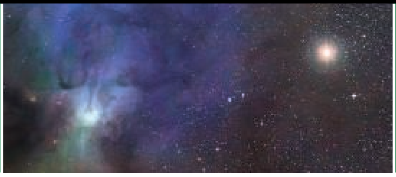

LETTERS

edited by Jennifer Sills

Literature Citations in the Internet Era

J. A. EVANS'S REPORT "ELECTRONIC PUBLICATION AND THE NARROWING OF SCIENCE AND scholarship" (18 July, p. 395) suggests that (i) the average age of citations to scientific papers dropped over the years as more electronic papers became accessible and (ii) the citations are concentrated on a smaller proportion of papers and journals. Such conclusions are not warranted by Evans's data.

To measure the evolution of the average (or median) age of the references contained in papers, one has to look at all the references in all published papers and observe the evolution of their age over time. As we have shown using Thomson Reuters's Web of Science data for the period 1900 to 2004 (for a total of 500 million references in 25 million papers), the average (and median) age of all references began to decrease in 1945 but has increased steadily since the mid-1960s. This trend is visible in all sciences, including the social sciences and the humanities (*1*, *2*). The median age of references in fields of science and engineering moved from 4.5 years in 1955 to more than 7 years in 2004, and in medical sciences it increased from 4.5 to 5.5 during the same period (*1*). In fact, Evans's conclusions only reflect a transient phenomenon related to recent access to online publications and to the fact that the method used does not take into account time delays between citation year and publication year. Our data also show that in disciplines in which online access has been available the longest (such as nuclear physics and astrophysics), the age of references declines for a number of years in the 1990s but then increases from 2000 to 2007, the last available year of our data set. We have also measured the concentration of citations (and journals) by three different methods, including the one used by Evans. All three measures clearly show that concentration is in fact declining for papers as well as for journals (*3*). Although many factors affect citation practices, two things are clear: Researchers are increasingly relying on older science, and citations are increasingly dispersed across a larger proportion of papers and journals.

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3. V. Larivière, Y. Gingras, É. Archambault, "The decline in the concentration of citations, 1900–2007" (http://arxiv.org/pdf/0809.5250).

Narrower Focus May Be More Efficient

IN HIS REPORT "ELECTRONIC PUBLICATION and the narrowing of science and scholarship" (18 July, p. 395), J. A. Evans expresses dismay that electronic publication narrows scholarship. He found that more recent articles included fewer, more recent citations. However, Evans gives us no reason to believe that this is actually detrimental to science. Indeed, he suggests that the integration of science in the days of paper-only journals may have been an unintended consequence of poor indexing. Contrary to what Evans claims, we may find that scientists' narrower focus on the literature is a good sign.

Science has frequently been compared to evolution by natural selection (*1*). In some species, relatively few offspring reproduce. Similarly, in science, relatively few papers affect subsequent scholarship. The citation norms that are emerging as a result of the growth of electronic publication may be making the scientific community more efficient. Scientists may be spending less time reading literature that is extraneous to their research. Before we bemoan the changes in citation patterns that Evans has discovered, we should examine more carefully the causes and effects of such changes.

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To Each Citation, a Purpose

THE REPORT BY J. A. EVANS ("ELECTRONIC publication and the narrowing of science and scholarship," 18 July, p. 395) claims that electronic publication "may accelerate consensus and narrow the range of findings and ideas built upon." But do the currently available data support this chilling conclusion?

Evans's argument is based on evidence that with electronic access, fewer papers and fewer older papers are cited, and that cited papers are less broad and diverse. To understand these

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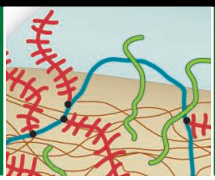

trends, one needs to consider the diverse purposes of citations as well as the mindset and motivation of authors when they decide which papers to cite (*1*). By expanding the range of papers known to authors, a more complete grasp of current literature helps them to select more appropriate citations. If the citations are more relevant and focused, the observed trends toward fewer citations may be a positive development.

But why are cited papers less broad and less diverse? Current citation indices do not distinguish the purposes of citations, which may serve as confirmation, refutation, background, technical details, or another role. Evans does not know whether narrow citers are more likely to converge with prevailing opinion than broad citers. Given the lack of evidence, it is speculative to equate narrow citing with hastening of consensus. Validation of this assumption requires a more refined analysis that is not available in Evans's databases: classification of citations (*2*). Disappointingly, Evans fails to consider such a roadmap, which would move the analysis to the next, more conclusive level.

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Letters to the Editor

Letters (~300 words) discuss material published in *Science* in the previous 3 months or issues of general interest. They can be submitted through the Web (www.submit2science.org) or by regular mail (1200 New York Ave., NW, Washington, DC 20005, USA). Letters are not acknowledged upon receipt, nor are authors generally consulted before publication. Whether published in full or in part, letters are subject to editing for clarity and space.

A Cycle of Tradition and Innovation

IN HIS REPORT ("ELECTRONIC PUBLICATION and the narrowing of science and scholarship," 18 July, p. 395), J. A. Evans states that "[b]y enabling scientists to quickly reach and converge with prevailing opinion, electronic journals hasten scientific consensus," and he warns that there may be a cost of this development. Findings that do not become part of the consensus quickly may be forgotten quickly, and interesting findings and ideas may be overlooked if the selection of literature is narrow in scope and time.

This warning is backed by classic arguments in the philosophy of science. Thomas Kuhn was the first to argue that the development of science builds on an essential tension between the convergent activity of normal science and divergent activity of scientific revolutions (*1*). On one hand, during phases of normal science, the confident and continuous use of accepted theories enables science to move faster and penetrate deeper than if dramatic theory changes were needed all the time. Thus, convergent thought often increases the effectiveness and efficiency with which scientific problems are solved. On the other hand, if this was the only mode of conducting science, there would be no fundamental innovation. Often, new discoveries lead to major rearrangement of the intellectual equipment as researchers discard elements of old theories, develop new theories, and establish new relationships between known theories. This requires flexibility and open-mindedness.

The consequences of the new patterns in the use of journal literature may differ for different phases of science. During phases of normal science, it is important to exhaust the full potential of the accepted theory to make sure that it is not abandoned too quickly. During such phases, a narrow focus on closely related findings will increase the effectiveness and efficiency with which existing theory and observation are adjusted and brought into closer and closer agreement. On the contrary, when anomalous results are encountered that question the adequacy of the previously accepted theory, alternatives must be developed. In these cases, it is important to distribute risk between several different approaches (*2*, *3*), and a narrow focus will substantially impede progress.

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Response

THE LETTER BY Y. GINGRAS *ET AL*. ALLOWS ME to clarify the scope of my research. I demonstrated the narrowing influence of online availability on the depth and breadth of attention in science. Each of my models controlled for year to test whether the availability of deeper online archives was associated with more shallow and narrow subsequent references to available journals than would have occurred had they not gone online. I acknowledged the historical trend and am relieved that Gingras *et al*. find the same. Citations deepen as more research lives in the past; articles cited are more numerous and less concentrated as more authors and universities produce research.

Gingras *et al*. question but do not test my claim that electronic availability narrows citation trends. They anecdotally note that online access came first to the physical sciences, where citations are deepest and deepening. Consider, however, that each field possesses distinctive features that confound comparison. For example, the physical sciences have recently received less funding and experienced slower growth than the biological sciences, increasing the relative importance of past research. I compared each journal and each subfield only to itself as its online availability shifted. The narrowing influence of online availability remained robust in analyses with varied time of online availability and citation years and for nearly all broad subfields. Indeed, under many of these alternative specifications, online influence appeared larger than recorded in my Report.

K. B. Wray and C. S. von Bartheld *et al*. express doubt that increased search efficiency and faster consensus could be anything but positive for scientists and science. However, we have no evidence that online availability gives researchers more proof or better judgment. We do know that scientists working with online journals have more exposure to what others find important as they hyperlink through citations and select references from the highest-impact journals in their search lists. Moreover, there is strong evidence from economics (*1*, *2*), sociology (*3*, *4*), and business (*5*)—and for varied markets, including those trafficking scientific ideas (*6*)—that the most popular products attract disproportionately more attention as (i) markets grow, (ii) the marginal cost of reproducing and distributing products is low, and (iii) consumers gain more exposure to others' choices. As articles become available online, each of these properties is enhanced.

Von Bartheld *et al*. appropriately observe that my Report counts references without identifying their purpose. Some meticulous classifications of this type have been performed (*7*), but problems remain (*8*). Most references, for example, are censored—an idea is mentioned but not formally cited. To move forward, we need the distribution of statements across articles themselves to understand the degree to which online availability influences scientific search, consensus, and advance (*9*, *10*). Emblematic is a recent study that analyzes millions of extracted, sequenced statements about molecular interactions from thousands of articles (*11*). It demonstrates that a skeptical interpretation about the truth value of scientific resolutions is at least as likely as a confident one, and so cautions us against assuming that quick resolutions are optimal.

H. Andersen draws on Thomas Kuhn's imagery of the "essential tension" to suggest that the shift to online information search optimizes "normal science" but undercuts revolutionary discovery. I agree with Andersen that recent patterns of online usage likely promote elaboration of recent ideas over the generation of new ones. It is unclear, however, whether these developments make normal science more effective. Scientific paradigms require generations for a research community to work out in detail. Consider the molecular science and engineering disciplines that have arisen in the wake of the discovery of DNA. Recent research that extracted molecular interactions from chemical and biological journals estimates that over one billion molecular interactions have been published in the past 25 years, but their number and the age and diversity of articles in which they appear make them practically inaccessible to individual researchers (*12*). Current patterns of online search will likely exacerbate the speed of forgetting. In other words, scientists find Internet information search more efficient for producing their articles (*13*) and it appears to hasten consensus within subfields; but this may not be optimal for normal science, which demands that myriad dispersed details be organized to complete a paradigm.

For this reason, I concur with Andersen's conclusion that other approaches to finding information should be cultivated. As we consider which, we must recognize that scientists will not return to bricks-and-mortar libraries (*14*). Electronic publication could support multiple research paradigms, but only when computer-assisted approaches move beyond searching, ranking, and summarizing. As we begin to computationally extract (*10*), compare, and link together claims from online literature into probabilistic inferences (*11*)—as we use computation to read and reason rather than simply shelve and retrieve volumes—online availability could enhance both normal and revolutionary science.

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CORRECTIONS AND CLARIFICATIONS

Research Articles: "Optical images of an exosolar planet 25 light-years from Earth" by P. Kalas *et al*. (28 November 2008, p. 1345). In the abstract, the phrase "matching predictions of its location" was inadvertently added to the end of two different sentences during final corrections. The phrase correctly appears at the end of the third sentence, whereas the fifth sentence should read "Dynamical models of the interaction between the planet and the belt indicate that the planet's mass is at most three times that of Jupiter; a higher mass would lead to gravitational disruption of the belt."

News Focus: "Reaching for the stars in Romania" by M. Enserink (21 November 2008, p. 1183). Romanian psychologist and former education and science minister Mircea Miclea, who chaired a presidential advisory committee on education and science, is not a member of Ad Astra, as reported on page 1185.

Brevia: "Magmatically triggered slow slip at Kilauea Volcano, Hawaii" by B. A. Brooks *et al*. (29 August 2008, p. 1177). The beginning data points associated with the HOLE site in Fig. 1B should have been medium and gray, identical to the rest of the data points, rather than small and purple. There is no change to the data.

Research Articles: "Draft genome of the filarial nematode parasite *Brugia malayi*," by E. Ghedin *et al*. (21 September 2007, p. 1756). The name of an author, Brian P. Anton, was inadvertently omitted after Owen White's. The author's affiliation is Division of Restriction Enzymes, New England BioLabs, Inc., 240 County Road, Ipswich, MA 01938, USA.

TECHNICAL COMMENT ABSTRACTS

Comment on "Log or Linear? Distinct Intuitions of the Number Scale in Western and Amazonian Indigene Cultures"

Jessica F. Cantlon, Sara Cordes, Melissa E. Libertus, Elizabeth M. Brannon

Dehaene *et al*. (Reports, 30 May 2008, p. 1217) argued that native speakers of Mundurucu, a language without a linguistic numerical system, inherently represent numerical values as a logarithmically spaced spatial continuum. However, their data do not rule out the alternative conclusion that Mundurucu speakers encode numbers linearly with scalar variability and psychologically construct space-number mappings by analogy.

Full text at www.sciencemag.org/cgi/content/full/323/5910/38b

Response to Comment on "Log or Linear? Distinct Intuitions of the Number Scale in Western and Amazonian Indigene Cultures"

Stanislas Dehaene, Véronique Izard, Pierre Pica, Elizabeth Spelke

The performance of the Mundurucu on the number-space task may exemplify a general competence for drawing analogies between space and other linear dimensions, but Mundurucu participants spontaneously chose number when other dimensions were available. Response placement may not reflect the subjective scale for numbers, but Cantlon *et al*.'s proposal of a linear scale with scalar variability requires additional hypotheses that are problematic.

Full text at www.sciencemag.org/cgi/content/full/323/5910/38c