

# Science Publishing and Science Libraries in the Internet Age<sup>1</sup>

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I want a poor student to have the same means of indulging his learned curiosity, of following his rational pursuits, of consulting the same authorities, of fathoming the most intricate inquiry as the richest man in the kingdom.

—Antonio Panizzi, the first librarian  
of the British Museum, 1836

THE INTERNET and the desktop computer have transformed the way science is practiced in virtually all fields, and the biomedical sciences have not been exempt. Today most scientists obtain, use, and produce information in ways that would have been unrecognizable twenty or thirty years ago. These changes have profoundly and most contentiously affected an aspect of science that is at the core of any scientist's life: the ways that we publish, disseminate, read, store, and retrieve research papers.

I will describe two of the most prominent features of this still evolving landscape—public digital libraries and “open access” publishing—both of which depend on an extraordinary feature of the digital world: one copy of a text can suffice to provide it electronically, instantaneously, and without further costs to anyone at any time and in any place. It will become clear that I have been an enthusiastic proponent of both the new libraries and the new publishing methods for nearly a

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<sup>1</sup>This paper, which was published under the same title as chapter 15 of the author's book *The Art and Politics of Science* (New York: W. W. Norton & Company, Inc., 2009), appears here with the kind permission of the author and the publisher. The material it contains has much in common with the author's Henry LaBarre Jayne Lecture, read on 25 April during the 2007 Spring General Meeting.

decade. As a result, this account will reflect my personal experiences and my passions for the subjects.

Public digital libraries of science are compendia of research articles, journals, and books; they constitute “databases” of published work that can be rapidly searched by anyone with an Internet connection. Unlike traditional public libraries, composed of paper copies of books and journals, their potential reach is infinite and thus threatening to publishers who depend on book sales and subscriptions. Because of this financial threat, we are still, despite recent progress, quite far from assembling open digital libraries that fulfill their potential as storehouses of knowledge.

The open access publishing movement seeks an even more radical change in the way scientific information is distributed. The goal is to deliver articles to all, immediately and freely, from an open access journal’s Web site and from a public digital library. By making scientific information widely and swiftly available, open access publishers intend to be more useful than traditional publishers, who base their business on barriers to access, financing their journals with subscriptions for paper copies and for permission to view digital versions. Open access publishing, like subscription-based publishing, has real costs that must be paid—for reviewing, editing, producing, and formatting its journals. Because it abjures subscription barriers to access, open access publishing has adopted an alternative financial model. The costs are paid by the authors or, much more commonly, by the agencies that support the research.<sup>2</sup>

Viewed together, public digital libraries and open access publishing promise great benefits for science and society: equity, through universal and unfettered delivery of knowledge, mostly a product of public funding; more effective practice of science; and reduction in overall costs.

Everyone agrees that information technology is already fully capable of performing the tasks necessary to build extensive digital libraries of the existing biomedical literature and to convert publication practices to an open access mode. But, as will become apparent, significant obstacles have slowed the development of these means for enhancing the use of scientific texts. Traditional publishers have been concerned that digital libraries and a change in business models could entail a significant loss of revenues from subscriptions—reducing the profits for commercial publishers, whose margins now often exceed 30 percent, and

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<sup>2</sup>The formal definition and characteristics of open access publishing were agreed to at a meeting of the interested parties at the headquarters of the Howard Hughes Medical Institute, in Bethesda, Maryland, in the spring of 2003. Bethesda statement on open-access publishing, 20 June 2003, <http://www.earlham.edu/~peters/fos/bethesda.htm>.

affecting the ability of some scientific societies that publish journals to sponsor other worthwhile activities and meet staff payrolls. Many laboratory scientists have also resisted the new developments because of loyalties to existing journals, fears of disturbing a cultural environment that has supported their career growth, or misapprehensions about how open access publishing would work.

#### BECOMING AN ADVOCATE FOR NEW PRACTICES

Early in 1999, my final year as NIH director, I became a radical exponent of new methods for creating and using the scientific literature. Before my conversion, I was, like most of my colleagues, relatively unconcerned with the practices of scientific journals and the evolution of libraries of science. I hadn't thought much about how journals distributed the work they published, how they were paid or how much profit they made, or who owned the articles after publication. Like everyone in my field, I was gratified by the improvements that had occurred in ways to search the scientific literature. In particular, I learned to love PubMed, the Web site made freely available to everyone in the world by the National Library of Medicine at the NIH.<sup>3</sup>

PubMed is not a true library: it doesn't contain full texts. But it provides a very important library tool, a digital card catalog, that allows any user to seek lists of authors and titles, with abstracts for most of the entries, from most of the very extensive biomedical research literature. These lists are therefore remarkably convenient guides to published scientific or medical work, explaining why millions of people—and not just scientists and physicians—use PubMed every day. In addition, those who are privileged to work at institutions that have paid for subscriptions to the journals in which desired articles appeared can be linked to those journals through their institutional libraries and print out the full texts, if they exist in a digital form.<sup>4</sup>

Before my eyes were opened to the potential for much wider electronic access to the scientific literature, I hadn't given much thought to how poorly the existing system served those who were not affiliated with major centers of learning and so could not get access to the full text of papers listed in PubMed. And I hadn't considered whether the computational advances that helped to create PubMed could be used to make

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<sup>3</sup> <http://www.ncbi.nlm.nih.gov/sites/entrez?cmd=search&db=pubmed>.

<sup>4</sup> Only a few journals have digitized articles published before 1990; increasingly, these must be sought in library archives since most institutional libraries have dramatically reduced the space they can assign to printed journals. Because most scientists now rarely bother with print versions, a large portion of our scientific legacy is consulted with decreasing frequency.

yet more dramatic changes, so that systems for publishing, storing, and distributing scientific reports could be made more effective and more equitable.

I did, of course, recognize the enormous significance that journals have in the lives of all scientists. From my perspective as a laboratory scientist, I knew which journals were likely to publish papers I cared about—those with high academic standards, a strong reputation, and a focus on my special interests, such as virology, cancer genetics, or the biology of cancer cells. Those journals were, not surprisingly, the ones to which I turned weekly or monthly for new information, and the ones in which I usually aspired to have my own work appear. But I gave little thought to the fundamental principles on which the industry was based or to its operations.

This attitude was not simply self-serving. My colleagues and I had good reasons to respect our favorite journals for both the quality of the work they published and the rigor and aesthetics of the editing process. But our loyalty to these journals also had a self-serving aspect, one that discouraged us from thinking about how methods for publishing and distributing new papers might be improved. Gratitude to these journals for accepting our articles for publication, hopes for future acceptances, and a traditional notion of good citizenship in the scientific community made us willing to oblige the journals in various ways. For instance, like most of my colleagues, I turned the copyrights on my accepted papers over to the publishers without pause or complaint, and I freely donated my services and time to review and edit the work of other authors. I viewed these activities, which often took several hours or more each week, as dues to the scientific community—efforts that were also inherently interesting or occasions for tutoring trainees about critical readings of new work. I don't think it ever occurred to me that I was also providing free labor to journals that were often making large earnings for stockholders (in the for-profit sector) or for scientific societies (in the nonprofit sector).

Occasionally, I lamented long delays in publication, high charges for color photographs or reprints, or high subscription fees (although many of those fees were paid by grants or institutional libraries). But I didn't develop a coherent point of view about how scientists publish their work and about how our institutions store and distribute published reports until the end of 1998, when a colleague at Stanford, Pat Brown, pushed me to think about some important questions: Was the scientific community taking adequate advantage of the Internet and new computational tools to improve publication practices and use of the literature? Could electronic public libraries provide much more than the titles and abstracts stored in the PubMed catalog—for instance, full

texts of published reports? If information from DNA sequencing efforts, such as the Human Genome Project, was made freely and fully available on the Internet, couldn't we do the same for the scientific literature?

Following Pat Brown's lead, I soon learned about new publishing practices and about the prospects for building public digital libraries. While still serving as NIH director, I became a strong advocate for these new methods and helped to launch the first public digital library for the biomedical sciences, PubMed Central. Since then, I have become almost obsessive about the goals of expanding such libraries and creating open access journals. Now, more than eight years later, I continue to devote a significant portion of each week to advocacy for library and publishing practices that would make the world's scientific literature a more potent and accessible resource. In particular, I remain deeply engaged in the oversight of an organization called Public Library of Science (PLOS), a thriving open access publishing group that three of us founded more than seven years ago.<sup>5</sup>

I will describe how my conversion occurred, why the battles over publication practices have been virulent, and what PLOS is trying to achieve. But first I need to explain why this issue is so important to scientists and why it should matter to others as well.

#### HOW SCIENTISTS ARE AFFECTED BY PUBLICATION PRACTICES

Just as appropriated dollars are the "lifeblood" of a federal agency, so is publication the lifeblood in the career of a working scientist. Publication is the means by which an investigator tells his or her colleagues, the world in general, and posterity about what he or she has found in the course of doing experiments and how those findings might be interpreted in the light of preexisting knowledge. Through publication, an individual's (or, more commonly, a group's) experimental work and thought become part of the fabric of science, something to be talked about, contested, admired, built upon, criticized, or even neglected (but with the potential for rediscovery at a more opportune moment).

The written record is also crucial to the development of a scientist's career in deeply pragmatic terms. It is the most decisive means by which a scientist is evaluated by others at every stage—early in career development, when postdoctoral fellowships and first jobs are sought; in the midst of careers, when decisions are made about promotion and tenure; and later, when an investigator may become a candidate for prizes or for election to academies.

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<sup>5</sup><http://www.plos.org>; P. O. Brown, M. B. Eisen, and H. E. Varmus, "Why PLoS became a publisher," *PLoS Biology* 1, no. 1 (Oct. 2003): e36.

In an ideal world, all scientists would advance their knowledge by carefully reading the work of all other scientists, or at least the work of all those in the same field. That may once have been possible in the biomedical sciences, certainly before the twentieth century and even as recently as the 1960s, when the fields of biology and medicine were still relatively small by today's standards. But our scientific community has gotten very large, and the number of articles published each year in fields like genetics or developmental biology or oncology, let alone biomedical sciences in general, is far too large for any one person to do more than sample the offerings and hope to find what is most important and useful for his or her own work.

Under these circumstances, faced with the need to read selectively, we have all sought ways to improve the odds of reading productively. One time-honored way is browsing—looking through the tables of contents of those journals that we have found from personal experience to be the most likely to contain papers we will value. These scans are intended to ensure that we encounter nearly everything of enormous importance to the broad expanse of biomedical research and most things of significance in our fields of special interest. Browsing is done most commonly by subscribing to perhaps a dozen selected journals—some wide in scope, others the leaders in a specialized field—and by reviewing the titles and authors of papers in every issue, reading relevant abstracts, and finally reading a few papers in full, carefully and critically.

Another way to approach the scientific literature is by searching—using whatever tools are available to survey a much larger set of journals systematically for articles that address particular topics of interest. Twenty or thirty years ago this was done using the *Index Medicus*, a printed tome that listed all papers by topic and authors. People like me would regularly need to travel to our institutional libraries to consult the *Index* when wishing to learn the latest information about an unfamiliar topic or when needing to ensure that we weren't overlooking papers published on a familiar topic in unfamiliar journals. Now, of course, personal computers and digital databases have changed our habits. For at least the past decade, searching for articles in the biomedical research literature has been performed with much greater ease and thoroughness, by using (especially) PubMed, the NIH's online archive of titles, authors, and abstracts.

#### PUBMED: VIRTUES AND LIMITATIONS

The PubMed database compiles the titles, authors, and abstracts from all articles published in legitimate biomedical research journals over

the past several decades, and it is used by millions of people, not just scientists, every day. (The others include students, teachers, journalists, observers of the biotech and pharmaceutical industries, science policy analysts, and patients, their families, and disease advocacy groups.) The method of use is simple: enter a couple of subject words or the name of an author or two, and the search engine will instantly deliver a long list of authors, titles, and journal citations, with an abstract available for most items.

The frustration comes when the user tries to see the entire papers, not just the abstracts. Until the start of 2000, access to the full text was possible only if the user had a personal subscription or worked at an institution that subscribed to the journal that published the article. Then he or she could link to the journal's Web site through the institution's library and view the complete paper. More recently, as I will describe in greater detail below, the situation has begun to improve, with the establishment of the NIH's full-text public digital archive called PubMed Central. Still, for most titles provided to most PubMed users, access to the full text will either be denied or permitted only after a fee is paid to the publisher (generally in the range of twenty to thirty dollars per article).

Not surprisingly, these barriers are irritants to many members of the public—especially to those who realize that much of the research was funded by their tax revenues, that the papers were written and reviewed at no charge by academic scientists, and that the charges and limitations on use are imposed by publishers to whom the authors have innocently relinquished copyright. Scientists at prestigious institutions may also become frustrated (and sympathetic with less well-connected individuals) when they find that they cannot gain access to articles when searching PubMed, at home or while traveling, from a computer terminal that does not belong to an academic institution's network.

#### WHY SCIENTISTS LOVE CERTAIN JOURNALS

Despite the importance and attractions of surveying the entire literature, nearly all of us maintain loyalties and subscriptions to certain journals that have traditionally contained articles of especially high interest and quality, particularly if those journals, such as *Science* and *Nature*, also contain essays, book reviews, political stories and commentary, obituaries, and other features. These allegiances to a few journals among the thousands of others in medical research also reflect established hierarchies of journals, based on the frequencies with which articles from them are cited. These rankings now have a profound and

often invidious influence on the cultures of science and higher education. Publication in the most prominent and oft-cited journals is frequently taken as a goal and a virtue in itself, irrespective of the quality of individual papers. Status conferred by the acceptance of papers in journals like *Science*, *Cell*, and *Nature*, or even in subsidiary journals of these “flagship” periodicals (e.g., *Molecular Cell* or *Nature Biotechnology*) has an indisputable effect on the process of recruitment and promotion of faculty.

Keeping track of the alleged impact of journals, as gauged by the number of times their papers are cited, has itself become a minor industry, sometimes called bibliometrics. The most famous (or infamous) of its indicators, the “impact factor,” is based on the average frequency at which a journal’s papers are cited by all other papers each year. The excessive attention given to this pseudo-science, especially in Europe and other parts of the world, is having a noxious effect on evaluation of scientists for recruitment and promotion. Such indices are not independent of the overall quality of the journal, of course, but they are averages, so they don’t apply to all papers. Furthermore, the numbers are influenced by other factors, including the number of papers published in an area of science. (If there are more papers in one specialized field than another, the number of citations of papers in that field is likely to be higher.)<sup>6</sup>

The tendency to look so favorably on those whose papers have appeared in certain journals—most famously *Nature*, *Science*, and *Cell*—has created an unhealthy compulsion among graduate students and postdoctoral fellows to attempt to publish in such journals, thereby reinforcing the hierarchy. Because of these pressures, other aspects of a journal that might contribute to its appropriateness (review processes and criteria, allowable length of articles, distribution and access policies, editing and presentation of figures) will be largely disregarded when a venue for publication is chosen. This can make it difficult for new journals, even those with more effective or more enlightened policies, including open access publication methods, to break into the upper echelons of the hierarchy.

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<sup>6</sup>The best way to break the dominance of the journal hierarchy and impact factors is for institutional leaders to say that reviews of candidates for appointment and promotion must include critical reading of the candidates’ best papers, not just an arithmetic accounting of the number of papers in “top journals.” At MSKCC we now do this by asking those being proposed for our top faculty ranks to describe the significance of their five best scientific papers over the past several years and by requiring members of the promotion committees to read and evaluate those papers.

## A BRIEF HISTORY OF SCIENCE PUBLISHING

How did things come to be this way? For over three hundred years—at least since the first issues of what was arguably the first real scientific journal, *Philosophical Transactions*, the Proceedings of the Royal Society of London, came rolling off the presses in 1665—the written record of science has been distributed on paper to paying subscribers and stored in private, academic, and public libraries. Compared with a system in which discoveries were usually announced and exhibited at elite gatherings of scholars and then written down in the form of large bound books by individual authors, the creation of the scientific journal as a compendium of relatively short articles, issued several times a year, was a major event that democratized science and fostered the communication of its findings. With the development of a process for reviewing contributions by fellow scientists (“peer review”), some control of quality was introduced. Payments for subscriptions sustained the journals published by scientific societies and eventually yielded profits for commercial publishers, especially as the number of scientists and research institutions grew.

This system worked reasonably well for a few hundred years, as long as the international scientific community was relatively small, the number of journals was few, and the segment of the population who wanted to read about recent discoveries had reasonable access to printed journals. Moreover, there was no obvious alternative. But we are now living in a very different world. Today there are over six thousand periodicals and numerous monographs in the biomedical sciences. Nearly all of them are produced by a few large, for-profit publishing companies, most of them international, or by a few dozen not-for-profit scientific societies and institutions. Science and medicine have assumed central roles in our society, and many people other than scientists and physicians want access to new information. Science is also increasingly a global activity, not just confined to academic institutions and industries in the most developed countries. So the traditional means of distributing information on paper are no longer adequate to the task of efficient distribution to potential readers. But, most important, our society’s approach to the use and dissemination of information has been radically altered by computer science and the Internet, yet the impact of information technology on scientific publishing has only begun to be felt.

## THE BUSINESS OF SCIENCE PUBLISHING

The economics of publishing scientific journals are unusual and differ from practices in other sectors of the publishing industry, in large part

because the authors—scientists who write the articles at no cost to the publishers—seek fame but not money.<sup>7</sup>After writing their manuscripts and revising them in response to critical reviews (which are also normally provided to journals free of charge by other scientists), the author-scientists celebrate an acceptance notice, not by signing a contract for payment, as most professional writers would expect to do, but by transferring the copyright, which they should be entitled to keep, to the publishers. Moreover, quite a few publishers ask authors to defray the cost of publication in the form of “page charges” or payments for reprints or special features, like color photographs. Then the publishers sell the journals to individuals (mostly scientists, many of whom are also frequent authors) and to institutions (the places where the authors work and read), generally with high profit margins, often exceeding 30 percent. Most of these charges—the publication fees and institutional subscriptions in particular—are absorbed by the government and other funding agencies that have underwritten the scientific work. Taken together, this represents a major subsidy, now probably close to one billion dollars annually, of the publishing industry by the NIH—paid either directly through publication costs and subscription expenses charged to individual grants or indirectly through support of library subscriptions at research institutions. From the perspective of funding agencies, such costs are reasonable and necessary. They represent a relatively small fraction, a few percent, of the cost of doing research; and, unless it is published, scientific work remains unknown and hence irrelevant to the growth of knowledge. But it is also in the interests of the funders of research to control costs of publication and to enhance access to all published work.

Because each scientific report has its unique characteristics and unique findings, and because scientists publish the primary description of new findings only once, all scientific journals consist of articles that are not published elsewhere. In this sense, they are inherently monopolies—there can be no competing journal with the same material. Hence if the information is desirable and cannot be obtained elsewhere, the journal can demand high prices from subscribers, especially when those subscribers are academic research institutions that depend on their scientists to procure government grants and feel obliged to satisfy scientists’ demand for the journals, even when they are extremely expensive. (At our own library at MSKCC, for instance, twenty journals that we

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<sup>7</sup>Although scientists are never paid for writing primary research reports, they are sometimes compensated for review articles or brief essays, and usually paid, sometimes handsomely, for writing books, especially textbooks that are widely used in high school or university classrooms.

purchase charge annual subscription fees of more than \$5,000.) When large commercial publishers produce journals of uneven quality and desirability, they sometimes resort to “bundling” journal offerings, especially to institutions, so that the purchase of subscriptions to literally hundreds of indifferent journals, perhaps at a modest cost reduction, may be required to obtain one highly desirable product.<sup>8</sup>

Needless to say, this business can be very profitable for stockholders at large companies like Reed-Elsevier, the European conglomerate that attracts much of the ire of people like me. This company owns literally thousands of journals in the worlds of science, medicine, and engineering, some that are revered (such as *Cell* and its sister journals) and many that provide some service for highly specialized fields but are relatively humdrum and infrequently cited. By combining high institutional subscription rates, bundling strategies, and other business practices, the companies can produce those high profit margins that the investment firm Bear Stearns has characterized as “a stockholder’s dream come true.”<sup>9</sup>

Many scientific societies have also come to depend on journal subscription revenues that exceed the costs of production to support their other good works, such as organizing meetings and helping with scientific careers. Some societies also claim that they attract new members by offering discounted subscription rates on their journals.<sup>10</sup> Most of the societies have been highly resistant to any movements toward greater access, even to the point of battling congressional directives to contribute to public libraries like PubMed Central, and hesitant to experiment with even those changes being contemplated by the private sector, like charging authors for an open access option. These inflexible policies have been largely championed by society staff, who (unlike the annually changing society officers from the scientific community) have long-term appointments, depend on society revenues for their salaries, know the financial plan that has worked historically, and often have an understandable allegiance to traditional features of their journals. Nevertheless, not all societies operate in this way. Some, like the American Society of Cell Biology, do not depend on their journals for income and receive most of their revenue from membership and meeting fees, allowing them to consider publication practices from the perspective of working scientists and the public.

The profits earned by publishers of scientific journals would be less

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<sup>8</sup>In the past few years, academic protests against the use of this practice by Reed-Elsevier and others have sometimes improved the offered contracts, but the practice persists.

<sup>9</sup>Bear Stearns, “European Equity Research Report on Reed Elsevier” (29 Sept. 2003).

<sup>10</sup>Although this perk would disappear if societies converted to open access publishing, the societies could instead offer reduced authors’ fees to members.

objectionable if subscription fees did not severely limit access to those journals throughout the world. Even in the United States and other leading economies, where the scientific work has been performed, largely with public monies, it is not easy to view most of these journals without being a faculty member or trainee at a wealthy academic institution or employed by a large corporation that does scientific work. Outside the advanced countries, it is nearly impossible to obtain access to these journals, except for copies (usually out of date) that have been donated by scientists in rich countries or digital versions that some publishers offer for free to the very poorest countries, which have very few scientists.<sup>11</sup>

An unfortunate secondary consequence of price inflation for scientific journals has recently become evident in the academic sector, where the journals are in greatest demand and where scientists (who bring in most of the grant money) have a disproportionate influence on library decision-making. Already strapped for cash, the libraries must compensate for the expenditures on scientific journals by reducing their purchases of journals and monographs in other fields—fields such as literature, history, and social sciences. As the historian and librarian Robert Darnton pointed out several years ago,<sup>12</sup> the loss of purchasing power at academic libraries affects the viability of university presses that publish scholarly work in the humanities and social sciences.

#### MY CONVERSION: THE MAKING OF A RADICAL

As recently as ten years ago, I was oblivious to the possibilities for transforming the ways in which scientific findings are disseminated. Like other scientists, I aspired to publish my work in what I considered to be the best journals; I subscribed to the journals I favored; and I worked at institutions that subscribed to most of the rest I might use. I applauded the electronic indices such as PubMed. (I was on hand, in my capacity as NIH director, when Vice-President Al Gore unveiled PubMed to the public in 1997.) And I was increasingly aware of the convenient digital forms of papers that some journals were providing to subscribers.

But my views broadened abruptly one morning in December of 1998 when I met Pat Brown for coffee, at the café that was formerly the famed Tassajara Bakery, on the corner of Cole and Parnassus, during a visit to San Francisco. Pat is an unusually brilliant medical scientist at Stanford who had worked with Mike Bishop and me in the

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<sup>11</sup> <http://www.who.int/hinari/about/en>.

<sup>12</sup> R. Darnton, "The new age of the book," *New York Review of Books*, 18 March 1999.

1980s, demonstrating for the first time that retroviruses could correctly integrate their DNA into another molecule of DNA in a test tube, not just in an intact cell.<sup>13</sup>

A few weeks before our coffee, Pat had learned about the methods being used by the physicist Paul Ginsparg and his colleagues at Los Alamos to allow physicists and mathematicians to share their work with one another over the Internet. They were posting “preprints” (articles not yet submitted or accepted for publication) at a publicly accessible Web site (called LanX or arXiv)<sup>14</sup> for anyone to read and critique. Pat had presented these practices to his own laboratory group. The subsequent discussions prompted him to think about the possibilities for publishing work in the biomedical sciences on the Internet, recognizing that the large size of our field and its many cultural differences from physics would probably require other kinds of models than the one the physicists had used.

Initially, I could only listen. But I knew enough about the advantages of presenting papers in a digital format, the virtues of searching a database of complete articles, and the costs of publishing to recognize that Pat’s ideas deserved a lot more attention. When I returned to my office at the NIH, I looked at Ginsparg’s Web site, continued my conversation with Pat by email, and started thinking about how Internet-based distribution and storage of biomedical research articles could dramatically alter the way we worked.

#### TAKING ON THE PROBLEM: E-BIOMED

The more I thought about this, the more I was convinced that a radical restructuring of methods for publishing, transmitting, storing, and using biomedical research reports might be possible and beneficial. In a spirit of enthusiasm and political innocence, I wrote a lengthy manifesto, proposing the creation of an NIH-supported online system, called E-biomed.<sup>15</sup>

The main goal was to create a central repository of scientific reports that would be immediately available to all Internet users for digital searches or browsing. Many of these articles would simply be online

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<sup>13</sup> Later, on his own at Stanford, Pat Brown developed some of the first methods for assessing thousands of genes for their activity (being read out to form messenger RNA) in selected cell types or tissues. These so-called high throughput arrays have revolutionized the practice of molecular biology, and Pat has been justly honored for his imaginative work in a variety of ways.

<sup>14</sup> <http://arxiv.org>.

<sup>15</sup> H. Varmus, “E-biomed: A proposal for electronic publication in the biomedical sciences” (NIH preprint 04.99doc; Bethesda, Md.: National Institutes of Health, 19 April 1999).

versions of existing journals, accepted for publication after traditional peer review by established editorial boards. Some would be articles submitted to and reviewed by the editorial boards of new online journals formed to publish within the E-biomed system. But E-biomed would also display, in a separate section, reports that were not peer-reviewed in the traditional manner, including papers that might normally not be published at all, such as those describing a new method or idea, or those reporting negative results from experiments or clinical trials. The costs of building and maintaining the electronic platform and software would be paid by the NIH, but the costs of reviewing, editing, and publishing would be covered by the editorial boards and the organizations that assembled them. An international governing board would oversee the operations and set the rules.

After showing my E-biomed document to some friends and the NIH institute directors, I was emboldened to send it to many scientists and reporters and to post it on the NIH director's Web site in early May of 1999. It did get attention: several dozen articles appeared in major newspapers and the leading science magazines, and I received hundreds of responses from scientists and other commentators from around the world. While there were many encouraging comments, there were at least as many criticisms, concerns, and troubled questions. I tried to respond to these about six weeks later by posting an addendum to the original E-biomed manifesto.<sup>16</sup> Some were easy to answer: the NIH was not trying to take over the publishing industry, the material that was not peer-reviewed would be clearly delineated from articles that were reviewed by traditional methods, the contents would be properly archived, and so forth. But other issues were harder to deal with. Most importantly, I had not explained how a journal's costs of publication would be met in a system that would surely reduce, if not eliminate, paid subscriptions to the journals.

In retrospect, I see that I failed to propose a clear plan to finance what we would now call open access publishing. I had presumed that scientists had a strong allegiance to publication on paper, and I was trying to convince them of the virtues of digital publication by proposing an appealing transformation of science publishing, one that promoted greater access and utility. In fact, however, most scientists were more protective of their favorite journals than of paper itself, and they sought a gentler transition to an increasingly electronic world, a transition that would not threaten the viability of those journals. Others in the scientific community, including some who were receptive to the underlying

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<sup>16</sup> <http://www.nih.gov/about/director/pubmedcentral/ebiomedarch.htm>.

concepts, worried that E-biomed might undermine peer review, that the multihued hierarchy of distinctive journals might be replaced by a gray monolith of government reports, that the NIH (and thus the federal government) would control all aspects of science publication, and that their professional societies and traditionally favored journals might be destroyed by this cyberjuggernaut. Some of these concerns were answerable; others led me to modify the proposal in style or substance.

The most shrill opposition came, disappointingly, from the staffs of many respected scientific and medical societies, including some (like the American Society of Biochemistry and Molecular Biology) that had been in the vanguard of electronic formatting of scientific articles in their own journals (such as the *Journal of Biological Chemistry*). They said I was demeaning their past and current efforts to improve publication practices and threatening to undermine their means of support for other beneficial activities. Other societies welcomed the new ideas for disseminating scientific work; the American Society of Cell Biology, in particular, eventually made its journal, *Molecular Biology of the Cell*, into one that is virtually open access.

The for-profit publishing houses were also unhappy, and sent their lead lobbyist, the former congresswoman Pat Schroeder, to Capitol Hill to talk to members of my appropriations subcommittees. Even my strongest supporter in Congress, John Porter, was sufficiently concerned by her visit to ask me to come to his office to explain what I was trying to do, in a chat that was uncomfortable for both of us. According to him, Schroeder claimed that I was trying to undermine the free enterprise system by turning the NIH into a federal publishing company. Some of the warnings raised by Schroeder and others were designed to appeal to his belief in the free market, although I was not proposing to eliminate publishers or the competition for readers and authors. Admittedly, if E-biomed had been adopted in its original form, many of the participating journals would have lost revenues; the proposal lacked a credible business plan. But at that stage there was also no obligation to participate.

#### HOW E-BIOMED BECAME A PUBLIC LIBRARY: THE BIRTH OF PUBMED CENTRAL

Despite continuing opposition to E-biomed from several quarters, by the end of 1999, as I was departing the NIH for MSKCC, I did have one important achievement to point to: the opening of a full-text public digital library of biomedical reports. Throughout the discussions of the E-biomed proposal and the subsequent modifications, I had received sensible and highly informed advice from David Lipman, the

leader of NIH's computer science programs at the National Library of Medicine and the genius behind PubMed. David recognized, more acutely than I did, that the most compelling and achievable feature of the E-biomed proposal was not its complex scheme for Web-based publishing. Changes in publication practices would need much more debate, preferably outside the domain of the NIH, to be accepted by the scientific community.

But David saw that another aspect of E-biomed, one that entailed the creation of a full-text public digital library, was within reach. He realized that a repository of this kind could be created, despite anticipated resistance from the publishers, if the deposition of articles occurred several months after the date of publication, so that the subscription base of existing journals would not be significantly eroded.<sup>17</sup>

By late August of 1999, largely through David's efforts, we promulgated an announcement of "an NIH-operated site for electronic distribution of life sciences research reports" called PubMed Central. As envisioned in the August announcement, PubMed Central would be less ambitious than E-biomed. It would have no role, not even an indirect one, in producing journals. But the new repository would be organized along the lines of the repository in the original E-biomed proposal, including a category of reports that were "screened but not formally peer-reviewed." When PubMed Central was launched at the end of December, however, that still contentious part of the proposal was also eliminated.

What remained in the PubMed Central plan seemed practical and achievable. The new digital library would make accessible to all Internet users the peer-reviewed articles voluntarily provided, preferably within six months of publication, by any journals, new or established, that were listed in PubMed. Importantly, PubMed Central would be conveniently integrated with PubMed, an NIH service that was already respected and time-tested. Copyrights could be retained by the journals, and did not need to be held by the authors as proposed for E-biomed (as is now prescribed for open access publishing).

We naïvely thought that many journals would willingly participate. The interval between publication and deposition would protect their subscription base. Making articles more easily available would enhance reputations and serve the public. And scientists would appreciate the enhanced access that others would have to their work and that they

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<sup>17</sup>Library research had shown that most subscribers browse their journals for only a couple of months after publication; after that, they find articles of interest by searches. So a delay of six months before articles become freely Internet accessible would deter all but a few readers from canceling subscriptions.

would have to the work of others. Yet, initially, PubMed Central was nearly empty. David, Pat Brown, and I persuaded a few journals to donate their material as an experiment—the *Proceedings of the National Academy of Sciences* was our most prestigious success—but nearly all subscription-based journals were nervous, if not antagonistic, fearing the proverbial slippery slope: shorter intervals between publication and submission, followed by declines in subscribers. An innovative commercial publisher in London, Vitek Tracz, was sufficiently convinced about the virtues of making scientific reports freely available that he founded a new organization, called BioMed Central,<sup>18</sup> to create open access journals—digital journals that derive income from authors' fees and from advertising. The name was clearly an homage to PubMed Central, and BioMed Central articles, placed in the digital library at the time of publication, constituted a significant fraction of PubMed Central's content in the early days.

For PubMed Central to thrive and for scientists to experience its advantages, more of the existing journals—especially the most prominent ones—had to make their articles available. The suggested interval between publication and deposition in the library was extended from six months to a year, in hopes of increasing the number of participating journals. By then, in 2000, I was no longer director of the NIH, and had been asked by the National Library of Medicine to serve as a member of PubMed Central's advisory board, along with Pat Brown and Paul Ginsparg (the inventor of the online archive of physics preprints). Those of us who were strong advocates for the new public library regarded the reluctance of publishers to participate as unacceptable obstructionism. After all, the publishers depended on the free services of publicly funded scientists to produce their journals, but were unwilling to improve public access to the work of those scientists, even on terms—a one-year delay before submission—that would not materially affect their subscription rolls.

#### THE ORIGINS OF PLOS: FROM ADVOCACY TO OPEN ACCESS PUBLISHING

Pat and I decided to take political action. In doing so, we were joined by Mike Eisen, a young and exceptionally smart computational biologist who had been recruited recently to the faculty of UC Berkeley after working with Pat during postdoctoral studies at Stanford. Late in 2000, Pat, Mike, and I wrote a short declaration of purpose—we called it a

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<sup>18</sup><http://www.biomedcentral.com>.

pledge, publishers called it a boycott—in which we said that, one year hence, the signatories would no longer submit articles, provide reviewing or editing services, or purchase individual subscriptions to journals that had not agreed to deposit their articles with PubMed Central.<sup>19</sup> We called our advocacy effort the Public Library of Science (PLOS) to denote our goal of building a science library that would be open to all.

More than thirty thousand scientists from over one hundred countries signed the pledge. The campaign attracted attention in the science press and spurred discussion among my colleagues. But, during the ensuing year, fewer than one hundred journals of the roughly six thousand in biomedical sciences agreed to participate, and not many of these ranked among the most prominent. The poor level of participation made the pledge hard to carry out, since both trainees and full-fledged scientists have an understandable need to publish their best work in the most prestigious journals for career advancement and appropriate dissemination of important work. Only a few of the most committed signatories (and, of course, those of us who wrote it) felt obliged to honor their commitment to the letter. Even for us, this position created difficulties when other members of our labs and our research collaborators wanted to publish jointly authored work in noncompliant journals.

Despite its slow start, PubMed Central has steadily grown over the past few years, so that by the middle of 2007 it contained nearly a million full articles. By then, nearly three hundred journals were participating, and some—including prominent ones, like the *Proceedings of the National Academy of Sciences* and several journals published by the American Society of Microbiology—provided many years of content, even back to the founding of some journals. Still, this represented only about 5 percent of the journals in our field, and many journals that refused to participate are among the most prominent and most frequently cited.<sup>20</sup>

#### PLOS BECOMES A PUBLISHER OF OPEN ACCESS JOURNALS

By 2002, Pat, Mike Eisen, and I realized that even widespread endorsement of the PLoS pledge was not going to persuade most publishers to participate in PubMed Central. So we sought stronger measures to transform science publishing and demonstrate the virtues of enhanced access, and decided to publish open access journals ourselves. Of course,

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<sup>19</sup> <http://www.plos.org/about/letter.html>.

<sup>20</sup> As will be evident near the end of this discussion, this situation has been dramatically changed by a congressional directive in the 2008 appropriations bill requiring deposition of papers by NIH-supported authors at PubMed Central.

we were not the first to do this—BioMed Central was publishing quite a few, and some traditionally subscription-based journals, like the *Journal of Clinical Investigation*, were making their content freely available on their own Web sites—but we envisioned something more dramatic.

We aspired to produce open access journals of the very highest caliber—journals that could compete for exciting articles with the traditional powerhouses, like *Cell* or the *New England Journal of Medicine*; journals that would generate high-impact factors to attract high-end authors; and journals that would prove to a still skeptical scientific community that greater access, even true open access, was a practical goal, not just sophomoric idealism.

To do this, we drew up a prospectus for an open access, online publishing house that retained the name of our advocacy group, PLoS, and we persuaded the trustees of the Gordon and Betty Moore Foundation to support the idea. Once we had developed a reasonable business plan, the foundation gave us enough money—nine million dollars—to fund a publishing project that could, in principle, make us self-supporting in five years.<sup>21</sup> The essential feature of the financial proposal was the use of authors' fees to cover publication costs, which we estimated to range between one and three thousand dollars. We viewed such costs as reasonable; they would represent about 1 percent of the average cost of doing the NIH-sponsored research required for one manuscript. Furthermore, we thought the publication fees should be considered a part of the cost of doing research; the work would be worth very little if it were not published.

At the heart of our plan was the creation of two outstanding, so-called flagship, journals, *PLoS Biology* and *PLoS Medicine*, which would be both broad in scope and sufficiently selective and prestigious to compete with the very best traditional, subscription-based journals in those large fields. Shortly thereafter, we would use the credentialed name PLoS to build a collection of journals dedicated to some of the most important disciplines in these fields, such as genetics, global health, computational biology, infectious diseases, and so forth. Finally, we would establish a broad, encyclopedic publishing site for all kinds of reports in biology and medicine that met a credible technical standard, regardless of perceived importance. This final step would be essential for two reasons. First, the high volume of publishing, with low editorial costs, would help to pay for the more selective, prestigious, and expensive journals. Second, this expansive repository would become the platform for many

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<sup>21</sup> Now, just over five years after beginning to publish, and with the help of some additional philanthropy from the Sandler Foundation and others, our budget projections indicate that we are about two years away from self-sufficiency. Not a bad record for a “start-up.”

kinds of experiments in electronic publishing, including the use of post-publication exchanges between readers and authors.

The principal source of revenues would be publishing fees, paid by authors, usually from their grants, once their papers had been peer-reviewed and accepted.<sup>22</sup> We also expected to sell advertising space on the journals' Web sites and to solicit various kinds of philanthropic support. These might include foundation grants, such as the one given to us by the Moores; institutional and individual memberships, of the type offered by National Public Radio for not dissimilar services; and donations from friends of open access publishing, both scientists and nonscientists.

Because the world of traditional publishing employs a lot of very talented scientist-editors who are disaffected with the current system, we were able to hire several well-known editors from some of the most highly regarded journals, such as *Cell*, *Nature*, and *Lancet*. These acts of editorial rebellion immediately alerted many leading scientists to our efforts. We and our new editors then assembled a technical staff, rented offices in San Francisco and in Cambridge, U.K., recruited boards of academic editors to help with reviews of manuscripts, and persuaded about ten outstanding people—including Paul Ginsparg, the creator of the physics preprint Web site, LanX; Larry Lessig, the founder of Creative Commons; and Allan Golston, then the chief financial officer of the Gates Foundation—to join the board of directors. With all these people in place, we were able to launch our first journal, *PLoS Biology*—covering, as we liked to say, “all of biology, from molecules to ecosystems”—in October 2003.

Right from the first issue, which featured a report of a brain stimulator to control movements of a mechanical limb,<sup>23</sup> *PLoS Biology* has been highly successful, with many outstanding articles, frequent coverage in the press, and enormous numbers of visitors to the journal's Web site. The journal has scored well from the first measurement of that problematic, but closely watched, indicator, the impact factor. The high score has doubtless contributed significantly to the number of submissions, which has grown to more than two hundred manuscripts per month.<sup>24</sup>

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<sup>22</sup>From the start, we recognized that some authors might not be able to afford these charges, and decided that no favorably reviewed paper would be turned away for this reason. In practice, over 90 percent of PLoS authors have paid their fees.

<sup>23</sup>J. M. Carmena, M. A. Lebedev, R. E. Crist, J. E. O'Doherty, D. M. Santucci, et al., “Learning to control a brain-machine interface for reaching and grasping by primates,” *PLoS Biology* 1, no. 2 (2003): e42.

<sup>24</sup>Since *PLoS Biology* generally publishes fewer than twenty articles per month, the rejection rate is high; this factor both ensures prestige and drives expenses up, since well-paid professional editors must monitor the review process for rejected as well as accepted papers.

The success of *PLoS Biology* has also influenced, and been influenced by, other signs of acceptance of open access publishing: support by many funding organizations; the continued growth of Vitek Tracz's BMC journals; and the introduction of an "open access option" for individual articles in a few prominent subscription-based journals, especially the *Proceedings of the National Academy of Sciences*. At the same time, PLoS itself has expanded in accord with the original plans, launching *PLoS Medicine* in October 2004, followed by community journals (*PLoS Pathogens*, *PLoS Computational Biology*, *PLoS Genetics*, *PLoS Neglected Tropical Diseases*), then the encyclopedic, high volume publishing site, called *PLoS ONE*.<sup>25</sup>

We anticipate that *PLoS ONE* will become a novel platform for convening groups of scientists and others interested in specific aspects of science for continuing conversations after publication. In one model, PLoS would cooperate with groups that have a special interest—a disease or a subdiscipline or a biological phenomenon—to build "hubs" or "portals" that contain up-to-date catalogs of relevant, publicly accessible articles, information about public events, links to serious blogs and other Web sites, and open conversations. We imagine a time when most people interested in an area of science would begin their day by logging onto one or more PLoS hubs to learn what is new—interactive publishing at its best.

PLoS has done these things and continues to thrive, while retaining its idealism. In less than five years, it has become a highly regarded scientific publishing house. At the same time, as an open access publisher and an advocate for public libraries, it has expanded the public's access to the scientific literature.

#### SUPPORT FOR PUBLIC ACCESS FROM THOSE WHO FUND RESEARCH

A turn of the political and cultural tide in favor of expanded public access to the scientific literature in just the past year or two encourages confidence in the future of PLoS, open access journals in general, and public digital libraries. This shift reflects an alliance of common interests. Funders of research, both government agencies and nonprofit institutions, want to know that publications emerging from the work they support have the greatest possible distribution and impact; that can occur only if access to those papers is as easy as possible. Librarians,

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<sup>25</sup> All of these journals can, of course, be seen and used by anyone, anytime, at [www.plos.org](http://www.plos.org).

strapped for cash by the rising prices of institutional subscriptions, which can range up to \$20,000 or more for journals that publish only once or twice a month, want more journals to be available through open access methods or digital public libraries. And many scientists have begun to appreciate the benefits of enhanced access, including the motivating prospect of being read and cited more frequently themselves.

Statements and actions from those who fund research have been especially important, because they get the attention of the scientists whom they support even more than do the journals that publish the scientists' work. The prestigious Howard Hughes Medical Institute (HHMI) was among the first to offer support, encouraging its investigators to publish in open access journals, providing them with supplementary funds to cover authors' fees, and, more recently (in the summer of 2007), insisting that all their work appear in PubMed Central within six months after publication. In taking this recent step, the HHMI was following the lead of the Wellcome Trust, the largest funder of medical research in the United Kingdom, which instructed its grantees in 2006 that they were permitted to use grant funds to pay authors' fees at open access journals and that, in any case, their work had to appear in a public digital library within six months of publication. Thus encouraged, and further stimulated by a favorable report about open access from the U.K. House of Commons<sup>26</sup> and supportive statements by the U.K. Research Councils and other funders, a group of British institutions established the world's second public digital library for life sciences research, UK-PubMed Central. This event was both symbolically important, as a sign of the international spirit of the movement toward greater access, and pragmatically reassuring, as evidence that electronic libraries had backup features in case of technical failures or fiscal uncertainty. Other European funding sources—in France, Germany, and elsewhere, and most recently the European Research Council—have also voiced enthusiastic support for enhanced public access. And, early in 2008, the Faculty of Arts and Sciences at Harvard University voted unanimously to require its members to provide all of their scholarly papers for posting on an openly accessible university Web site.<sup>27</sup>

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<sup>26</sup> Science and Technology Committee, UK House of Commons. *Scientific Publications: Free for All?* (London: Stationery Office, 20 July 2004).

<sup>27</sup> <http://www.news.harvard.edu/gazette/2008/02.14/99-fasvote.html>. This policy requires that authors negotiate with journals to allow a license to be given to the university, a step that some journals may be unwilling to take. To avoid penalizing faculty who insist on publishing in such journals, the policy also provides an "opt-out" clause. But Harvard faculty must recognize how much the journals need them; the claim by Pat Schroeder that "some journals will be less than enthused about publishing Harvard faculty" is an empty threat. A. Lawler, "Harvard faculty votes to make open access its default mode," *Science* 319 (22 Feb. 2008): 1025.

Although in 1999 the NIH was the first to set up a public digital library, recently the United States has yielded leadership of the drive toward greater access to the United Kingdom and other European countries. Although some members of Congress were persuaded that federally supported research articles should appear in PubMed Central, the first legislative effort to encourage this was largely abortive. In 2005, a statement in its appropriation bill directed the NIH to develop a so-called public access policy. However, under pressure from publishers, the formulated policy was inherently weak—"requesting," rather than mandating (or even encouraging), grantees to deposit NIH-supported articles in PubMed Central within a year after publication. Some recalcitrant society publishers, such as the American Society of Hematology and the American Association for Cancer Research, told their members and authors that they were not obligated to fulfill the request, that the deposition process might be difficult, that the societies would not help, and that papers posted in PubMed Central might differ from versions published in the society's journals.<sup>28</sup> Not surprisingly, compliance with the policy was poor—only about 4 percent of NIH-supported reports were deposited by investigators (in addition to those published in the 5 percent of journals that already provided their contents to the digital library).

In response to this ineffective showing, in 2007 a coalition of concerned members of Congress, librarians, open access publishers (including PLoS), and some scientific leaders worked to put a stronger policy in place, one that would mandate the deposition of all reports of NIH-funded research in PubMed Central. Although strong resistance from commercial and society publishers managed to extend the maximum delay from six months to one year after publication, the new measure survived scrutiny and remained in the appropriations bill through protracted debates.

On 26 December 2007, when President Bush signed the highly contentious appropriations bill for fiscal year 2008, the new NIH public access policy became the law of the land, and the policy was put in place by the NIH on 7 April 2008. This was a momentous occasion for the open access movement, for PLoS, for PubMed Central, for the NIH—and for me personally.<sup>29</sup> All journals must now accept the idea that at least some of their articles, those describing work supported by the NIH, will appear in the public library. If they don't comply, the journals will run the unacceptable risk of not attracting manuscripts from anyone

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<sup>28</sup> [http://www.hematology.org/policy/statements/nih\\_policy.cfm](http://www.hematology.org/policy/statements/nih_policy.cfm).

<sup>29</sup> H. Varmus, "Progress toward public access to science," *PLoS Biology* 6, no. 4 (2008): e101.

whose work is supported by the NIH. The expansion of PubMed Central is likely to build enthusiasm for it, most journals will lose very few, if any subscribers, and journals may even recognize the benefits—to them and the public—of placing all their content, including old issues, in a public library. The general movement toward public access is also likely to increase the attractions of true open access journals, which routinely place their papers in a digital public library at the time of publication.

#### A FINAL WORD ABOUT PUBLICATION PRACTICES

From the time of my fateful conversation with Pat Brown in a San Francisco café, enormous progress has been made toward a more equitable, more efficient, and more useful means of publishing and distributing reports of scientific work. Despite impressions that might be created by this personal account, movement toward greater access did not originate with us, nor would it have occurred without many thousands of people who have taken up the cause. Some of these people have come from the rank and file of the scientific community—investigators who want their work to be readily found, easily read, and frequently used and cited. Some have come from funding agencies that have learned that current practices may impede access to the work the agencies have paid for in the public interest.<sup>30</sup> More scientific allies have come from less well-endowed academic institutions, small commercial laboratories, lower-income countries, and other places where the lack of funds to buy subscriptions to journals limits access to published work that the public has largely paid for.<sup>31</sup> And many more supporters have come from groups of nonscientists—health care workers, patients and their advocates, teachers and students, reporters and their readers—frustrated by the obstacles to material they want to see and, as tax-paying citizens, feel a right to see.

Nor would it be correct to conclude that the battles have been won. Open access publishing is now accepted, but it is not yet nearly as widespread as it deserves to be. Public digital libraries are well established and rapidly growing. But, even with the new edicts from funders and the new NIH public access policy, a significant amount of current work

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<sup>30</sup>In one important epiphany, the then new head of the Wellcome Trust, Mark Walport, found that he could not gain access to an electronic copy of a published paper describing work that was financed by his own agency, while using his personal computer on a trip. Such moments produce converts.

<sup>31</sup>Imagine being a scientist in one of these places and recognizing that your colleagues at rich institutions have access to all of the most desirable journals in your field, placing you at a distinct disadvantage in a competitive field.

will not be included. Furthermore, most older work, a legacy of many billions of dollars worth of research supported by federal and other funding agencies, has not been deposited in digital libraries and remains under copyright restrictions in its original, paperbound, and now largely warehoused journals.

I know about this deficiency from personal experience. One night, preparing for a class on the history of modern cancer research, I tried to get an electronic copy of the 1976 paper in *Nature* that describes our discovery of the c-src gene,<sup>32</sup> the work that was cited as the basis for our Nobel Prize in 1989. I searched PubMed and found only the authors and title, not even an abstract. The article was not deposited in PubMed Central. I eventually found a copy only by searching with Google Scholar. A professor in the Midwest had provided a poorly scanned copy to his class, and that copy made its way into the pages searched by Google. Surely, this is not the way to treat our scientific heritage. Increasing the world's access to the legacy we have and the legacy we are building will be an important project for a very long time.

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<sup>32</sup>D. Stehelin, H. E. Varmus, J. M. Bishop, and P. K. Vogt, "DNA related to the transforming gene(s) of avian sarcoma viruses is present in normal avian DNA," *Nature* 260 (11 March 1976): 170; see also *The Art and Politics of Science*, chap. 5, n. 14.