Current Comments

The Einstein Centennial and Citation Analysis

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Everybody knows that Albert Einstein changed the world. Though few of us fully understand the work for which he is most famous—the theory of relativity—it altered our perception of space and time. Later his equation of $E=mc^2$ "symbolized" the power of the atom bomb.

The occasion of the 100th anniversary of Einstein's birth on March 14, 1879, inspired a new appreciation of his work. A magnificent statue of Einstein by Robert Berks now stands in front of the National Academy of Sciences (NAS) in Washington, DC. The memorial was erected largely due to the efforts of Philip Handler, whose term as NAS president expires in July. In addition, books, newspapers, magazines, television documentaries, and scientific journals have reminded us of Einstein's lasting impact.

Einstein never heard the terms black holes, quasars, and pulsars—but all these modern areas of astronomy are inextricably linked to his theories. And physicists pursue the work Einstein left unfinished: a "unified field theory" to explain all the forces in the universe in terms of a single theory. And it would serve no useful purpose to recite here the almost countless other fields affected by his work. But when it was suggested that ISI® mark the centennial with a citation analysis of Einstein's work, I discussed the idea with Tony Cawkell, then our director of research.[1] We agreed to use the *Science Citation Index®* (*SCI®*) as our starting point. Although our paper, "Assessing Einstein's Impact on Today's Science by Citation Analysis," was written two years ago, it was just published by Pergamon Press in *Einstein: The First Hundred Years*.[2] Since then Tony has established his own firm but continues to serve ISI as a consultant.

The book was co-edited by my dear friend, physicist-sociologist Maurice Goldsmith, director, Science Policy Foundation, London. Maurice is also a member of our *Social Sciences Citation Index®* and *Arts & Humanities Citation Index™* editorial advisory boards. The other editors are crystallographer Alan Mackay, London University, and physicist James Woudhuysen, editor, *Design* magazine. The papers in the book deal with Einstein the man, as well as his impact on science, society, world politics, and the arts. The contents page is reproduced in Table 1. What follows is a summary of the detailed study that Tony and I wrote. A limited number of reprints are available for *Current Contents®* readers.

In some ways it is remarkable that Einstein continues to be cited much at all. Most scientific research, even of Nobel class, that was done over 50 years ago is cited only occasionally today, and usually in an historical context. Such work is part of the fabric of science that today is taken for granted.

Not so with Einstein's work. About five years ago I did a study of 19th- and 20th-century classics.[3] Of the 11 classic articles published before 1912, four

Table 1: Table of contents for *Einstein: The First Hundred Years.* Goldsmith M, Mackay A & Woudhuysen J, eds. Oxford: Pergamon Press, 1980. 200 p. $19.95.

were written by Einstein. From 1961-1975 one of those papers received over 225 citations—all four collected almost 700.

To get a more precise picture of Einstein's impact on modern science, Tony and I checked the 1970-1974 five-year cumulation of the *SCI* to identify Einstein's most-cited works during this period. Einstein was cited over 500 times. In Table 2 the cited works are grouped by subject and translated into English. References to reprints or translations have been grouped with references to the original papers. The originals were of course written in German. The exception is the 1935 paper from *Physical Review*.

To find out *why* Einstein continues to be cited, we looked at key words in the titles of a random sample of 1974-1977 papers citing Einstein. These key words included or implied word-stem terms like EINSTEIN, RELATIVITY, GRAVITY, RADIATION, or PHOTON. A prefix like QUANT led to papers with terms such as quanta, quantum, and quantum mechanics. This procedure showed us the subject connection between the cited and citing articles.

We expected Einstein to be heavily cited in papers on particle physics, cosmology, and black holes, and he was. In fact, F.J. Tipler claims that "at least half" the papers on general relativi-

Table 2: Einstein's work by subject, with 1970-1974 citations to each subject field.

Subject	Times Cited
Special Theory of Relativity	56
On the electrodynamics of moving bodies. *Ann. Phys. Leipzig* 17:891-921, 1905.	
Does the inertia of a body depend on its energy content? *Ann. Phys. Leipzig* 18:639-41, 1905.	
General Theory of Relativity	175
Foundation of the general theory of relativity. *Ann. Phys. Leipzig* 49:769-822, 1916.	
Quantum Theory	98
On a heuristic viewpoint concerning the production and transformation of light. *Ann. Phys. Leipzig* 17:132-48, 1905.	
On the quantum theory of radiation. *Phys. Z.* 18:121-8, 1917.	
Can quantum-mechanical description of physical reality be complete? (with B. Podolsky and N. Rosen). *Phys. Rev.* 47:777-80, 1935.	
Brownian Movement; Diffusion	147
On the motion of small particles suspended in a stationary liquid according to the molecular kinetic theory of heat. *Ann. Phys. Leipzig* 17:549-60, 1905.	
On the theory of Brownian movement. *Ann. Phys. Leipzig* 19:371-81, 1906.	
A new method of determining molecular dimensions. *Ann. Phys. Leipzig* 19:289-306, 1906.	
Correction to my work; a new determination of molecular dimensions. *Ann. Phys. Leipzig* 34:591-2, 1911.	
Mixtures; Light Scattering	58
Theory of opalescence of homogeneous liquids and liquid mixtures in the neighborhood of critical conditions. *Ann. Phys. Leipzig* 33:1275-98, 1910.	

ty today are about black holes.[4] Also in this group of articles on relativity is a debate about whether Einstein was wrong about the famous "clock paradox."[5-8]

Many of the papers in the other areas—quantum theory, Brownian movement and diffusion, and light scattering—also continue to cite Einstein from a theoretical standpoint. What might surprise many people is that Einstein is often cited from a "practical" standpoint. Einstein's quantum theory is cited in papers about lasers and masers. Einstein is also cited in reports of "practical" work on metallurgy, glass technology, and polymers.[9] His work in the area of Brownian movement and diffusion is quoted in papers about semiconductors,[10] the mechanics of aerosol particles in the atmosphere,[11] and the properties of milk.[12] One unusual article cites Einstein's principle of equivalence in the context of food-seeking hornets' direction finding.[13] We found citing articles published in journals such as *Tectonophysics*, *Polymer and Engineering Science*, *Rheological Acta*, and *Industrial and Engineering Chemistry*.

This is not the first time Einstein's work has been shown to cut across the boundaries of several unlikely areas of study. To illustrate the interdisciplinary nature of the *SCI* when it was relatively new, Irv Sher, director of development and quality control, and I found that among the journals containing articles that cited his classic 1906 paper on the diffusion equation were journals on chemistry, polymer science, and dairy science.[14] There was no other way to search for applications of this equation.

Cawkell and I examined a sufficiently large sample of the recent citing articles to note that a high proportion of them stem directly from Einstein's research or contain discussions of developments prompted by his various theories. The number of these articles, their interdisciplinary character, and the comments made by their authors verify the outstanding influence and direct impact of

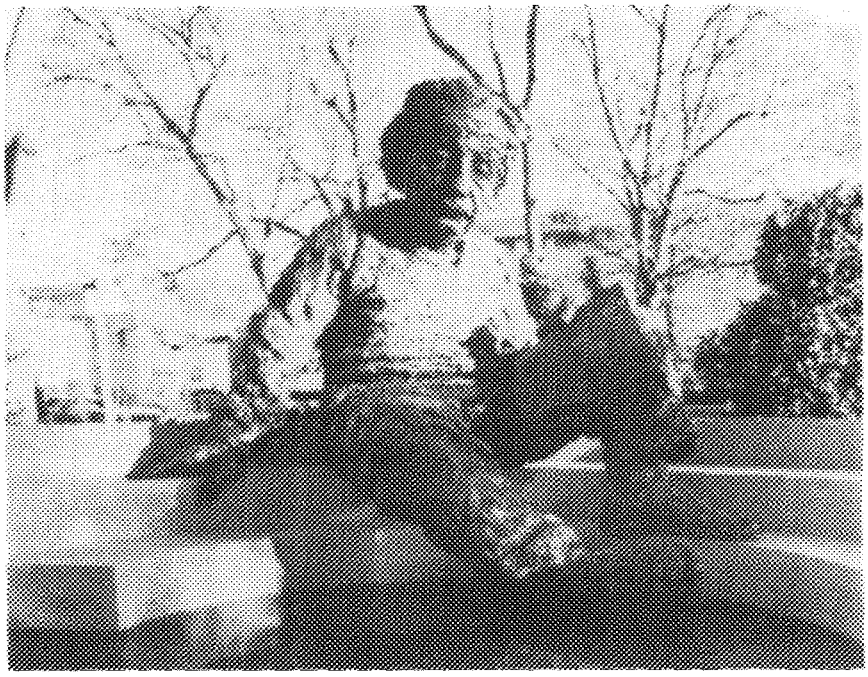

Photo by Diana H. Walker for the NAS.

The Einstein Memorial at the National Academy of Sciences, Washington, DC.

Einstein's work on today's science. In 1977, Einstein's work was explicitly cited by over 400 papers. One could do an interesting sociological study to determine why Einstein's work does not suffer from the oft-observed obliteration phenomenon. Only a part of it can be attributed to the fact that much of his work in relativity is still controversial.

Now that we have confirmed the continuing relevance of Einstein's work by citation analysis, I would like to debunk a myth about Einstein and citation indexing. Some people believe that revolutionary papers need not cite earlier literature. Some of Einstein's papers contain no references and are used as an illustration; for example, "On the Electrodynamics of Moving Bodies," the 1905 paper that introduced the Special Theory of Relativity.[15] One might conclude from this example that papers reporting world-shaking theories do not need references. However, in a 1907 review of relativity, Einstein did include formal bibliographic references to works of authors who were "implicitly" cited in his 1905 paper.[16]

The implication of giving examples of landmark papers that don't contain references is that such original thinking requires no reference to the past. While examples of papers without references may exist—and they are rare indeed—the implication is absurd. While I would like to hear from readers about other authentic cases where milestone papers failed to include bibliographic citations, it is not a particularly exciting issue at a time when the average paper in physics contains about 30 references. However, there is a theoretical point about information retrieval that is implied. If you are relying on citation in-

dexing alone to find papers, how will a paper that cites nothing at all get into the citation network?

Many readers will recall that I have admonished them to cite the competition lest their papers fail to turn up in the citation index when others look up their competitors. But it should be obvious that it will make no difference who you cited once *your* paper is cited by others. These papers will turn up not only in citation indexes, but, if cited often enough, in historical or other maps created by co-citation analysis.

The study above illustrates how citation studies can be used to identify the continuing impact of certain immortals. While citation analysis was not needed to prove that Einstein was our century's greatest scientist, it did provide an insight into his influence that is beyond the capability of those most conversant with his work.

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