Current Comments

The 1980 Nobel Prizewinners

Number 31

August 3, 1981

Last year, when discussing the 1979 Nobel prizewinners, we introduced a new term—of Nobel class. One major indicator that a scientist is of Nobel class is the publication of several papers of high impact. More often than not, when consistently cited for a long period, such papers can be identified with major breakthroughs. Let's see whether this is true of the 1980 Nobel prizewinners, and if not, why not.

In compiling lists of highly cited authors, we identify many people who can be considered of Nobel class. However, we cannot predict which individuals or fields will be singled out in a particular year for the coveted award. We can use citation analysis to identify those scientists whose contributions have had wide impact. Our studies indicate that most of these same individuals are also identified as outstanding when their peers are asked to provide subjective opinions. Awards, of course, only confirm eminence. They do not change the quality of work done before the award.

As in most years, six of the ten 1980 Nobel prizewinners had already appeared on our published lists of highly cited authors. When this is not the case, it usually reflects a decision to award the prizes in fields which contain a relatively small body of literature. But since many of the 1980 prizewinners were selected from highly active areas, such as recombinant DNA and immuno-

genetics, it is not surprising that they have appeared on a number of our lists. These are fields which have experienced an explosion of activity, and publication, in the past ten to 20 years.

When preparing these citation analyses, we are often faced with questions about the most appropriate method of examining a scientist's citation record. Aggregate citation counts do not distinguish the author-scientist with a few superstar papers from the scientist who has published numerous papers, each of which received a fair, but not remarkable, number of citations. If both scientists have been cited equally, it would be absurd to conclude that their work is equally significant.

Among the 1980 Nobelists, we find scientists who have consistently produced significant, and highly cited, papers. As Derek Price, Yale University, points out, this indicates that most of the 1980 Nobel prizes went to "discoverers" with many contributions, whereas in physics, this year's award was given for a "discovery." Such discoveries turn up in our citation cluster analyses, as will be seen later.

Chemistry

In her study of Nobel prizewinners,³ sociologist Harriet Zuckerman, Columbia University, points out that the Nobel is usually awarded for work that was done as long as a generation ago. The decision to award this year's prize in

chemistry for the relatively recent work on recombinant DNA is a departure from this practice.

Paul Berg, Stanford University, Walter Gilbert, Harvard University, and Frederick Sanger, Medical Research Council, Cambridge, were awarded the Nobel for developing methods that have made it possible to map and recreate the structure and function of DNA, the substance that governs the workings of a living cell.

Berg, a pioneer in gene splicing and a leader in the movement to insure the safety of this new "technology," received half the award for his "fundamental studies of the biochemistry of nucleic acids, with particular regard to recombinant DNA." Although there is some debate on the issue, a press release from the Academy states Berg was the "first investigator to construct a recombinant DNA molecule."

Gilbert and Sanger were awarded the other half of the award for independently developing methods for determining the precise chemical structure of large segments of DNA. Their methods permit researchers to rapidly reconstruct a DNA molecule. The Sanger method generates nested segments of nucleic acids by separating the two strands of DNA to be sequenced and making partial copies of one of these strands. The method developed by Gilbert and his colleague, Allan Maxam, Harvard University, generates these segments by breaking the DNA at specific bases.4 This is Sanger's second Nobel prize in chemistry. His first was awarded in 1958 for determining the structure of the insulin molecule.

After achieving eminence, scientists in certain fields choose not to be named as first authors on papers toward which they make significant contributions. This practice of noblesse oblige³ may explain why a few of this year's winners did not appear on some of our earlier lists of most-cited authors. These earlier

lists were based on first-author data. Such authors might not have appeared on these earlier and limited lists. We found that, in many cases, scientists' citations increased dramatically when all-author data were used. Our more recent studies include all-author data.

Berg provides an example of how this practice of noblesse oblige can affect a citation record. His work was cited "only" 1,937 times from 1961 to the present when just his primary authored papers are considered. However, when a count was made of citations to all his papers, 1965-1978, the number of citations increased to 3,535. Berg did, in fact, appear on several of our earlier lists.

Oddly enough, a 1972 paper, 5 said to be Berg and his colleagues' "formal claim to priority on a design for hybridizing in the laboratory DNA molecules of any two living species," 6 (p. 39) has not yet appeared on any of our published lists of highly cited articles. In response to a questionnaire sent him for our upcoming 1,000-authors most-cited from 1965-1978 study, Berg said he considers this paper, which he coauthored with D. A. Jackson, University of Michigan, and R. H. Symons, University of Adelaide, Australia, his most important publication. 7

The paper has received a very respectable 182 citations since its publication in 1972. This may not seem impressive when compared with the almost 900 citations of his 1962 most-cited paper.⁸ However, as shown in Table 1, only a

Table 1: Citation frequency distribution data for 1979 SCI®.

Times Cited	Number of Items	% of File	
1	2,754,669	70	
2-4	906,046	23	
5-9	202,130	5	
10-16	50,051	1	
17-25	14,622	.5	
26-50	7,067	.3	
51-100	1,381	.1	
101-Over	369	.1	
Total	3,936,335	100%	

small percentage of papers will ever exceed this citation threshold. In fact, it qualifies as a Citation Classic. Although the 1972 paper coauthored with Jackson and Symons had an immediate impact upon the scientific community, it seems to have become somewhat "displaced." in that other articles describing the methods used by Symons, Jackson, and Berg often have been cited instead.9 We asked Joshua Lederberg, president, Rockefeller University, the possible reason for this. He pointed out that this paper was followed by a "blitz" of articles dealing with similar work. So there is a tendency to cite those more recent articles rather than the original primordial one.9 This obliteration phenomenon is not at all uncommon. Indeed, in reviewing citations to the 1972 paper by Jackson, Symons, and Berg, we found many of the citing documents were review articles which, in turn, were subsequently well cited. For example, a 1974 review article by W.A. Salser, 10 which cites the 1972 paper, has received 58 citations since publication.

In a case study of citation context analysis, ¹¹ Henry Small and Ed Greenlee of ISI® found that the Jackson, Symons, and Berg paper was cited heavily with a 1972 article by Stanley N. Cohen, ¹² also of Stanford. This paper, on genetic transformation of *E. coli* by R-factor DNA, ¹² has received 445 citations since its publication. Thus, it too is one of the seminal documents in the history of recombinant DNA research.

Further confirmation of Berg's primary role in recombinant DNA research is provided by the appearance of his "core" papers in other co-citation clusters. Co-citation analysis is a research method used at ISI and elsewhere that provides a non-obtrusive and presumably objective method of tracing important ideas in science. Co-citation clusters are assembled by first identifying a group of papers highly cited in the Science Citation Index® (SCI®) data

base for a particular period of time. The next step is to identify those articles that are cited together, or co-cited, in the more recent literature. Those documents that are cited together in the more recent papers form the core of the clusters that we use in our studies. Since the literature that is cited changes from year to year in response to changes in the focus of research, our clusters change from year to year. By monitoring the periodic changes in these clusters, one can observe the transition of ideas from year to year. While lists of highly cited individual papers are interesting, they do not reveal the relative impact or influence of papers as clearly as do clusters of closely related papers. 13,14

The 1972 Jackson, Symons, and Berg paper has appeared in four distinct, though related, clusters from 1976 to 1979. These clusters had their origin in a very large 1976 cluster representing a close-knit group of researchers working on closely related problems. Eventually the methods became diffused throughout the scientific community, as DNA recombination became a widely used technique in many areas of biomedical science. This is reflected by the fragmentation of the original 1976 cluster into smaller clusters, several of which include the Jackson, Symons, and Berg paper. The development of this field from 1973 to 1976 is traced by cocitation cluster analysis in the paper by Small and Greenlee.11

The effect of noblesse oblige is also illustrated in the case of Gilbert. The 1,337 citations he received as a primary author from 1961 to 1976 is almost half the number he received when all his citations during this period are taken into account. This phenomenon is further illustrated by the fact that his most-cited primary authored paper, a 1963 article on the polypeptide chain and S-RNA, 15 has received only about a quarter of the citations a 1977 paper 16 he coauthored

with Maxam has received. This 1977 paper—which has been cited over 1,697 times—reports the "Maxam-Gilbert" method of sequencing DNA, the method for which Gilbert was awarded the Nobel prize. As I've said many times before, 17 methods papers are of varied significance in science.

Although Gilbert has been cited at least 100 times every year since 1964, the impact of his work increased in the 1970s. During this time his papers were cited over 150 times per year.

Not surprisingly, a number of Gilbert's papers-including the one reporting the Maxam-Gilbert sequencing method-have appeared on our list of most-cited 1977 articles. 18 Studies of citations received by papers shortly after they are published help identify areas of very active research, since a paper that receives a sudden and large burst of citations is generally influential in "hot" research areas. The presence of the Maxam-Gilbert paper, and of several other papers by Gilbert, on this list and on our list of most-cited 1978 articles. 19 indicates that Gilbert's impact on DNA research was rapid and widespread.

Not surprisingly, examination of the appropriate clusters shows precisely how Gilbert's work has influenced the last decade of research. His 1963 article on polypeptide synthesis in E. coli, 15 and his more recent contributions on RNA polymerase and the lactose repressor and operator, 20-23 have served as focal points for lines of research being followed in the late 1970s. As a matter of fact, his paper on RNA polymerase²⁰ is the most-cited item in a 1979 cluster on operon promoters. As might be expected, our new online system, called ISI/BIOMED 'M, 24 has a research front specialty entitled "Operon Promoters."

Our cluster data demonstrate the influence of Sanger's work on two new rapidly growing research areas. The earliest of these deals with DNA sequencing. His 1973 paper on a method for de-

termining a nucleotide sequence in phage f1 DNA²⁵ was a precursor paper for research on nucleotide sequences of transfer RNA. Our cluster data also demonstrate Sanger's influence on molecular biology. Three of his papers²⁶⁻²⁸ form the core of a 1979 cluster called "Nucleotide Sequence Analysis of DNA and Messenger-RNA."

Our earlier studies demonstrated the immediate impact of Sanger's recent work on the field. His papers, like those of Gilbert and Berg, appear on the lists of 1977¹⁸ and 1978¹⁹ papers most cited immediately after publication. In fact, one of his papers, ²⁹ and the Maxam-Gilbert paper on sequencing DNA, ¹⁶ were the two most-cited items in our study of 1977 papers.

Sanger's long-term influence on a number of fundamental research areas is also clearly reflected in his overall citation record. For example, the paper for which he was awarded the 1958 Nobel prize in chemistry³⁰ is still his mostcited publication. That paper also turned up as one of the most-cited papers of the 1940s,³¹ More recently, Sanger's paper on fractionation of radioactive nucleotides³² appeared as a Citation Classic,³³

Physiology and Medicine

As with the chemistry winners, this year's physiology and medicine Nobel prizewinners were drawn from a currently active area of research. Barui Benacerraf, George Snell, and Jean Dausset were awarded the prize for their work on the genetically determined structures on the surface of cells which regulate immunological reactions. These structures, called histocompatibility antigens, help determine whether a transplanted organ will be rejected by the recipient's immune system. This discovery has also helped scientists determine whether an individual can mount an immune response to a given disease. Since work on histocompatibility antigens has triggered a great deal of related research on the immunological system, it is not surprising that Benacerraf and Dausset will appear on our forthcoming 1,000 authors study.

Snell, emeritus senior staff scientist, Jackson Laboratory, Bar Harbor, Maine, was awarded the Nobel prize for identifying the genetic locus responsible for graft rejection in mice. This locus, which he called the H-2 locus, was later identified as the major histocompatibility complex (MHC), the complex of closely linked genes responsible for the rejection of transplanted tissue in mice. A similar locus in humans has been identified and is known as the HLA.

Despite the cumulative significance of his work, as shown by the 3,966 citations made to his work since 1961, Snell has appeared on only one of our lists of highly cited articles. This was a list of highly cited articles from East European journals.³⁴ The 1968 article³⁵ mentioned on the list discussed the MHC of the mouse, and was published in Folia Biologica. His most highly cited works, at present, are contributions to a 1966 book he also edited, Biology of the Laboratory Mouse.³⁶

But these do not constitute his seminal works on transplantation genetics. Rather, several of the papers he published in the late 1940s and early 1950s have been crucial to the development of the field. These include two 1948 papers, in which he first names the H-2 locus,³⁷ and reports findings on the genetic and antigenetic basis of tumor transplantation.³⁸ Although they were published over ten years before the SCI was initiated, these papers were cited 116 and 61 times since 1961. The continuing significance of these papers is reflected by the 36 and 27 citations these papers have still received, respectively, from 1976 to 1980. Incidentally, Snell was largely responsible for "inventing" the idea of congenic mice, which are genetically identical except at the region to be studied. These mice were developed over a long period of

time, beginning in the 1940s, and are now widely used in genetic research.

An interesting aspect of this discovery is that there is no single publication that could be considered the primordial citation. Rather, according to Snell, there is a whole series of publications involved.³⁹ Since the SCI does not yet cover the 1940s or 1950s, the citation of Snell's work during that time would not be reflected in our counts. This problem will be partly overcome when we complete the 1955-1964 SCI cumulation.

The SCI clearly demonstrates that Dausset, University of Paris and St. Louis Hospital, Paris, is of Nobel class. His work has been cited about 4.401 times since 1961. While he was cited by the Royal Caroline Medico-Chirurgical Institute for work performed during the 1950s, the growing number of references made to his papers each year attests to the impact of his work. Dausset was cited for his contributions to defining the human histocompatibility system (HLA). In fact, Dausset recently stated that his 1958 Acta Haematologica40 paper on HLA antigens in humans was his most important contribution. Although this paper has clearly been essential to our present understanding of the human histocompatibility system. it is not as highly cited as many of his later works. Did publication in French in a less than widely circulated journal affect its frequency of citation? Perhaps. I suspect it just became easier for people to cite his later work in English. In fact. Dausset's most-cited works are his three contributions to a 1966 book, Histocompatibility Testing, published in English.41 These papers, describing a system of antigens (later identified as HLA), led to a better understanding of the human histocompatibility complex. They have received about 700 citations since their publication.

The choice of Benacerraf for the Nobel prize was no surprise to us. He happens to be among the 50 most-cited authors, as our forthcoming essay on

the 1,000 most-cited authors will show. Benacerraf, now chairman, department of pathology, and Fabyan professor of comparative pathology, Harvard Medical School, was singled out for his work on the genetic control of immune responses. He has shown that genes located in the MHC control the many interactions among immune cells that are responsible for the human immune response. As often happens in our citation studies, one of Benacerraf's papers appears repeatedly on our lists of highly cited articles. Entitled, "Histocompatibility-linked immune response genes," this 1972 Science article has been cited about 900 times. 42 As a matter of fact, it ranked seventh on our list of 1972 papers highly cited in that year, 43 and fourth on our later list of 1972 papers highly cited from 1972-1975.44 This was a clear indication that this paper and, of course, his work, had a very immediate impact.

Its importance to immunogenetics is further confirmed by its dominant position on a 1974 co-citation cluster of papers focusing on genetic control of immune responses. Benacerraf's paper was the most-cited of 69 core documents in the cluster. It discusses the then-newly discovered class of Ir genes that control specific immune responses. Most recently, he appeared on our list of 300 most-cited authors, for the period of 1961-1976.45 Benacerraf's leading role in the field of immunogenetics was again reflected in his appearance on our lists of 197718 and 1978¹⁹ most-cited articles. It is notable that Benacerraf's citation record improves remarkably when his coauthored articles are included. Although he ranks in the top 50 on our list of 1,000 mostcited authors, with 8,964 citations, he has received "only" 4,958 citations as a first author, 1961 to present.

Physics

The 1980 Nobel prize in physics was awarded to James W. Cronin, Universi-

ty of Chicago, and Val L. Fitch, Princeton University, for their work concerning the symmetry of subatomic particles. They performed experiments at Brookhaven National Laboratory in 1964 with James H. Christenson, now at New York University but then a graduate student, and Rene Turlay, who then was a postdoctoral fellow and now is at the Center for Nuclear Studies in France. They found that certain elementary particles violated a fundamental symmetry principle in the thencurrent general theory of weak interactions. 46 Specifically, their classic experiment measuring charge conjugation parity (CP) conservation demonstrated that time at subatomic levels is not always reversible, as had been assumed. Their findings were based upon experiments done with elementary particles called K mesons, which have played an important role in breaking several conservation laws of physics. More recently, their findings have contributed to explanations of why matter in the universe is more predominant than antimatter. despite grounds for believing that the amount of matter and antimatter should have been the same at the birth of the universe. Proponents of the big bang theory hold that asymmetries similar to those found by the Nobelists and their colleagues can explain why the universe is composed primarily of matter.

The impact of the Cronin and Fitch work on elementary particle and cosmological research is reflected by the 450 citations their paper has received. Citations to this paper peaked in the mid-1960s, particularly in 1965. At that time, according to a paper on co-citation analysis by Daniel Sullivan, Carleton College, and colleagues, 47 finding an explanation for the asymmetry discovered by the award winners was "clearly the top research problem in the field" of weak interactions. However, Sullivan reports that interest in the field waned as researchers realized "no resolution was immediately forthcoming."47

We confirmed this by a simple chronological citation analysis of the 450 citations to this paper. One hundred and twenty occurred in 1965 alone! Then the number of citations dropped abruptly to 11 in 1966. It moved up again to 64 in 1967, 49 in 1968, and 34 in 1969. It averaged about 22 citations a year in the five years following.

D. Hywell White, physicist and sociologist of science, Brookhaven National Laboratory, "guessed" that this citation pattern may have been caused by the immediate response of theoretical physicists in 1965, followed—after a delay of a year or so needed to get experiments underway—by the reports of experimentalists on their related work.48 White said that researchers will continue to return to the problem whenever more accurate methods become available for measuring and analyzing the anomaly found by Cronin and Fitch. In fact, he added that related experiments will be done in the next year or so by Cronin and colleagues at Fermi Laboratory, Illinois, and by others at Brookhaven National Laboratory. 48

One reason the Christenson, Cronin, Fitch, and Turlay paper has not received an even greater number of citations, according to physicist Gino Segré,⁴⁹ University of Pennsylvania, may be that physicists have sometimes cited papers analyzing, rather than the paper reporting, the award-winning experiment. In fact, two such papers by Lincoln Wolfenstein, Carnegie-Mellon University, 50 and T.T. Wu, Harvard University and C. N. Yang, State University of New York, Stony Brook⁵¹ (and a 1957 Nobelist), have received 210 and 161 citations, respectively, since their publication. Indeed, these two papers appeared in a 1965 weak interaction cluster created by Sullivan and his colleagues in their evaluation of co-citation analysis and clustering.⁴⁷ This cluster (see Figure 1) reveals the close relationship between the Christenson, Cronin, Fitch, and Turlay paper (d),

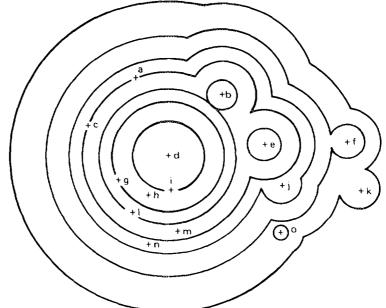
and the papers authored by Wu and Yang (g) and by Wolfenstein (h). While all three papers continue to be cited, the paper by Christenson and colleagues has received the greatest number of citations in recent years.

A review of citations to the primary authors in this cluster (see Table 2) shows that the four most-cited authors. all of whom are cited almost twice as often as the other physicists, are theorists (and Nobel prizewinners). According to White, theoretical physicists tend to publish a greater number of papers and presumably cite one another more often than do physicists involved in experimentation.⁴⁸ This is consistent with the citation records presented in Table 2. Whereas such theorists as Gell-Mann and Feynman have received several thousand citations, experimentalists such as Cronin and Fitch have received a few hundred.

Similarly, since our previous studies of most-cited physicists have been general, and not divided into experimental or theoretical physicists, it is not surprising that Cronin and Fitch have not turned up as highly cited authors. One of Cronin's many articles⁵² on large transverse momentum phenomena did appear on our list of the 1977 physical science articles most cited from 1977 to 1979.53 Our cluster data show that this article, and another of Cronin's articles on this experimental problem, have had a significant influence on other researchers in the field. Fitch has continued to work on charge conjugation parity invariance and other problems, but his articles have not appeared on any of our published lists.

The Christenson, Cronin, Fitch, and Turlay paper, together with a paper by J. Bernstein, G. Feinberg, and T. D. Lee,⁵⁴ formed the basis of our 1970 cluster on charge conjugation parity. When the core of a cluster is represented by only two papers and the cluster, such as this one, has not been cited by relatively many papers, it generally

Figure 1: Weak interactions co-citation map for 1965.



LEGEND:

- a. Abashian A, Abrams R J, Carpenter D W, Fisher G P, Nefkens B M K & Smith J H. Search for CP nonconservation in K § decays.
 Phys. Rev. Lett. 13:243-6, 1964.
- b. Feynman R P & Gell-Mann M. Theory of the Fermi interaction. Phys. Rev. 109:193-8, 1958.
- c. Lee T D & Yang C N. Parity nonconservation and a two-component theory of the neutrino. Phys. Rev. 105:1971-5, 1957.
- d. Christenson J H, Cronin J W, Fitch V L & Turlay R. Evidence for the 2# decay of the K⁰₂ meson. Phys. Rev. Lett. 13:138-40, 1964.
- e. Cabibbo N. Unitary symmetry and 'leptonic decays.' Phys. Rev. Lett. 10:531-3, 1963.
- f. Lee B W. Transformation properties of non-leptonic weak interactions. *Phys. Rev. Lett.* 12:83-6, 1964.
- g. Wu T T & Yang C N. Phenomenological analysis of violation of <u>CP</u> invariance in decay of K⁰ and K⁰. *Phys. Rev. Lett.* 13:380-5, 1964.

- Wolfenstein L. Violation of CP invariance and the possibility of very weak interactions.
 Phys. Rev. Lett. 13:562-4, 1964.
- Schwinger J. Broken symmetries and weak interactions. Phys. Rev. Lett. 13:355-8, 1964.
- Gell-Mann M. Nonleptonic decays and the eight-fold way. Phys. Rev. Lett. 12:155-6, 1964.
- k. Hara Y. Nonleptonic decays of baryons and the eight-fold way. Phys. Rev. Lett. 12:378-9, 1964.
- Cabibbo N. Possibility of large CP and T violation in weak interactions. Phys. Rev. Lett. 12:137-9, 1964.
- m. Bell J S & Perring J K. 2π decay of the K⁹₂ meson. Phys. Rev. Lett. 13:348-9, 1964.
- n. Bernstein J, Cabibbo N & Lee T D.
 CP invariance and the 2π decay mode of the K⁰₂.
 Phys. Lett. 12:146-8, 1964.
- Cabibbo N. Unitary symmetry and the nonleptonic decays.
 Phys. Rev. Lett. 12:62-3, 1964.

Source: Sullivan D, White D H & Barboni E J. Co-citation analysis of science: an evaluation. Soc. Stud. Sci. 7:223-40, 1977.

Table 2: Total first-author citation count of weak interaction physicists on 1965 co-citation cluster, 1961-1980.

R.P. Feynman*	8,965
M. Gell-Mann*	8,965
J. Schwinger*	6,641
T.D. Lee*	6,162
B.W. Lee	3,216
N. Cabibbo	2,847
T.T. Wu	2,493
J. Bernstein	2,228
J. Bell	1,841
Y. Hara	1,455
L. Wolfenstein	1,382
J.W. Cronin*	812
J.H. Christenson	695
A. Abashian	389
V.L. Fitch*	287

*Nobel prizewinner

reflects a specialty area being investigated by a small number of researchers. This cluster apparently reflects the tail end of a highly active research area that declined, as I mentioned before, when researchers—unsuccessful in their attempts to explain the asymmetry noted by Christenson, Cronin, Fitch, and Turlay—left the field.⁴⁷

Economics

It is important, when reviewing the citation records of scientists, social scientists, and humanities scholars in different fields, to remember that the citation rates for normal and exceptional papers vary from field to field. For example, we have found our lists of highly cited Social Sciences Citation Index® (SSCI®) articles and books tend to be dominated by psychology papers.55 This overshadows the work in sociology and other social sciences. The number of citations to a paper, and to a field in general, is proportional to both the number of papers published in that field and the number of references per paper.56 However, even though the average impact may be the same for many fields, the larger field will dominate the list of most-cited papers and journals.⁵⁷

This is exemplified by the field of biochemistry, which is not only large, but has an average of about 23 references per paper. 58 Thus, biochemistry papers tend to dominate our lists of most-cited papers and authors. Ideally, we should perform our citation studies field by field. We have done so on several occasions. 17,31,53,58 However, time and technical restraints prevent us from doing so in every study. As I'll explain in the following paragraphs, this problem is particularly evident in our analyses of the economics and literature Nobel prizewinners. Hopefully, we have provided enough perspective to help vou understand the significance of these authors' citations within their own fields.

Lawrence R. Klein, University of Pennsylvania, was awarded the 1980 Nobel Memorial Prize in Economic Science for the application of mathematical models to the analysis of economic systems. Klein's econometric models are now widely used to chart the future course of the economy and to predict its response to a variety of economic events. These highly complex models often involve 2,000 or more different interrelated equations that must be solved simultaneously.

Klein, who founded the Wharton Econometric Forecasting Associates. located in the same complex of high technology companies in Philadelphia as ISI, has been cited at least 1,465 times since the SSCI was initiated in 1966. This may not sound terribly impressive when compared with the citation records of the Nobelists in the natural sciences. However, the significance of the number becomes clear when you consider that fewer than 1,000 social scientists have been cited more than 500 times in the period 1966 to 1979. Only a fraction of these were economists. Although Klein does not appear on our lists of the 100 most-cited SSCI books, 59 authors, 60 or articles, 55 he would have ranked as the 260th

most-cited social scientist had we extended these lists. We found that only four of the most-cited articles and seven of the most-cited books on our SSCI studies were authored by economists. Similarly, we found that only 11 of the most-cited authors on our study of the 100 most-cited SSCI authors were economists. Also, we found that the second 100 authors on our list of mostcited SSCI authors60 had averaged about 1,260 citations from 1969 to 1977. Klein's 959 citations for this same period falls below this range. Remember, however, that most books and articles on these lists were no more than 20 years old, while much of Klein's pioneering and probably most-cited work was done in the 1940s and 1950s.

It is interesting that a book written by the graduate student with whom Klein developed one of the first in the current generation of econometric models appeared on our list of most-cited SSCI books. 59 Econometric Theory. 61 written by Arthur S. Goldberger, University of Wisconsin, has received 874 citations since its publication in 1964. It has been one of the major texts of econometrics. 62 The most-cited of Klein's books. A Textbook of Econometrics, 63 first published in 1952, has been cited 130 times since 1966. The first book on the econometric model developed by Klein and Goldberger, An Econometric Model of the U.S.,64 published in 1966, has received 79 citations. It seems likely that Klein's book, and many of his other early papers, received a large number of citations in the late 1940s and 1950s, immediately after he first developed the econometric models. Unfortunately, this was before the SSCI was begun so we have no record of these citations. We do know that many of his works from this period are still being cited. Also, it seems likely that Klein and Goldberger's seminal document has been displaced by more recent books written by other economists. We'll know more about this when we complete the citation record for econometrics in our new ISI/CompuMath 1th data base.

Zuckerman, in Scientific Elite,³ points out that Nobelists tend to produce a body of important, and sometimes unrelated, work throughout their careers. This phenomenon was clearly illustrated by the appearance of one of Klein's early works on two recent clusters of papers concerned with a consumer demand system and an extended linear expenditure system. According to Klein, this 1947 paper entitled, "A Constant-Utility Index of the Cost of Living," 65 was rediscovered by a number of researchers who entered the field in the mid-1970s. 62

Literature

When establishing the Nobel prize in literature, Alfred Nobel instructed the Swedish Academy to present the coveted award to the "person who shall have produced in the field of literature the most outstanding work of an idealistic tendency."66 The Academy's choice of Czeslaw Milosz for the 1980 prize demonstrates that this edict is still being followed. A Polish emigrant, poet, and novelist, Milosz's background as a World War II resistance fighter is reflected in his poems. According to exiled Russian poet Joseph Brodsky, many deal with the "unbearable realization that a human being is not able to grasp his experience."67 A professor at the University of California, Berkeley, for the last two decades. Milosz is best known in the English-speaking world for his poetry collections, Bells in Winter⁶⁸ and Selected Poems, ⁶⁹

Although the Academy has been criticized for its frequent choice of relatively unknown writers, 23 of the authors on our list of the 100 most-cited authors of twentieth-century literature were Nobel prizewinners. To In other words, the Academy frequently chooses writers who eventually, if not beforehand, are

recognized by scholars through citations. Milosz, who has received 23 citations since our Arts & Humanities Citation Index ^{1M} (A&HCI ^{1M}) was initiated in 1977, not surprisingly did not appear on our list of the 100 most-cited authors of twentieth-century literature. As Academy members state in their citation, Milosz's work can "only be fully appreciated by those who read it in Polish."71

As I've pointed out before, 70 A&HCI has a distinctly Anglo-American bias. Although many of Milosz's works have been translated, a great deal of it is only available in Polish. But I don't think this is a factor. As with so many other Nobel prizes in literature, the prize itself will be the spur to scholarship on this poet. Even so, the 23 citations his work has received since A&HCI was initiated places Milosz among the 150 most-cited authors in that data base. The least cited author on our list of the 100 most-cited authors of twentieth-century literature had received 26 citations. Odvsseus Elytis, who won the prize in literature in 1979, had received no citations in our data base, and Isaac Bashevis Singer, who won in 1978, had received only 14. Unlike most scientists whose work will inevitably be obliterated, these literary figures will be increasingly cited in the future as their work is studied and appreciated by scholars.

We will soon be publishing a series of essays on our study of the 1,000 most-cited scientists. It will be interesting to learn which of these scholars of Nobel

class have been or will become the future prizewinners. In reviewing the 1980 Nobel prizewinners, one is reminded that there is a strong correlation between publication, citedness or impact, and the subjective evaluations of peers. It is important that we carefully examine those cases where the selections are not matched by our citation expectancies. Whether this is simply due to the selection of small fields or other factors becomes evident once a reasonable effort is made to understand.

The trouble with many evaluations of scientific accomplishment today is that the nontrivial effort needed for an intelligent appraisal is not made. Surely the members of most award selection committees know this. Indeed, recent legal actions taken in connection with a Lasker⁷² award indicate that award committees may have to work much harder in the future if they are to avoid such conflicts. If award committees are unwilling to make the effort required in evaluating candidates, just imagine what goes on when a "mere" professorship is to be conferred. Citation data alone cannot solve these problems. But the data can point one in the right direction or provide the kind of indicators one needs for intelligent decisions.

My thanks to Joan Lipinsky Cochran and Edward M. Sweeney for their help in the preparation of this essay.

REFERENCES

- 1. Garfield E. Are the 1979 prizewinners of Nobel Class?

 Current Contents (38):5-13, 22 September 1980.
- 2. Price D J D. Telephone communication. 26 May 1981.
- 3. Zuckerman H. Scientific elite. New York: Macmillan, 1977. 335 p.
- 4. Kolata G B. The 1980 Nobel prize in chemistry. Science 210:887-9, 1980.
- Jackson D A, Symons R H & Berg P. Biochemical method for inserting new genetic information into DNA of Simian Virus 40: circular SV40 DNA molecules containing lambda-phage genes and the galactose operon of Escherichia coli. Proc. Nat. Acad. Sci. US 69:2904-9, 1972.
- 6. Lear J. Recombinant DNA. New York: Crown, 1978. 280 p.
- 7. Berg P. Personal communication. 4 December 1979.

- 8. Chamberlin M & Berg P. Deoxyribonucleic acid-directed synthesis of ribonucleic acid by an enzyme from Escherichia coli. Proc. Nat. Acad. Sci. US 48:81-94, 1962.
- 9. Lederberg J. Personal communication. 8 April 1981.
- 10. Salser W A. DNA sequencing techniques. Ann. Rev. Biochem. 43:923-65, 1974.
- Small H & Greenkee E. Citation context analysis of a co-citation cluster: recombinant-DNA. Scientometrics 2:277-301, 1980.
- Cohen S N, Chang A C Y & Hsu L. Nonchromosomal antibiotic resistance in bacteria: genetic transformation of Escherichia coli by R-factor DNA. Proc. Nat. Acad. Sci. US 69:2110-14, 1972.
- Garffeld E. ABCs of cluster mapping. Part 1. Most active fields in the life sciences in 1978. Current Contents (40):5-12, 6 October 1980.
- ABCs of cluster mapping. Part 2. Most active fields in the physical sciences in 1978. Current Contents (41):5-12, 13 October 1980.
- Gibert W. Polypeptide synthesis in Escherichia coli. II. The polypeptide chain and S-RNA. J. Mol. Biol. 6:389-403, 1963.
- Maxam A M & Gilbert W. A new method for sequencing DNA. Proc. Nat. Acad. Sci. US 74:560-4, 1977.
- Garfield E. Most-cited articles of the 1960s. 2. Biochemistry and molecular biology. Current Contents (35):5-14, 27 August 1979.
- The 1977 articles most cited from 1977 to 1979. Part 1. Life sciences. Current Contents (29):5-18, 21 July 1980.
- Gibert W. Starting and stopping sequences for the RNA polymerase. (Losick R & Chamberlin M, eds.) RNA polymerase. New York: Cold Spring Harbor Laboratory, 1976. p. 193-205.
- 21. Gibert W & Muller-Hill B. Isolation of the lac repressor.

Proc. Nat. Acad. Sci. US 56:1891-8, 1966.

- Gibert W & Maxam A. The nucleotide sequence of the lac operator. Proc. Nat. Acad. Sci. US 70:3581-4, 1973.
- Gilbert W, Gralla J, Majors J & Maxam A. Lactose operator sequences and the action of lac repressor. (Sund H & Blauer G, eds.) Protein-ligand interactions. New York: Walter de Gruyter, 1975. 193 p.
- Garfield E. ISI's on-line system makes searching so easy even a scientist can do it: introducing METADEX automatic indexing & ISI/BIOMED SEARCH. Current Contents (4):5-8, 26 January 1981.
- Sanger F, Dozekon I E, Coukon A R, Kossel H & Fischer D. Use of DNA polymerase I primed by a synthetic oligonucleotide to determine a nucleotide sequence in phage f1 DNA. Proc. Nat. Acad. Sci. US 70:1209-13, 1973.
- Sanger F, Nicklen S & Coulson A R. DNA sequencing with chain-terminating inhibitors. Proc. Nat. Acad. Sci. US 74:5463-7, 1977.
- Sazger F & Coulzon A R. The use of thin acrylamide gels for DNA sequencing. FEBS Lett. 87:107-10, 1978.
- A rapid method for determining sequences in DNA by primed synthesis with DNA polymerase. J. Mol. Biol. 94:441-8, 1975.
- Sanger F, Atr G M, Barrell B G, Brown N L, Coulson A R, Fiddes J C, Hutchton C A, Slocombe P M & Smith M. Nucleotide sequence of bacteriophage Φ X174 DNA. Nature 265:687-95, 1977.
- 30. Sanger F. The free amino groups of insulin. Biochem. J. 39:507-15, 1945.
- Garffeld E. Highly cited articles. 35. Biochemistry papers published in the 1940s. Current Contents (8):5-7, 21 February 1977.
- Sanger F, Brownlee G G & Barrell B G. A two-dimensional fractionation procedure for radioactive nucleotides. J. Mol. Biol. 13:373-98, 1965.
- 33. Sanger F. Citation Classic. Current Contents/Life Sciences (3):16, 19 January 1981.
- 34. Gartield E. Highly cited articles. 32. Articles from East European journals.

 Current Contents (46):5-9, 15 November 1976.*
- Snell G D. The H-2 locus of the mouse: observations and speculations concerning its comparative genetics and its polymorphism. Folia Biol. Prague 14:335-58, 1968.
- 36. Snell G D, ed. Biology of the laboratory mouse. New York: Dover, 1966. 497 p.
- 37, Methods for the study of histocompatibility genes. J. Genetics 49:87-103, 1948.
- Gorer P A, Lyman S & Snell G D. Studies on the genetic and antigenetic basis of tumour transplantation. Linkage between a histocompatibility gene and 'fused' in mice. Proc. Roy. Soc. London Ser. B 135:499-505, 1948.
- 39. Snell G D. Personal communication. 3 April 1981.
- 40. Dausset J. Iso-leuco-anticorps. Acta Haematol. 20:156-66, 1958.
- Bahzer H, Cleton F J & Eerakze J G, eds. Histocompatibility testing 1965.
 Baltimore, MD: Williams & Wilkins, 1966. 288 p.

- Benacerraf B & McDevitt H O. Histocompatibility-linked immune response genes. Science 175:273-9, 1972.
- 43. Garfield E. Were the 1972 papers most cited in 1972 the most significant? Current Contents (42):5-7, 17 October 1973.*
- 44. The 1972 articles most frequently cited in the years 1972-1975.

 Current Contents (19):5-9, 10 May 1976.*
- The 300 most-cited authors, 1961-1976, including co-authors at last. 1. How the names were selected. Current Contents (28):5-17, 10 July 1978.
- Christenson J H, Cronin J W, Fitch V L & Turiay R. Evidence for the 2π decay of the K₂^o meson. Phys. Rev. Lett. 13:138-40, 1964.
- Sullivan D, White D H & Barboni E J. Co-citation analysis of science: an evaluation. Soc. Stud. Sci. 7:223-40, 1977.
- 48. White D H. Personal communication. 1 April 1981.
- 49. Segré G. Personal communication. 18 February 1981.
- Wolfenstein L. Violation of CP invariance and the possibility of very weak interactions. Phys. Rev. Lett. 13:562-4, 1964.
- 51. Wu T T & Yang C N. Phenomenological analysis of violation of CP invariance in decay of K° and K °. Phys. Rev. Lett. 13:380-5, 1964.
- 52. Antreasyan D, Cronin J W, Frisch H J, Schochet M J, Kluberg L, Piroué P A & Sumner R L. Production of π⁺ and π⁻ at large transverse momentum in p-p and p-d collisions at 200, 300, and 400 GeV. Phys. Rev. Lett. 38:112-14, 1977.
- Garfield E. The 1977 articles most cited from 1977 to 1979.
 Physical sciences. Current Contents (30):5-17, 28 July 1980.
- Bernstein J, Feinberg G & Lee T D. Possible C, T noninvariance in the electromagnetic interaction. Phys. Rev. B—Condensed Matter 39:1650-9, 1965.
- 55. Garfield E. The 100 articles most cited by social scientists, 1969-1977. Current Contents (32):5-14, 7 August 1978.
- 56. Price D J D. Little science, big science. New York: Columbia University, 1963. 118 p.
- 57. Garfield E. Citation indexing: its theory and application in science, technology, and humanities. New York: Wiley, 1979, 274 p.
- 59. The 100 books most cited by social scientists, 1969-1977.
 - Current Contents (37):5-16, 11 September 1978.*
- The 100 most-cited SSCI authors, 1969-1977.
 How the names were selected. Current Contents (38):5-11, 18 September 1978.
- 61. Goldberger A S. Econometric theory. New York: Wiley, 1964. 339 p.
- 62. Klein L R. Personal communication. 7 April 1981.
- Klein L R & Goldberger A S. An econometric model of the U.S., 1929-1952.
 Amsterdam: North-Holland, 1966, 165 p.
- 65. Klein L R. A constant-utility index of the cost of living. Rev. Econ. Stud. 15(2):84-7, 1947.
- 66. Sinha S M. Nobel laureates of literature 1901-1973. New Delhi: S. Chand, 1975. 397 p.
- 67. Brodsky J. Poet's view: a true child of the century. NY Times 10 October 1980, p. A10.
- 68. Milosz C. Bells in winter. New York: Ecco, 1978. 73 p.
- 69. Selected poems. New York: Seabury, 1973. 140 p.
- Garfield E. The 100 most-cited authors of 20th century literature. Can citation data forecast the Nobel prize in literature? Current Contents (4):5-11, 28 January 1980.
- 71. Borders W. Polish poet in U.S. gets Nobel in literature. NY Times 10 October 1980, p. A1; A11.
- 72. FDA clips psychodrug pioneer's IND wings. Med. World News 22(4):9-10, 16 February 1981.

^{*}Reprinted in: Garfield E. Essays of an information scientist. Philadelphia: ISI Press, 1980. 3 vols.