circulation.

Epistemic Infrastructure in the Industrial Era: Adaptability of Purpose

Francis Bacon foretold the rise of epistemic infrastructure in 1594. In his *Gesta Grayorum,* he said that knowledge was acquired through libraries, botanical gardens, zoos, aquaria, museums, and laboratories.[25] Two centuries later, the world was reaping the rewards of that infrastructure. Daniel Webster captured this in a speech given on June 17, 1825 at the groundbreaking for the Bunker Hill monument in Massachusetts, in which he said that "a vast commerce of ideas" had emerged wherein knowledge had "triumphed over distance, over differences of language, over diversity of habits, over prejudice, and

over bigotry."[26] Webster saw that the pursuit of knowledge had grown from a pastime for curious individuals, into a great dynamo of social and economic advancement. By the time of Webster's speech, the steam engine had been applied to ship and rail transport, mechanistic agriculture had begun with the cotton gin, vaccination against smallpox was underway, and manufactured methane was being used to light cities. Within fifty years of the speech, Henry Bessemer revolutionized the making of steel, the railroad industry invented operations management, the telegraph was in regular use, Pasteur pioneered profound changes in human health, and warfare reached new levels of carnage through new weaponry such as the machine gun. The changes went far beyond economic progress. By 1835 the British monarchy had weakened in favor of Parliament, the American and French revolutions had transpired, and modern democratic institutions had been established. By 1875, most industrial nations had abolished slavery, instituted compulsory primary and secondary education, and were beginning major expansions in higher education.

The 19th century saw the creation of nearly all of the world's great museums, the rise of the great state libraries, the establishment of many academic libraries, and the beginning of public library systems. Industrialization, urbanization, and mass literacy created further pressures to transform private collections of information and artifacts into public goods. During the latter half of the 19th century, private benefactors founded and provided resources for countless museums, galleries, historical societies, and libraries so that a broader public could appreciate and learn from collections of treasures that had accumulated over the centuries.[27] These institutions aided the social mission of universal education in consort with mandatory education and the establishment of countless public and private colleges and universities. Public libraries provided citizens with information and tools to make informed decisions, and taught immigrants and new urban residents how to make intelligent use of their leisure time.[28] Museums and archives contributed to nation building by assembling documents and artifacts that provided a basis for a shared sense of the past and a common national and cultural identity.

During this expansion, librarians, bibliographers, archivists, and curators developed highly refined practices of organization and classification for texts, objects, living plants and creatures, and cultural artifacts to serve the specific needs of increasingly specialized collections tuned to particular audiences. One vital innovation in modern epistemic infrastructure was the creation of systematic methods of cataloging that could scale to the industrial production of books, magazines, newspapers and other mass-produced texts. This required cataloging and classification schemes that were built on explicit principles and rules so that efforts to create bibliographic information for one work could be shared and reused by other libraries that also owned a copy of the same work. Sir Anthony Panizzi, a librarian at the British Museum, first developed 91 rules for cataloging in 1832. Melvil Dewey introduced the more precise Dewey Decimal System in 1876, which classified knowledge into 10 categories, each of which could be sub-divided decimally in sub-categories, sub-sub-categories, etc. A key breakthrough came near the end of the 19th century, when Charles Cutter built on Dewey's concepts to create a highly logical and scholarly system. Inspired by Dewey's work, Cutter began work on his own classification system in the 1880s while serving as Librarian of the Boston Athenaeum.

Although Cutter's classification scheme was not adopted as widely as the Dewey system, he introduced basic principles for library cataloging that inform most bibliographic classification systems today. Cutter believed that if a patron knew the author, title, or subject of a desired work, he or she ought to be able to locate that item in the library catalog. Cutter also proposed an expansive system of classification, with seven levels ranging in specificity from one level for the smallest libraries to the all seven levels for the largest libraries.[29] Dewey was also concerned with the standardization and efficiency of library operations. He established the Library Bureau in 1876 "for the definite purpose of furnishing libraries with equipment and supplies of unvarying correctness and reliability."[30] When he founded the first American "library school" at Columbia University it was named the School of Library Economy.

In the early 20th century, when the Library of Congress started organizing its one million volumes for public use, librarians adapted Cutter's scheme, known today as the LC classification scheme. This created a platform for the development of uniform standards for cataloging, classification, and eventually inter-library lending of materials. In 1902, the Library initiated a card distribution service that made it possible for other libraries to purchase pre-printed library cards for their catalogs, rather cataloging their collection according to idiosyncratic and institution-specific practices. The extension of the Library's classification and cataloging schemes to the rest of the nation led to a uniformity of cataloging across libraries subscribing to the service; but more significantly the standard classification system provided a common "user interface" to print publications through the card catalog. This epistemic infrastructure became further refined during the mid-twentieth century when the Library of Congress and national libraries elsewhere developed standard classification schemes and cataloging rules for subjects, names, titles, and an expanding variety of new media types.

The selection and organization in museums, libraries, and archives of specific types of collections for particular audiences, conveyed to the public where to go to seek types of information and objects of interest. Careful selection of the best exemplars or most appropriate materials put marks of authenticity, legitimacy, and authority on collections. The naturalist seeking physical specimens, the historian searching for documents, or the private citizen looking for uplifting fiction could trust the epistemic infrastructure to provide the best evidence, the highest quality sources, or the most useful reading material. This infrastructure was a source of continuity, with a focus on the perpetual care of knowledge even when knowledge-bearing objects had become obsolete, outdated, or irrelevant. The preservation function reinforced a conservative ethos in the institutions of the infrastructure that forced them to balance continuity with change. Institutions often became reluctant to change their practices for selection, access, and exhibition, and tended to resist pressure to discard or limit access to information deemed subversive, dangerous, or politically unpopular.

This pull toward conservatism in collection development and practice intersected with a variety of social, cultural, and economic pressures in the late 20th century to put epistemic infrastructure under stress. Established institutions found audiences dwindling for exhibits that were viewed as elitist, and user communities began shrinking in relationship

to collections viewed as conservative, nationalistic, and bourgeois. In response, starting in the late 1960s, many museums redefined their role and image from that of a temple containing clearly interpreted objects and toward an interactive forum for learning and open-ended interpretation.[31] Public libraries built new facilities in rapidly growing suburban areas, actively targeted young readers, and expanded services such as outreach programs and organized events that helped to integrate libraries into neighborhoods and communities.[32] In response to a growing interest in social history, local history, and genealogy, many archives reassessed their collecting policies and aggressively sought materials on women, ethnic and linguistic minorities, popular culture, and social movements.

In recent years, core elements of the epistemic infrastructure have faced both declining public subsidies and rising costs. Some institutions have responded primarily with internal structural changes that rationalize collecting, make internal processes more efficient, and take advantage of networks for sharing little used materials. Research libraries, for example, under the pressure of rising acquisition costs for books and scholarly journals, have reduced acquisitions and begun to develop networks for sharing expensive, but little used, items.[33] At the same time that networks for cooperation and sharing have evolved, cultural institutions have been forced to compete with eachother for limited funding from private foundations and public agencies in an economy that is increasingly hostile to the concept of public goods. Museums, galleries, zoos, aquaria, and other institutions of display have adopted market-oriented strategies such as charging admission, introducing museums shops and cafeterias as profit centers, and seeking corporate sponsorship for capital campaigns and high-profile exhibits. Ironically, museums that emerged from the *Wunderkammern* tradition of entertainment and display have once again begun to place great emphasis on exhibition and outreach. This has increased tension over the professional authority and autonomy of curators and librarians to control the content and presentation of their collections. Responding to the demand-based and pay-as-you-go economic model raises the specter of curators forced to produce exhibitions or librarians required to build collections that are popular and trendy rather than critical and thought provoking.

These shifts have spurred intense debate over what constitutes transparency in the epistemic infrastructure, and who has the right to question the legitimacy of the contents, organization, display, and interpretation of knowledge and cultural heritage. The very act of selecting what will be displayed, and how those displays will be presented, has become increasingly politically charged. This is seen with clarity in recent efforts by fundamentalist religious groups to prohibit science museums from displaying materials that contradict their notions of creation, and by parents who wish to ban from school libraries books they do not agree, but the issue is broader. Should holocaust museums focus only on the Nazi extermination of Jews, even though the Nazis also targeted the Romany, the mentally ill, homosexuals, socialists and communists for extermination? Should local taxpayers insist that public libraries install filters to block pornography from young people when those same filters also erroneously block legitimate medical information?[34] Sometimes everyone agrees on the appropriateness of having a given exhibition, but disagree over the way the exhibition is framed. In the mid-1990's, the

Smithsonian Institution's National Air and Space Museum planned an exhibit of the newly-restored *Enola Gay*, the B-29 airplane that dropped the atomic bomb on Hiroshima, along with an exploration of the larger context of using nuclear weapons at the end of World War II. Curators were soon caught in a crossfire between those who wished to focus on the decision to use nuclear weapons and those who wished to focus on the heroism of the bomber crew. Tom Crouch, curator of the exhibit, remarked, "Do you want to do an exhibit intended to make veterans feel good, or do you want an exhibition that will lead our visitors to think about the consequences of the atomic bombing of Japan? Frankly, I don't think we can do both." Crouch was proved right: the museum could not do both, and the exhibit was constructed to make veterans feel good.[35]

Constructing narratives remains a perplexing challenge for epistemic infrastructure. A narrative is the means by which materials are used to create a story for the visitor that cannot emerge simply from the presence of the materials themselves. Going back to the skeleton of *Iguanadon*, that narrative was nothing more than the display itself in light of growing tension between strictly biblical accounts of creation and new interpretations of the geological record in early 19th century science. The presentation of the *Iguanadon* skeleton was itself a challenge: "Explain *this*." If *Iguanadon* was destroyed in Noah's flood, what else failed to make it onto the Ark? The concreteness of the fossils threw the accepted narrative of the time into confusion, and laid the groundwork for the controversy that surrounded Darwin's theory of evolution in 1859. Museums still face that controversy 150 years later. The Enola Gay exhibition tried and failed to create a master narrative for multiple audiences, enlightening all and offending none. No one disagreed about the facts of the Enola Gay, the war, the bombing, and the aftermath. The argument was about what it all *means*. Epistemic infrastructure is increasingly pushed past the problem of knowledge and into the realm of political discourse, from the question of how things are to the question of how things ought to be.[36]

Epistemic Infrastructure in the Knowledge Economy

Epistemic infrastructure is facing a period of deep uncertainty at the dawn of 21st century. Economic pressures, competition from alternative service providers, changing expectations from consumers and users, and a fundamental shift in their material base from tangible objects to digital representations are part of this uncertainty. There is evidence to suggest that significant shifts in the organization and economics of epistemic infrastructure are underway. One instance is the development of commercial alternatives to the services that traditional components of the epistemic infrastructure provide. The online bookseller, Amazon.com, has an extensive online database, not unlike a library catalog, listing several million book titles, 250,000 CD titles, and data about 250,000 motion pictures and entertainment programs from 1891 to the present. Amazon's "collection" probably compares well with major research libraries in the number of titles available, and it is likely that more people search the Amazon databases on any given day than search the catalogs of any single research library, and possibly all research libraries combined. Moreover, Amazon competes with other online booksellers by adding services that mimic some of the selection and legitimating functions that libraries

traditionally perform, such as alerts and recommendations based on user profiles and past purchases, and opportunities for consumers to post and read book reviews.

Another instance is illustrated by new enterprises that take advantage of potential complementarities between investments in public goods and commercial interests. Google Print is a case in point. The search engine company is working with several major libraries to digitize their print collections and make them available online to the extent possible under the current intellectual property regime.[37] At no cost to the libraries, Google will invest millions of dollars in exchange for a digital version of their print content, which the company will use to draw more consumers to its site. Google clearly has a commercial stake in the project, but also claims that its aim is to "help maintain the preeminence of books and libraries in our increasingly Internet-centric culture by making these information resources an integral part of the online experience. We hope to guide more users to their local libraries; to digital archives of some of the world's greatest research institutions; and to out-of-print books."[38] Google Print will point users to libraries in their vicinity that own the titles they are seeking and direct them to booksellers of new, used, and out of print books.[39] Echoing the 18th century rise of national libraries that re-enforced notions of national, cultural, and linguistic identity, the announcement of Google Print set off a firestorm of controversy in France and several other European countries about diversity and bias in the Google Print collection.[40]

There also are moves in the direction of making formerly private goods into public goods. The Open Source software movement has created an alternative to proprietary commercial products for developing and licensing software. Librarians have been working since the 1980s to develop and implement new models for scholarly publication and access to scholarly communications. By 2004 there were more than 700 open-access journals available in a wide variety of disciplines.[41] Some government funding agencies are starting to require the authors of government-funded research to publish in open access journals so that the public at large can benefit from the results of public investments.[42] "Knowledge conservancies," such as the Creative Commons, are being established for owners of intellectual property to place their works voluntarily in the public domain in order to contribute to the larger social good. Finally, advocates for the next generation of research and learning environments are urging massive public investments in "cyber-infrastructure" that includes not only building bigger networks and faster computers, but also developing the missing elements of the epistemic infrastructure in the form of digital repositories, powerful ontologies, and skilled persons, to ensure persistence and coherence of the new digital collections.[43]

For most of the last two centuries, traditional epistemic infrastructure has operated as a public good in which a patronage structure of universities, governments, and non-profit philanthropies provided funds, and the institutions of libraries, archives, museums, galleries, botanical gardens and so on carried out their missions as best they could. This arrangement never required robust means for judging the economic value of the infrastructure. Crude input/output models considered materials (papers, books, objects) inputs and the number of patrons served or the number of reference questions answered outputs. There was no cost accounting to show how invisible functions like selection,

organization, curation, and so on contributed to the services delivered, or more importantly, to the effect of those services in the economy.[44] In a period of both skepticism about the need for public goods and a reorganization of the provision of epistemic infrastructure, these models put traditional institutions at a disadvantage because they provide no way to determine the value of the actual work being done. The contributions of both individuals and institutions that have built and who maintain epistemic infrastructure are both invisible and taken for granted. They are not included in the balance sheet, and it is impossible to determine how any particular input leads to any changes in a user's welfare. As long as the infrastructure was seen as an important public good to be funded at the appropriate level, this was fine, but new models of knowledge generation, dissemination, and exploitation call into question the value of the traditional infrastructure that has no useful measures of costs and benefits to fall back on.

We are not arguing that the epistemic infrastructure of the industrial age could or should be mapped to the present environment. In fact, we contend that the established epistemic infrastructure and the institutions in which it is embedded have survived for millennia by finding the right balance between conservatism and innovation, and by adapting to fundamental shifts in the production of knowledge. Those who care for the traditional infrastructure must decide whether and how to shape the next transformation, while recognizing and convincing others that the market is not likely to provide all of the services required. Indeed, the new commercial enterprises, like Amazon and Google Print, are deeply dependent on the products of traditional infrastructure. Amazon does not catalog the books, magazines, and CDs it sells. It uses the cataloging-in-publication infrastructure, which originated at the Library of Congress, in which quality control over cataloging and classification is managed by national libraries or by consortia like OCLC, the Online Computer Library Center. Nor does Amazon maintain a warehouse of out-of-print or obsolete materials in anticipation of some potential demand long in the future; those services are provided by national and research libraries. The International Standard Book Number (ISBN) convention, arising from the traditional infrastructure, provides all booksellers with a powerful inventory control mechanism. Likewise, Google Print does not acquire simple bags of bits on which to unleash its powerful search engines when it scans the collections of research libraries. It also inherits the accumulated wisdom of generations of selectors who were knowledgeable about the needs of scholars and students in specific disciplines and well versed in the criteria for judging the quality of works. Web-enabled market forces and the traditional epistemic infrastructure are not inherently in competition with one another. In fact, they are complementary. The challenge is to find ways to exploit that complementarity that will also strengthen the knowledge economy. Four areas of complementary are worth noting: access, information quality and integration, social memory, and information property.

Access

The traditional epistemic infrastructure, together with the Web, can dramatically improve effective access to information for all strata of the population. Improvements in Information and Communications Technologies (ICTs) make it increasingly possible for people to participate in online discussions; seek information on healthcare, employment

opportunities or government benefits; use e-mail to communicate with friends and family, or post their own content on the web. However, the technology alone is only part of a broader challenge that includes development of skills required to exploit the technology.[45] The traditional epistemic infrastructure has long provided free access to materials that individuals cannot afford to purchase or that individual scholars could not collect with their own resources.

Another complementarity is the co-location of physical collections and the information necessary to learn from them. The Web can make images of and textual information about objects in a museum's collections available to remote users, and it can allow users of library, archival, and other collections to explore countless possibilities before traveling to consult particular resources. Preliminary reviews of online collections and commentary can dramatically narrow the search space and provide structure to the study when the individual can go to a culture institution in person. Provision of online information at varying levels of depth helps users gain knowledge tailored to their needs. The entire holdings of information on each object can be made available to the user at will, providing unparalleled access to collections for users on-site or anywhere.

Information Quality Assurance

The Web can permit easy access to information, but it is inadequate for teaching and research where definitive and high-quality information resources are instrumental for critical analysis, innovation, and new knowledge generation. Search engines index mainly the "surface" Web of unrestricted and static web pages. The "deep" Web remains unseen by most users, even though it contains as much as 500 times the information of the surface web and is growing faster.[46] Deep web resources, like the curated collections in traditional institutions, also tend to be selected, indexed, and controlled for quality and authoritativeness by subject experts or editors. It is possible to put traditional epistemic infrastructure services on the Web, tied to large traditional collections, and managed by experts who know the collections intimately but doing so is not cost-free. One example is the Internet Public Library (http://www.ipl.org), which began in 1996 as a student experiment to create an online service providing features of a public library, and has grown dramatically. The IPL is used heavily by students in elementary and secondary school for assistance with their schoolwork, not only by providing online access tp content selected for this audience, but also through a global network of librarians and student volunteers who respond meaningfully to the kinds of reference questions that commercial sites like "Ask Jeeves" could not begin to answer. One key to services that integrate traditional epistemic infrastructure and the Web is information quality: content authenticated by experts who know both the subject matter and the patterns of user demand.

Social Memory

A critical aspect of social memory is long-term preservation of vital knowledge, which requires both the mechanisms for preservation and the sophistication to know what to

delete over time. Libraries, archives, and museums maintain collections over centuries, and are the most important form of institutionalized long-term social memory. Even in the print world, the idea of "comprehensive collection" has largely disappeared: no library on Earth collects everything that is published, and it is virtually impossible to ascertain the fraction of total global titles held in all the libraries taken together. Large amounts of material disappear forever each year, even as librarians, archivists, and curators presume that other institutions are preserving those items. Contemporary social memory is created through the integration of widely distributed objects and collections using skills in organization and classification, as well as understanding of the epistemic regimes that those systems of knowledge organization impose on the worlds they describe. Even in the world of physical evidence, there is no way to tell whether the material being lost is of long term value. The situation is far worse on the Web, where loss of information is massive, routine, and undetectable. There are no established institutions to collect and preserve digital objects that are generated without consideration beyond first-order uses. Digital objects cannot be collected and organized the way physical books, documents and objects have been for the past centuries, and it is not clear whether anyone is going to keep them at all. Libraries are reluctant to rely on publishers for archiving services because publishers have never been in the archiving business. Besides, they come and go. The University of Michigan Library, one of the participants in the Google Print project, will retain the physical copies of everything that Google digitizes and acquire a complete copy of the digital corpus. This decision acknowledges that Google has no commercial interest in long-term preservation. It further recognizes that the University of Michigan Library had been in existence for almost two centuries, while Goggle has been around less than a decade. With few tools to capture and preserve Web documents that are critical sources of information and important cultural artifacts, long-term preservation and social memory are endangered. This is one more area where the services of traditional epistemic infrastructure must not be taken for granted.

Information Property

Information property management is one of the most challenging but important areas of complementarity between the traditional epistemic infrastructure and the Web. Copyright, designed originally to provide authors with an inducement for creativity and generation of new knowledge, has expanded in scope and duration and limited the public's alternatives to purchasing or leasing access to the increasing amount of content protect by copyright.[47] The digital realm challenges this evolving tradition of copyright by making possible wholesale downloading, digital copying, and manipulation of digital objects to make exact replicas and create derivative works. Content providers are fighting back with encryption and digital rights management regimes that diminish the public domain and undermine the traditional "fair use" exceptions and practices upon which much of the epistemic infrastructure has relied. The neutral platform encouraging free flow of content that once characterized the Internet seems to be eroding, with potentially disastrous effects on high-quality scholarship, academic freedom, collaboration, and creativity. Some argue that restrictions on digital content are becoming counter-productive to innovation and knowledge generation that copyright was supposed to encourage.[48] Others argue that the "propertization" of knowledge is transforming key

knowledge communities, such as universities, from "gift" economies to "market" economies, upsetting the basic model of academic operation of the past several hundred years.[49] While the propertization of knowledge might produce new knowledge communities that rival universities in content and quality, this is by no means certain and the potential for loss if the bargain goes bad is enormous. Alternative strategies for producing, evaluating, and distributing intellectual property on the Web are evolving, such as open source software, online pre-print services, open access journals, and community knowledge projects such as Wikipedia (http://www.wikipedia.org). It remains to be seen whether these efforts will merely change the current parameters of information property, or whether they will create fundamentally new means for valuing and distributing knowledge, but they are important for developing the complementarity between the Web-based market strategies and the strengths of the traditional epistemic infrastructure.

Conclusion

Two examples of contemporary problems readily illustrate society's dependence on epistemic infrastructure. One is the prospect of global climate change. The empirical basis for distinguishing variations in climate is deeply tied into long-standing epistemic infrastructure. No one deliberately collected data and specimens over the past centuries in anticipation of global climate change, but such data were nonetheless collected and conserved in libraries, archives, museums, zoos, and botanical gardens simply because they might be useful at some point.[50] Bones, shells, fossils, and ice cores are now being calibrated with maps, ship's logs, weather station reports, crop data, observations of bird migrations, and even personal diaries to develop a more complete picture of climate conditions over time. Without these seemingly mundane sources of information, there would be no factual basis to determine whether climate change was even occurring, much less to decide what to do about it.

The other example involves the mapping of the human genome, which could lead to victory over myriad diseases. To use the genome data, it is necessary to distinguish strictly inherited diseases from those that have a genetic base but that must be triggered through environmental causes or diet, exercise, and other habits. The mapping of the genome created a whole new regime of intellectual property, including the astonishing case of a private firm patenting the entire genome of Iceland.[51] The Icelandic genome is particularly valuable because of the isolation and relative stability of the population and because Iceland has deep epistemic infrastructure that makes the genome information useful. Icelanders have long kept family genealogies that can be used along with detailed medical records from the public health system to analyze the role of genetics in a wide range of diseases. The technical and scientific aspects of human genome mapping are justifiably seen as great accomplishments, and they are themselves part of the evolving epistemic infrastructure. Nevertheless, they are of relatively little practical value without the complementary utility of many other aspects of epistemic infrastructure that are typically overlooked.

Epistemic infrastructure grew up around selection processes evolved by curators, librarians and archivists to filter knowledge according to professional norms and standards, subject and domain knowledge, and attentiveness to the needs of user communities. This kind of systematic collecting builds trust in knowledge resources. A knowledge economy built on digital information will likewise depend on clear indicators of quality, authoritativeness, and authenticity. The lessons from the building of epistemic infrastructure in the nineteenth and early twentieth centuries are powerful guides in this evolution. The knowledge economy will undoubtedly need new tools as it grows, but it already has a great deal of capacity and capability in the traditions of museums, archives and libraries. Handled carefully, this traditional epistemic infrastructure will simultaneously build the value of knowledge in the society, and decrease disparities between "information haves" and "information have-nots" with respect to ability to acquire, evaluate, manipulate, and generate information. This infrastructure is modern society's most vibrant and effective resource for dealing with extraordinarily challenging and conflicting demands. Those working at the forefront of the knowledge economy should recognize and strengthen it.

NOTES

[1] The Center for Educational Research and Innovation (CERI) of the Organization for Economic Cooperation and Development (OECD) sponsored this work as part of the project, "Innovation in the Knowledge Economy: Implications for Education and Learning" (OECD, 2004, ISBN 9264105603). An earlier version was published on-line by OECD (www.oecd.org/edu/km/mappinginnovation). The authors gratefully acknowledge the assistance of Dominque Foray, Paul David, Michael Cohen, Paul Edwards, Bob Frost and Brian Kahin.

[3] Karin Knorr Cetina, *Epistemic Cultures: How the Sciences Make Knowledge.* Cambridge, Mass.: Harvard University Press, 1999. Our notion of epistemic infrastructure is related to the concept of epistemic cultures, but we use epistemic infrastructure on a macro-level to discuss similarities and patterns across numerous environments and vast times spans.

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[5] See Peter Burke, *A Social History of Knowledge, Cambridge: Polity Press, 2000, pp. 103-106.*

[6] See MacGregor, Arthur. *Ark to Ashmolean: The Story of the Tradescants, Ashmole, and the Ashmolean Museum.* Oxford: The Ashmolean Museum and the Tradescant Trust, 1997. MacGregor, Arthur. *The Ashmolean Museum: A Brief History of the Museum and its Collections.* London: Jonathan Horne Publications, 2001. Josten, C.H. *Elias Ashmole, FRS.* Oxford: Ashmolean Museum, 2000. Of special value is Leith-Ross, Prudence. *The John Tradescants: Gardeners to the Rose and Lily Queen.* London: Peter Owen, 1984.

[7] Patrick Mauries, *Cabinets of Curiosities, London: Thames & Hudson, 2002, pp. 141-45.*

[8] See essays contained in Impey, Oliver and MacGregor, Arthur (Eds.). *The Origins of Museums: The Cabinet of Curiousities in Sixteenth- and Seventeenth- Century Europe.* Oxford: Clarendon Press, 1985.

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[10] Burke, Chapter 3, pp. 32-52.

[11] Lugli, Adalgisa. " Inquiry as Collection: The Athanasius Kircher Museum in Rome." *RES* 12 (Autumn, 1986): 109-124. This idea finds further expression in Daston, Lorraine. "Curiosity in Modern Science." *Word and Image,* 11:4, 1995. Daston, Lorraine. "Marvelous Facts and Miraculous Evidence in Early Modern Europe." *Critical Inquiry,* 19:93-124, 1991. Daston, Lorraine and Park, K. *Wonders and the Order of Nature.* New York: Zone Books, 1998. Weschler, Lawrence. *Mr. Wilson's Cabinet of Wonder: Pronged Ants, Horned Humans, Mice on Toast, and Other Marvels of Jurassic Technology.* New York: Pantheon, 1995.

[12] No Cabinets of Curiosities have survived intact. What we know about their contents, organization, and aesthetics must be extracted from paintings and woodcuts that often served as frontispieces to their catalogs. See, Mauries.

[13] See Burke, Chapter 4, pp. 53-80.

[14] Burke, pp. 79-80.

[15]Elizabeth Eisenstein, *The Printing Revolution in Early Modern Europe,* Cambridge: Cambridge University Press, 1983; and Jonathan M. Bloom, *Paper Before Print: The History and Impact of Paper in the Islamic World: New Haven, Yale University Press, 2001*.

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