MARK W. NEFF

How Academic Science Gave Its Soul to the Publishing Industry

Self-governance of science was supposed to mean freedom of inquiry, but it also ended up serving the business model of scientific publishers while undermining the goals of science policy.

America's globally preeminent university research enterprise is constructed on two bedrock principles of self-governance. The first is autonomy: academic scientists should be left free to determine their own research agendas. The second is internal accountability: the quality of academic science is best assessed by academic scientists. The commitment to scientific self-governance carries with it a policy requirement as well: support for research will mostly have to come from the federal government; companies will never make the necessary investments in undirected research because they cannot capture the economic benefits for themselves.

The origin story of how this arrangement came about is a familiar one. During World War II, civilian scientists and engineers developed pivotal innovations that contributed to the allied victory. Their work was funded, overseen, and coordinated by the US Office of Scientific Research and Development, directed by Vannevar Bush, formerly the president of the Carnegie Institution for Science and dean of engineering at the Massachusetts Institute of Technology. Closely administered for relevance in advancing the war effort, wartime research and development activities were managed in a manner antithetical to contemporary ideals of scientific self-governance. Following the war, Bush made a pitch in his now famous report *Science, The Endless Frontier* that to secure social and economic benefits in the postwar period, including more and better paying jobs, more productive agriculture, and innovative industrial products desired by consumers, "the flow of scientific knowledge must be both continuous and substantial." To achieve this knowledge flow he felt that the government should provide generous funding for the scientific community, as it had during the war.

But counter to the coordinated wartime R&D effort he had headed, Bush insisted that scientists must be allowed to work "on subjects of their own choice, in the manner dictated by their curiosity for the exploration of the unknown." Such curiosity-driven basic science would yield essential but unpredictable benefits at unknowable points downstream, he argued, and was an essential prerequisite for solving social problems. The quality of a proposed research project could not therefore be judged by its potential benefits to society—those were unforeseeable. Scientists would judge scientific merit according to their own internal criteria.

The influence of Bush's argument for scientific self-governance would be difficult to overstate. *Science, the Endless Frontier* ultimately served as the justification and model for the creation of the National Science Foundation as a new science funding agency within the federal government, with federal funds distributed by technical experts to technical experts in a process designed to be largely insulated from political influence. And the National Science Foundation has served as a model for other US science agencies, and internationally for countries looking to build their own scientific capacity.

How can scientists' dependence on taxpayer dollars coexist with the no-strings-attached bedrock principles of academic research? Self-governance combined with unpredictable, yet inevitable, societal benefit from research relieved scientists of the obligation of having their work judged by the policy-makers and taxpayers who funded it. Yet the performance of scientists would still have to be assessed. Their publications represented a contribution to the pool of knowledge that would eventually yield benefit, and a citation in the scientific literature demonstrated that other scientists were making use of that contribution. The currencies of publication counts, citation counts, and journal impact factors (a metric based on citation counts) came to be the way that scientists competed with one another for jobs and funding within the broader scientific community, the way they were assessed for professional advancement within universities, as well as the way they articulated their value to outside audiences. These numbers are now widely accepted proxies for scientific productivity, quality, and impact, and they are compiled by authoritative sources to facilitate evaluation processes. The Web of Science (WoS) suite of products, to which any serious institution has subscription access, calculates an impact factor for every journal worth considering, and tallies citations to each published paper from others within its database. These metrics appear unambiguous and seem to capture key assessment criteria in simple numbers; they are therefore appealing to scientists who seek to remove bias from the self-governance process.

Though mechanically objective, the limits of publication and citation measures for assessing scientific quality and impact are increasingly well understood. The number of papers a scientist has published says little or nothing about the importance or even quality of those papers. Papers are cited for many reasons (including because they are notably bad). A journal's impact factor says nothing about how much any individual article has been cited; a small proportion of articles in high-impact journals tend to account for most of the citations. Nonetheless, publication metrics remain an influential element of scientific self-governance.

But here I will focus on another, little-recognized reason to rethink current reliance on publication and citation statistics in scientific self-governance: it actually gives the publication industry significant yet invisible influence over science policy. The foundational premise behind scientific self-governance is that the scientific enterprise works best—and makes its maximum possible contribution to society—when isolated from external influences. In accepting publication metrics as defined by corporate interests as the lodestar for judging science, however, the scientific community willfully cedes a significant degree of that self-governance to a small number of scientific publishing companies that are fundamentally responsive to the interests of corporate shareholders, not to the societies that fund and are promised the benefits of research.

Measuring Mexican science

To help make visible the dangers of linking scientific self-governance to publication and citation statistics, I start by stepping outside the American context to examine the experience of scientists in Mexico. Mexico provides a natural experiment in the policies of researcher evaluation because, unlike in the United States where there is substantial inter- and even intra-institutional variation, it has adopted a single national policy for research assessment.

By standard scientific metrics, Mexican science has come into its own in the past few decades. In the early 1980s Mexico produced few if any articles in journals listed by WoS; today Mexican scientists in some disciplines are averaging a publication per year in that database, a particularly notable feat given the comparatively limited government support for science. Whereas Mexican scientists formerly had to go abroad to complete their doctorates, students today can get their training in Mexico with internationally recognized mentors. Mexico now has substantial in-house scientific talent and the capacity to keep building on that success. By standard scientific metrics, continued success is limited only by lack of adequate funding.

Mexico's scientific ascent constitutes a remarkable achievement by countless talented and dedicated scientists, guided by policies focused on quantitative metrics of science: publication counts, citation counts, and journal impact factor. But this success also serves as a cautionary tale. By codifying standard notions of scientific quality in its national science policies, Mexico also steered research away from nationally-relevant topics and placed systematic barriers between Mexican scientists and potential users of science in that country.

Mexico's increased presence in WoS-listed journals is the result of science policies developed to protect and retain that nation's scientific workforce during a time of economic turmoil. Rampant inflation in the early 1980s created a crisis for Mexican science. Scientists could not afford to live on their salaries, and many had to take on additional jobs to make ends meet or flee to other nations where they could secure adequate salaries. Mexico's science policy-makers responded by creating the Sistema Nacional de Investigadores (SNI; the National System of Researchers) to identify and reward—and thus retain—the country's most productive scientists. Researchers with adequate productivity and training are granted SNI levels I, II, or III, or emeritus status, and are paid substantial nontaxable annual salary bonuses commensurate with their SNI level. Depending on the cost of living in a given region, these salary bonuses today constitute essential supplements to the standardized base pay rate, and many research institutions reinforce SNI incentives by creating pay-bonus systems that rely on the same metrics.

The SNI system functions as follows: Researchers in all academic disciplines, covering such diverse areas as agronomy, engineering, history, literature, and nuclear physics, are assigned according to their discipline to one of seven Area Committees for evaluation. Fourteen SNI-level III researchers serve on each committee, and they are charged with establishing and implementing researcher evaluation criteria for researchers in their remit. The entirety of the Mexican research enterprise is overseen and evaluated by these seven committees of 14 researchers, meaning that each committee covers a substantial breadth of topical areas, methods, and disciplinary traditions. While conducting their evaluations of hundreds of candidates annually, the committee members themselves must maintain the substantial productivity associated with their SNI-III status. To accomplish these goals the committees not surprisingly rely on time-efficient quantitative metrics of research quality.

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My own research has looked closely at the experiences of ecologists under this system. The 14 members of Area Committee II conduct the evaluation of scientists across ecology, life sciences, and chemistry. Typical of the committees that oversee natural science disciplines, this committee bases its evaluation criteria on specified quotas of "recognized" publications and citations. Recognized articles are those that appear in WoS-listed journals with an impact factor of at least 0.5, a score that indicates that on average articles published in that journal receive 0.5 citations from other listed journals within two years of publication. On its face, this expectation seems modest, but it results in the near-total exclusion of journals published in languages other than English, and thus of most journals published in Mexico or Latin America. The Web of Science is not intended to be comprehensive, but rather is curated for salability to institutional subscribers, largely university libraries in wealthy countries. Listed journals are frequently too expensive for Mexican research institutions and are nearly inaccessible to other potential users of research in the country. The WoS requirement thus systematically pushes scientists to publish in cost-prohibitive, foreign language journals and creates unnecessary barriers between science and its potential beneficiaries.

Plenty of legitimate research journals exist that would not pose these linguistic and financial access barriers, but publishing in them does not yield rewards under SNI. Mexico's National Council for Science and Technology (CONACYT), the administrative home of SNI, maintains a list of scientific journals published in Mexico—some by CONACYT itself—that meet standards of peer review and other scientific norms, but Area Committee II does not consider publications in those journals to be adequately rigorous unless they are also WoS-listed and meet the impact factor minimums. SciELO, an innovative collection of open access, peer-reviewed journals, has extensive coverage of Mexican and Latin American journals. Even though SciELO is now searchable via the WoS interface at institutions with appropriate subscription access, these journals are not included in the WoS's *Journal Citation Reports* and thus publication in them does not reap any rewards either. Latindex, a database of scholarly journals that strives to comprehensively list scholarly outlets in Latin America, counts 5,408 journals from the region that meet baseline standards of peer review and rigor. Many of these are available via open access, are published in Spanish or Portuguese, and have strong research traditions. As of 2019, only 238 Latin American journals were included in the WoS databases, and of those only 156 meet the required 0.5 impact factor score. Thus, 97% of Latindex journals don't count for SNI rankings under Area II standards.

Requirements for publishing book chapters similarly focus on international publishers to the exclusion of national ones. To count, book chapters must be from "prestigious publishers," with the list including "Springer, Taylor and Francis, Wiley, CRC, Elsevier, etc." Again, there are respected academic publishers in Mexico and the rest of Latin America that could be included.

Current requirements to climb from SNI level I to level II include an average over the preceding three years of two "recognized" publications per year, or an average of 1.5 per year if at least one appears in the top quartile of WoS journals, as well as a minimum of 200 citations (excluding self-citations from coauthors) in the Scopus database, a commercial product owned by Elsevier with slightly better coverage of Latin America. Level III expectations scale up from there, maintaining emphasis on WoS-listed journals and citations from the Scopus database. Because many scientists achieve level I status but do not climb higher, Mexico has additional mechanisms that grant graduate programs additional resources if sufficient numbers of affiliated faculty climb to SNI levels II and III.

SNI policies, intended to strengthen Mexico's research base, thus systematically deprive Mexico's own journals of submissions from its most active and ambitious scientists. Although it is tempting to assume that "international" is superior to "national" or "regional," the international emphasis means that scholars are now publishing in pay-walled foreign language journals that they themselves might not even be able to afford access to.

In addition to creating access barriers for domestic potential users, SNI policies allow the corporate owners of the Web of Science and Scopus products to shape what counts as legitimate and worthwhile science, in some cases steering scientists away from known knowledge needs and toward topics valued by editorial boards and collaborators in wealthier nations. The topics that yield the greatest rewards for researchers are those that happen to thrive under the conditions established by publication industry players as they curate their products for salability.

Within SNI Area Committee II, taxonomy and biological surveys, though potentially invaluable to ecological management decisions and a prerequisite for subsequent ecological research, are systematically discouraged by the incentive structures. Journal impact factors are calculated based on the number of citations received by a journal within two years, and the journals that publish taxonomy and biological surveys tend to require much longer periods to achieve peak citation rates. Thus, many of those journals have inadequate impact factors to yield professional rewards for potential authors. In the course of interview work in that country, I heard this concern both from scientists who desire to do survey and taxonomy work, and from CONABIO, Mexico's National Commission for the Knowledge and Use of Biodiversity, which had funding for that type of research but was unable to find enough scientists willing to do it.

The invisible science policy

Branches of research that rapidly yield publishable results thrive under metrics emphasizing journal impact factors, citation counts, and publication counts; research suffers comparatively in fields where data collection and interpretation are slower and more painstaking. In the discipline of ecology as defined by WoS, technology-dependent topics of genetics and remote sensing are ascendant. Research driven by these technologies can often be undertaken with minimal time spent doing field research and time-consuming preparation and analysis of field samples and data, in turn allowing higher publication rates and easier access to highly cited journals. Moreover, for Mexican ecologists—whose pay depends on publishing in prestigious WoS-listed journals—the equipment and datasets necessary for this type of work are often unaffordable, which makes them dependent on collaborators from wealthier nations, which in turn frequently means adopting portions of those collaborators' research agendas.

Tying research priority-setting to chasing high-impact journals and citation counts distorts other branches of science as well. Agricultural scientists in southern Mexico, the ancestral source of corn, are pushed toward research on commercial varietals rather than those still grown by smallholders in the marginal hilly croplands of the region, where subsistence agriculture still dominates. Because of the slow pace of building necessary relationships, researchers are penalized for work that involves community engagement. Laboratory studies are favored over field studies because the latter may require working for multiple seasons to capture the variability of nature, such as atypical weather and pest infestations. Thus, the influences of publication metrics on research priorities are systematic, but they are tied to neither societal knowledge needs nor any nuanced consideration of how to balance level of effort among multiple fields of science.

The national surrendering of substantial control of scientific research priorities to the profit model of the scientific publication industry should be grounds for revolt by scientists, policy-makers, and the public alike. That, on the contrary, this condition remains largely unacknowledged likely reflects the fact that the industry model takes advantage of nearly universal scientific norms. For example, Mexico's policies differ from those in the United States primarily in that SNI applies nationwide, whereas individual institutions in the United States usually establish their own criteria for professional advancement. Many institutions in the United States and around the world similarly build their researcher evaluation systems around publication counts, citation counts, and impact factor scores; these institutions are frequently equally reliant on the Web of Science to define important, legitimate, and credible science. Students aspiring to academic jobs learn early on that they need numerous highly cited publications in high-impact-factor journals in order to compete in a tight job market.

The impacts of orienting science around publication industry statistics likely plays out differently in the specific contexts of different nations, but the same underlying problems apply anywhere researcher evaluation is built on publication and citation statistics: scientific merit is conflated with citation frequency in a subset of journals curated for other purposes. For scientific disciplines globally to orient themselves in this way is to make a substantial—yet unexamined—commitment to allowing science priorities to be steered by commercial products that were not designed for that purpose. And, simultaneously it is an unexamined commitment to an idea that science is a global pursuit with universal research agendas. But in the case of ecology, it is not clear whether research is capable of generating universal principles that could do much to inform actual decision-making. Even in a discipline such as physics, where the phenomena that are the subjects of research function the same way the world over, different nations might legitimately have vastly differing research priorities. Yes, a scientist in a relatively poor country could work on "spooky connectivity," but whether a sponsoring nation should incentivize that is another question. Similar questions might apply to prioritizing research on genomics-based approaches to health improvement over population-based approaches, as discussed in the article by Richard Cooper and Nigel Paneth elsewhere in this magazine.

Scholars of the science-society interface have long noted that science is more likely to be utilized when it is deemed to be credible, relevant, and salient by those who stand to act on that knowledge. Such qualities emerge from long-term trusting relationships of mutual learning between those who create and those who use knowledge. The time and effort that scientists devote to cultivating such relationships means time and effort that does not go into writing papers. Scientists devoted to assuring the social value of their research may thus be systematically penalized in systems built around publication and citation rates. Indeed, even at their best, impact factors still measure only impact internal to science. If a scientific paper informs an important policy decision or legal case or newspaper story, it is quite literally not counted: by the definition of impact embraced by science, it has had no impact at all.

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The publication industry owns science

In addition to shaping the content of science, researcher evaluation policies focused on publication statistics contribute to what is essentially a publication industry oligopoly that undermines user access to the research that is published. Because of entrenched journal hierarchies, codified by journal impact factor scores, a handful of large corporate publishers have secure positions in owning "must publish" outlets for scientists. For example, the RELX Group—the corporate owner of the publisher Elsevier, the Scopus database (an aspirational competitor to WoS), the prestigious journals *Cell* and *The Lancet*, and the publication database ScienceDirect, among other products—boasts in its 2018 annual report that its Scientific, Technical & Medical division organized "the review, editing and dissemination of 18% of the world's scientific articles." By its numbers, the group received a whopping 1.8 million article submissions to 2,500 journals, overseen by 20,000 editors and countless peer-reviewers, and in the process reaped $3.3 billion in revenue. Subscriptions constituted 74% of that revenue. To achieve those revenues, the group continues to expand its offerings: Elsevier published 60% more articles in 2018 than a decade prior.

Economists may not have terms adequate to describe a market as dysfunctional as the one operating for academic publishing. Universities employ the content providers—academic researchers—who conduct the research that is paid for by governments and other third-party sponsors. Academics then write the articles, are incentivized to publish them in journals owned by a small number of companies, give them to those journals for free, vet the content for others in the process of peer review—for free—and serve on editorial boards organizing the review process—usually for free—thus providing a free labor force for those aspects of scientific publishing that require the greatest expertise and effort. Libraries in turn have little choice but to pay whatever subscription fees the publishers demand to secure access to the resulting content.

Typically, one or a small handful of corporate publishers (e.g., Elsevier, Springer Nature, Taylor and Francis) owns the top journals within a discipline. Those publishers have sufficient market control that subscription to their content is almost mandatory for libraries that strive to serve an active research community. Publishers use this market power to their advantage in negotiations with libraries and other institutional subscribers. Rather than offering individual journal subscriptions, large publishers and content providers typically offer libraries subscriptions to packages of journals. Just as cable companies force customers who desire one or a few channels to pay for a package including access to hundreds of channels, so too publishers require libraries and other institutional subscribers to pay for packages containing hundreds or thousands of titles to gain access to the relatively few that they need. Libraries have the option to purchase individual titles á la carte, but publishers set the costs for individual titles so high that for a library to break a package deal but retain high-use journals typically does not save much money. Furthermore, some publishers' annual subscription packages are structured to punish libraries that elect not to continue a package by depriving them of access to the content that they paid for in previous years. With many journals held by libraries only in digital form, institutions thus have little choice but to pay what the publishers demand for content packages if they want to maintain access to back issues.

The power and control of the major publishers in the market is self-reinforcing. Details from my institution, Western Washington University, exemplify the dynamic. Our libraries spend 15% of their resource acquisition budget on individual subscription titles, compared with 45% percent on journal subscription package deals and 26% on databases. The major publishing houses know that institutions such as ours depend on large packages to assure the viability of teaching and research, and thus have been able to demand annual price increases of 5%–15% per year, far outpacing inflation. Yet, our library budget has no built-in capacity to deal with even base-level inflation; cuts in subscriptions are inevitable. And it is much easier for the libraries to eliminate independently published individual titles that appeal to single disciplines, regardless of how intensively those resources are used, than to drop an entire package. Independent journals are thus under substantial pressure to join one of the larger publishers if they hope to remain viable. Through time, more and more of the publishing industry is thus assimilated into the portfolios of a very few corporate publishers.

The predictable consequence of these practices is extraordinary profit margins for corporate publishers and database providers in recent years. Elsevier's 2017 profit margin of 36.8% is typical of its success over the past decade. Public funding of self-governed academic research is what makes these profits possible.

The Web of Science suite, including the *Journal Citation Reports* and the *Science Citation Index*, is similarly profitable. These products were purchased from Thompson Reuters by the private equity firms Onex Corporation and Baring Private Equity Asia in 2016 for $3.5 billion and set up as an independent company named Clarivate Analytics. Clarivate Analytics then merged with Churchill Capital, a "Special Purpose Acquisition Corporation," in early 2019 in a deal valued at $4.2 billion. Churchill Capital reports that the merger "earned a total return of 51% … over an 8-month hold period" for investors in its initial public offering. The resulting corporation is listed on the New York Stock Exchange and is thus very much subject to the year-over-year profit expectations of publicly traded stocks. The de facto arbiters of quality of science, and the stewards of the scientific literature, are now accountable not to science but to shareholders. Subscribers, like my university's library, face the difficult choice of acceding to whatever the corporate owners demand for subscription fees or losing access.

Economists may not have terms adequate to describe a market as dysfunctional as the one operating for academic publishing.

Whence the power of the publication industry?

By building scientific self-governance around publication statistics, we academic researchers have guaranteed the publication industry a supply of government-subsidized content, free labor for assuring quality through peer review, and a virtually certain demand that our host institutions will purchase those products back. These self-imposed standards orient much of science around the pursuit of knowledge deemed interesting to a small set of journals selected for reasons unrelated to any systematic (let alone democratic) consideration of societal importance. And journals are so expensive that subscriptions are stretching already-limited university budgets even in wealthy countries.

How is it that the academic scientific community came not just to accept this situation, but to vigorously defend it as the essence of scientific self-governance? One explanation lies with Vannevar Bush's "just-so" story about scientific self-governance: in his telling, because science's benefits are unpredictable but inevitable, university science best serves society when it is left entirely to its own devices. This in turn means that scientific quality can be judged only by scientists, who quite sensibly judge one another based on contributions to the academic literature.

But this arrangement alone did not have to lead to the publishing industry's current power over science. Two other vignettes dating to the decades following World War II show how the needs and interests of scientists, profit-seeking entrepreneurs in publishing, and the information management needs of libraries converged to create the dysfunctional publishing market today.

Vignette 1: Maxwell's equation

In the postwar years, the United States was not the only industrialized nation to become an enthusiastic sponsor of civilian academic research. An international boost in research support in turn fed explosive growth in scientific publication. Many journals at the time were financially stressed and struggling to make articles widely available in a timely manner. According to Stephen Buranyi, a former immunology researcher turned science writer, the British government paired the Butterworths publishing house with the German publisher Springer, hoping the resulting company could be profitable and more efficient than many existing small scientific publishers. An entrepreneur, Robert Maxwell, came to head the effort, and he eventually purchased sufficient shares of both Springer and Butterworths to control the new company, which he named Pergamon Press.

Maxwell and his business partners were creative in finding ways to build their business as the scientific enterprise grew. Rather than waiting for scientific societies and others to propose new journals, as had been the practice, Maxwell and partners reversed the roles by proposing new journals to academics and academic societies. Every new journal was a new product to sell to libraries, and each journal that increased its publication frequency brought increased subscription fees. As Buranyi tells it, to enlarge the portfolio of his publishing house, Maxwell garnered a reputation for wining and dining potential authors and editors, for traveling abroad to secure exclusive contracts to publish English-language journals of foreign scientific society journals, and for other innovative and aggressive tactics. Between 1959 and 1965, Pergamon grew from 40 titles to 150. Whereas scientific norms at the time viewed scientific publishing as a public good that should not be subject to profit motives, Maxwell understood that scientific publishing was a market unlike others because there was an almost ceaseless growth of demand, and free labor. Scientists would pressure their institutional libraries to secure access to any serious journal publishing work relevant to their own. If the generous postwar government funding of science was the push that fueled rapid growth of science, the profit-seeking appetite of publishers was the pull.

Vignette 2: Garfield's dream

As other publishing houses came to emulate Maxwell's growth-oriented practices in order to secure a piece of the profits, libraries found themselves awash in journals and articles. Libraries faced substantial challenges as they tried to determine which were worth purchasing, and researchers faced their own challenges in trying to stay current with their fields as the number of relevant journals ballooned. In a pre-internet era, this created opportunities for other entrepreneurs who could curate the expansive and expanding scientific literature for libraries and library users.

Enter Eugene Garfield, the information scientist who founded the Institute for Scientific Information and created the Web of Science, the *Science Citation Index*, the *Journal Citation Reports*, and the journal impact factor. Garfield's first notable innovation was the 1957 creation of *Current Contents*, a book-length weekly periodical that contained the tables of contents from selected recent journals and provided indexes by author and title words. As the literature grew, *Current Contents* became an invaluable resource for library users seeking to keep up. Garfield's next innovation was a citation index, proposed in the journal *Science* in 1955, that would allow scholars to track citations between papers. This citation index would serve as an "association of ideas" index that would allow scholars to identify whether critiques had been proposed to ideas they were planning to cite. Funding from the National Institutes of Health and the National Science Foundation allowed him to test these ideas with the experimental 1961 *Genetics Citation Index* and a broader *Science Citation Index* he developed in tandem. The resulting 864-page book comprised a list of references to all articles cited by more than one hundred thousand source articles in 613 journals.

Two aspects of this innovation are worth noting. First, it made it possible to follow the citations to a given paper through the literature, which, with time, comes to be one of the central tenets of contemporary researcher evaluation schemes. Second, though this initial index was impressive, its scope and coverage were limited by punch-card computer technology and substantial labor costs. Garfield's dataset was dominated by a subset of English-language publications. Coverage limitations of these early databases became increasingly important as Garfield built on them to create newer products and as his product line gained traction with libraries and scientists. When he re-sorted the data to focus on journals and thus create the *Journal Citation Reports*, his products retained their early focus on English journals resources and their bias in favor of journals citing those in his original dataset.

These biases were further codified when Garfield created the journal impact factor, which he conceived as a tool to help decide which journals to add to the *Science Citation Index*, as well as to help libraries identify which journals were most important to subscribe to. Impact factor calculations depend on citations from journals in his databases. Journals not heavily cited by his original set for whatever reason, including those from nations and regions with less-developed science enterprises, were inevitably filtered out.

Two years is not enough

Garfield selected the two-year time frame for calculating impact factor because, he reports, it worked well for molecular biology and biochemistry. But it is inappropriate for disciplines such as taxonomy, which may yield crucial foundational knowledge but typically do not accumulate many citations in the early years after publication. A systematic comparison of citations accrued by journals in different disciplines suggests that although the two-year window accounts for 50% of the citations to some fields, for others it amounts to a mere 10% of the citations an article will eventually receive. Fields where data acquisition and interpretation can proceed quickly do well with the two-year window; slower fields are defined by Garfield's choice as less important, regardless of their utility to the progress of science or to society.

My own research demonstrates the impacts of this biasing in ecology, but it will occur in any discipline where methods that depend on rapid data acquisition and mining tools exist alongside field-based, case-based, and longitudinal approaches to research. The former displacing the latter may look on its face like the inexorable advance of science—as, say, high technology tools for collecting and analyzing enormous amounts of genomics information in ecology or biomedical science displace field- and clinically focused studies, respectively. Or in social sciences, where large databases can be mined to test cause-and-effect hypotheses much more quickly and cheaply than studies that depend on field-based, qualitative, and historical methods. But what's going on is not simply that science is being done faster, or that newer approaches are inherently better. Different types of science are being treated as if they are better *because* they are being done faster.

The Web of Science has come to define science, but it does so in ways that are exceedingly problematic for those working in disciplines, and in regions, and on topics that were not represented in Garfield's early experiments with the genetics literature. Garfield likely never intended his choices of what was included and what was excluded from his early products to define the boundaries and contours of what constitutes worthwhile science. As the scientific community came to rely on publication counts, citation counts, and impact factors for researcher evaluation, design decisions by Garfield and his colleagues became de facto, yet mostly invisible, drivers of powerful science policies. People who knew Garfield say that he never intended his products to become metrics of researcher merit; it is safe to assume that he did not intend them to steer science. Even as he explicitly cautioned against it in some of his writings, however, he acknowledged that the key reason for the success of *Journal Citation Reports* and its impact factors was their utilization in evaluating scientists.

Disciplines evolve through time in response to any number of factors, but that scientists working on subjects of their own choice," as Vannevar Bush put it, would come to mean choices at least partly made in response to incentives for faster publication and citation accrual seems to challenge the very integrity of scientific self-governance as advanced in *Science, the Endless Frontier*.

Renewing self-governance

To an extraordinary degree, then, the careers paths of university scientists, and the directions of science itself, have grown subservient to science-quality metrics designed to serve the business model of the publishing industry, not the knowledge needs of society.

In recent years, frictions between the scientific community and the publication industry have emerged, mostly centering on the expenses associated with accessing the results of research. As libraries, either individually or acting through consortia, negotiate contracts with publishers, an emerging sticking point for many is open access publishing. The entire University of California university system recently dropped its subscription to all Elsevier-published journals, citing a desire to transition to open access publishing and an unwillingness on the part of the publisher to meet their related demands. The venerable Max Planck Society in Germany, with 14,000 associated researchers, dropped its Elsevier subscription when the publisher was unwilling to meet its demands regarding open access publishing. The same is true of consortia representing 300 universities in Sweden and Germany, and France dropped Springer Nature over similar disputes. Innumerable individual universities, including Cornell University and Florida State University, and other subscribers are actively choosing to drop or being forced by financial considerations to substantially reduce their access to journal packages offered by Elsevier, Springer Nature, Taylor and Francis, and other profit-oriented publishers.

Research funders have increasingly joined the fray in pushing publishers to transition to open access. A consortium of European funders including the European Research Council and the European Commission announced Plan S, which requires, starting in 2021, that all research they fund must be immediately available via open access upon publication.

That several of these publication industry players have market values in the billions of dollars means they are not likely to surrender their profitable places at the center of science without a fight. The corporate group RELX's 2018 annual report addresses the threats posed by the increasing interest in open access publishing by telling shareholders: "We are open to serving the [science, technology, and medicine] community under any payment model that can sustainably provide researchers with the critical information tools that they need." Elsevier's actions over the past decade demonstrate how it is positioning itself in the open-access world: when academic institutions began making more extensive repositories of the scholarship they produce, frequently to improve access, Elsevier purchased BePress, the most popular software system for those repositories. It acquired the Social Science Research Network (SSRN), a heavily used repository facilitating sharing of preprints and working papers within the social sciences. It bought Mendeley, a social network where researchers often share resources. It bought 1Science, a company that was founded with the vision of helping institutions find open access alternatives that meet their scholarly publishing needs.

Such acquisitions have not fully maintained industry control over the literature. Third-party sources, such as SciHub, ResearchGate, and others, still provide alternate access to much of the scientific literature—albeit frequently without permissions from the corporate publishers to whom scientists sign away their intellectual property—and as such constitute a threat to the profit margins of publishers. In response, publishers have banded together to create software that would route traffic through their websites in a bid to retain their profitability in the shifting publication landscape.

What these acquisitions and innovations will mean as the scientific community evolves toward open access publishing remains to be seen. For European science to suddenly shift toward open access outlets represents a substantial challenge to the dominance of these publishers, as do the decisions of prestigious institutions and indeed entire nations to drop subscription packages that are seen as obstacles to effective scholarly communication.

Open access norms, however, will not themselves restore true self-governance to a scientific community that continues to hold science careers, scientific choice, and the links (or lack thereof) between science agendas and social need hostage to publication metrics. Additional change must occur on two complementary fronts. First, the de facto control of scientific quality and impact by a limited number of high impact factor journals, almost all of which are owned by the academic publishing oligopoly, will have to be broken. Although corporate publishers played essential roles in distributing scientific findings in past decades, there is no reason that the scientific community—nor the taxpayers on whom researchers and their institutions depend—should accept the damaging dependence today. The journals these publishers own are "essential" to science only because the metrics of self-governance say they are. All of the research published in them today could be published in journals not subject to shareholder demands of continual profit growth. The PLoS (Public Library of Science) journal family, for example, is organized as a nonprofit entity, allows authors to retain copyright, and allows free and unrestricted access by users anywhere. Publication fees offset editorial costs instead of paying shareholders, as they do for corporate-owned journals. And the software platform that it relies on is open source, meaning that it is itself freely available for other journals that might want to adopt an open platform.

Second, the metrics themselves will have to change, so that the rate at which scientists publish, the impact factors of the journals they publish in, and the rate at which their publications accrue citations are no longer understood to be proxies for scientific quality, but are rather recognized as what they actually are: relicts of the academic publishing industry's efforts to capture market share and maximize shareholder profits.

The crowning irony in the story I have told here is that the power of publishers over science has been created by the mechanisms of scientific self-governance. But if science is self-governed, we scientists can change the metrics by which we assess our own work, and we can change our relationship to an industry that damages science. Many of us in academic institutions have a hand in writing and implementing tenure and promotion guidelines. We serve on grant review panels, and we serve on committees advising universities and libraries. We provide our free reviewing and editing labor to corporate publishers. We scientists therefore hold the power to help restore to science both a notion of self-governance that is consistent with the ideals expressed in *Science, the Endless Frontier* and a notion of quality that is appropriate for a world whose improved well-being depends on the creation of useful new scientific knowledge.

***Mark W. Neff** is an associate professor in environmental studies at Western Washington University.*

Recommended reading

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