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This report explores the scope and limitations of the use of citations of published works as measures of the influential productivity of scientists, and suggests that publication citations be utilized for educational research. The Science Citation Index is a list of references (cited works), each of which is followed by a list of the sources (citing works) which cite it. There is no limitation of citations to domestic publications or to year of publication. Although the Index is primarily intended to be used as an information retrieval system, other potential uses are presented in the report. Counts of citations of published work measure the quality of a publication and of an individual's contribution to science. Data are presented which bear on the nature of citation counts and the usefulness of these counts in evaluating the statistical evaluation of experimental groups. The control of these groups includes control of the academic fields in which individuals work and publish. Although the extensive educational literature would be more difficult to index than scientific works, it is felt that the expansion of the Index to include nonscientific fields would increase the value of this research tool. (WM)

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Table of Contents

Tables

Tables (continued)

The Use of Publication Citations in Educational Research[1]

John A. Creager

American Council on Education

Many educational research studies seek to ascertain the quantity and quality of tangible achievements of the subjects. Such information may constitute one or more elements of a composite criterion in studies of the outcomes of educational selection, types of support, learning processes, or exposures to kinds of educational environments. Astin (1964) has stressed the importance of noting the ecological nature of criterion variables; from the viewpoint of measurement, this implies the need for insight into factors affecting the criterion measurements. Evaluating tangible achievements may be necessary in selecting persons to be admitted to some program, and in ascertaining the outcomes or impacts of a program. In any case, the relevance, reliability, and relationships to other measurements of the items counted, the methods used to count, and factors affecting the counts must be explicitly known. The purpose of this report is to examine the scope and limitations of citation counts as measures of the influential productivity of scientists, and to suggest that the art in its present state might possibly be extended to the nonscientific disciplines.

A number of people reflecting on the limitations of using the number of publications as a measure of contribution to science, have suggested that the number of _citations_ of published work be used instead. Presumably, many mediocre publications are never cited in contrast to seminal works which are cited more frequently and for a longer time. Citation counts should therefore represent some selection on the basis of quality. By dint of a great deal of effort, Pelz (1955)

[1]A shorter version of this paper will appear in _The Journal of Educational Measurement_. 1967, In Press.

was able to compute citation counts as a criterion measure within the field of physiology. As a practical matter, however, such computation was far too laborious a job to be undertaken in large-scale studies until the appearance of the Science Citation Index (Garfield and Sher, 1963) produced by the Institute for Scientific Information with support of the National Science Foundation. This index makes this kind of data readily available. The 1963 edition of this index covers a wide range of journals published in 1961. The 1965 edition covers a still wider range of the 1964 Journals.

The Science Citation Index

The basic idea underlying citation indexing is expressed in the following quotation: "A citation index is an ordered list of references (cited works) in which each reference is followed by a list of the sources (citing works) which cite it. The cited work may have been quoted, discussed, criticized (as in a book review) etc."(Garfield, 1965a). The mechanics of constructing such an index consist first of examining the journals and other source documents published in a given year (e.g., 1961, 1964 or 1965, the three source years for which general science citation indexes have been published). The first-named authors of articles in the source documents become the units of a source index. Then the authors of each reference cited by the source authors in a source document becomes a unit of the citation index, no matter what year the cited reference was published. Indeed, one can find Aristotle, Galileo, Faraday, and Darwin among the cited authors in the 1964 Science Citation Index. This fact also illustrates that there is no restriction of citation to domestic publications. The editor of the Index has provided a detailed description of its nature and potential uses (Garfield, 1964b); Steinbach (1964) has reviewed the 1961 Index and commented on its potential uses and misuses. The Index is intended primarily as an information retrieval system facilitating searches of the literature. However, Price (1965) shows its value as a source of information about the sociology and history of science. As indicated earlier, the use of such a citation index for evaluation purposes has also been suggested, not without some misgivings. It is therefore relevant to consider the various factors which may affect the evaluative significance of citation counts.

The meaning of an individual citation is implicit in Garfield's statement, quoted above, about the basic idea underlying citation indexing. On the face of it, a single citation means only that the cited work, whatever its year of publication, its authorship, or its quality, was referred to by someone in a publication appearing during the source year. Works may be cited for a variety of reasons, but it is plausible to assume that the drudgery of bibliographic presentation tends to minimize irrelevant listings. Most commonly, an author cites another work to connect his work with current relevant activity in the field of investigation. This is part of the "sociology of science": one has noticed and reacted to a cited work. In this sense, at least, a cited work is influential. With the exception of summaries and reviews, articles rarely cite works in order to criticize them. Where the purpose in citing a reference is primarily to establish connections with related scientific activity, it may be presumed that most authors prefer to enhance the prestige of their own papers by citing the references of higher technical quality as well as the most relevant and the more recent. When a particular reference or a particular author is frequently cited, we can presume that this frequency is positively correlated with the quality of the cited work.

Temporal Effects

Citation counts for individual authors are a function of the extent of coverage provided by a given citation index. The coverage in turn is dependent upon field variations in publication and reference citing practices. The probability of an author's having a citation based on a given source year is considerably greater if his publication appeared in years immediately prior to the source year. For example, a paper published in 1964 in a journal covered by the 1964 Science Citation Index would be more likely to refer to papers published in 1960-64 than to those published in 1950-54 (Weiss, 1960). For reasons discussed below, a person may not have published much during the 1960-64 period, however extensive and excellent his publications in other periods. Conversely, a person may have completed an extensive block of work about 1960, submitted several papers in 1961, and had them published in 1963. The implication is that counts based on a single source-year index will result in an evaluation measurement limited in reliability and validity. The accumulation of counts based on several source years will increase the reliability of a citations variable. So far, the Science Citation Index has been published only for 1961, 1964, and 1965. The publishers hope to fill in the missing years, 1962-1963, and to keep up the Index on an annual basis.

Coverage

The number of source journals covered by the Science Citation Index has gradually been expanded. The 1961 Index covered 613 source journals, the 1964 Index, 700, and the 1965 Index covers about 1000. Similar growth in the coverage may be noted in the number of source articles, the number of citations, and the number of authors. The 1961 Index was generally thorough in its coverage of journals in biology, chemistry, and physics. Geology journals were not included, but are covered in the 1964 Index. Thus, an earth scientist would receive 1961 citations only if he had published in the physical science journals. Within physics, coverage of astronomy and space science was improved in the 1964 Index. Interdisciplinary journals are fairly well represented. Journal coverage is better in science than in technology. Most of these coverage policies, however, are a function of differing publication and referencing practices in various fields. For example, citation counts in engineering, mathematics, and geology are likely to be low and those in biology, chemistry and physics relatively high. Such factors as the scope and heterogeneity of a field, the number and size of journals published in given areas, the state of historical development as it affects the publication net in a given field, and different degrees of encouragement to publish and to relate one's work to others' in the network all affect the field differences in citation counts. The implication is that, if citation counts are to be used in evaluation studies, within-field base rates for citations should be considered and the counts must be statistically controlled by field. These considerations along with others to be discussed later, warn against evaluative use of individual counts for personnel decisions that may affect a person's career. However, with proper controls, individual counts may be used as data in statistical evaluation of groups.

Effects of the Career Situation

Different types of career situations provide different opportunities for producing publishable work, getting it published, and then having it cited by others, In addition to the field effects mentioned earlier, time factors in career progression, type of employer, and on-the-job functions affect publication and citation rates. A person's opportunity to publish in the scientific journals is extremely limited prior to his attaining the doctorate degree, rises to one or more peaks in his early post-doctoral years, and then may drop as his professional activity shifts from research to administration. Heavy teaching loads as well as administrative activity may limit publication and therefore citation rates. Industrial employment may be associated with research not immediately publishable, if publication involves competitive disadvantage for the employing company. In government, publication may be restricted to classified documents or to agency reports having limited circulation. The Science Citation Index has best coverage in the scientific journals for fields which emphasize research results. The Index also covers citations of books, dissertations, personal communications, and patents, but articles in source journals are more likely to refer to other journal articles than to industrial and governmental reports. The implication for evaluative use of citation counts is that controls are needed to take into account stage of career, employer category, and relative amounts of time in various functions (research, teaching, administration).

What and How to Count

When the Science Citation Index is used as a basis of evaluative information about individuals, various methodological problems arise, some of which have been discussed already. For a given individual either the number of items cited or the number of citations may be directly counted. From this information one may compute the number of citations per cited item, or the ratio of cited publications to total publications (obtained from a separate bibliography). Some information concerning the interrelations among these several variables will be presented later in this report. Evidence and experience so far suggest that, for evaluative purposes, citation counts are preferable to counts of cited items or to derived ratios.

Should all citations be counted? Approximately 8% of the total citations in the 1961 Index are self-citations; most individuals never cite themselves; a few are cited primarily by themselves. Although extensive self-citation appears to be associated with only average or below average performance on other indicators of quality and may be primarily a form of self-advertisement, some self-citations are quite legitimate. Not only do some obviously excellent persons (such as Nobel prize winners) do it, but also in a field like mathematics, small and relatively isolated groups of scientists, interested and cooperating in a new area may be communicating primarily with each other. For most educational research purposes, self-citations should probably be excluded from the counts, unless it can be shown that they contribute to the intrinsic measurement of impact on science. Similar considerations apply to other special categories of those referring to private communications, dissertations, patent disclosures, and other publications where counting such citations is relevant to the aims of a study. None of these categories is likely to amount to an appreciable percentage of the total count.

Multiple Authorship

The *Science Citation Index* lists citations by first-named author. In the frequent case of multiple authorship, various procedures are used to determine the order of listing authors: by alphabet, seniority, direct or indirect responsibility for the article, or other means. Obviously these practices imply some hazards in using counts for evaluative purposes. However, in follow-up studies of applicants for graduate fellowships, a check on citation counts for subjects at various positions in the alphabet failed to detect any bias from this source. Another check of the bibliographies supplied by questionnaire respondents indicates that multiple authorship is not common in the follow-up samples, and when it does occur, the subject is usually the first-named author. If complete reference information for a subject is available in his bibliography, it is theoretically possible to enter the index under the name of the senior author and count the number of citations of the articles of which the subject is a secondary author. Due to the extensive effort required and because not all subjects are consistent in giving complete bibliographic information, it may be necessary to accept this as a source of unreliability in the citation counts. Nevertheless, fairly reliable information could be obtained by more extensive and careful effort, if considerations of validity and relevance should justify it.

Reverse J-Curves

Among persons whose publications are cited at all, the distribution of numbers of persons receiving given numbers of citations is markedly skewed: many are cited only once, fewer twice, and so on. Although a count of five or six citations based on a given source year is not uncommon, the frequency of higher citation counts drops offrather rapidly, more than a dozen or so being rather rare. However, in an unselected group of scientists, we find that many are not cited at all, even though most of them are in academic situations and doing reasearch work. Either they do not publish, or their work is not referred to by others. In such a group the skewness is so marked as to be essentially a reverse J-curve, the situation typical for former fellowship applicants and for the members of a professional society.

For research purposes, either gross grouping of the counts or nonlinear transformations may be required in statistical treatment of the data. Although such treatment may result in lower validity coefficients, fine distinctions among the heavily cited subjects are of doubtful relevance.

Evaluative Content

The significance of citation counts as a measure of one's contribution to science may be discovered by counting how many citations are received by persons awarded Nobel prizes, or by persons elected to the National Academy of Sciences, for a year preceding such a nomination and therefore unaffected by it.

Although such recognition is partly a reflection of earlier visibility and cited achievement, it is an alternative, but not wholly independent, indication of recognized scientific achievement and contribution.

These counts have been made, and show that persons so selected were cited, on the average, over twenty times as frequently as were the general run of persons cited. As an indicator that citation is a measure of quality of an article, it was found that this was not just a function of the fact that these people had published much. The articles they authored were also cited about twice as frequently as were all other articles that were cited. On the basis of such evidence as this, serious study was undertaken of the utility of citation counts, and of some derivative measures such as ratios of citation counts to number of cited works for former fellowship candidates.

If citation counts are to be used in selection research for purposes of evaluating on-the-job performance and of validating selection variables, it is relevant to ask whether any external evidence exists that such counts have evaluative content. The 1955 Universtiy of Utah Research Conference on the Identification of Creative Scientific Talent included some relevant comments by Pelz (1956), referring to an earlier study by Lieberman and Meltzer (1954). The study in question examined the Annual Reviews of Physiology for three years and obtained citation counts on about 1800 members of three major physiological societies. A correlation of .50 was obtained between the number of publications published during the interval and the number of citations. Of course some were cited who had not published in this particular period, but the mean number of publications by each subject was about six and the mean number of citations, three. As Pelz commented, ". . .a selective process is operating, presumably in terms of quality."

Nobel Laureates

The publishers of the Science Citation Index, although cautious about the evaluative use of the Index, counted citations in the 1961 Index for several Nobel prize winners. What is important to realize here is that the citations were made prior to the awarding of the Nobel prize, and are not, therefore, attributable to publicity from the prize itself. Whereas the base-line number of items cited per author was 3.37 in the 1961 Index, the Nobel winners in physics, chemistry, and medicine for 1962 and 1963 averaged 58.10 cited items. The average number of citations was 5.51 for the total file and 169.00 for the Nobel winners. The number of citations per cited item was nearly twice that expected from the base rate.

Members of the National Academy

A count was made of the citations in both the 1961 and the 1964 Indexes for 35 persons elected to membership in the National Academy of Sciences in April, 1965. Election to the National Academy of Sciences is generally regarded as a mark of distinction based on original and extensive contribution to science and technology. All 35 had received one or more citations, and only four of the 35 had fewer than six citations. These four were persons in either fields or functions where publication and citation is less likely. Most electees had counts that were very high, in the 20-100 range, and several had more than 100.

Former Applicants for Graduate Fellowships

Various kinds of reliability and validity data bearing on the evaluative content of citation counts were obtained in follow-up studies of former applicants for National Science Foundation graduate fellowships. The details of these studies provide the sampling information and context for evaluating citation counts (Creager, 1962a, 1962b, 1965; Creager and Harmon,1966). One study, based on terminal applicants, that is, those in final stages of graduate education in 1952-53-54, provided the basis for a pilot study of citation counts. Most had finished graduate study and had published in time to be cited in the 1961 and 1964 Indexes. Further validation data were obtained from the first-year and intermediate applicants of 1955 and 1956, using counts based on the 1965 Index. First year applicants seek fellowship support for the first year of graduate study. Intermediate applicants have already been admitted to graduate study.

Fifty percent of the 1506 men and 48% of the 48 women in the terminal group received one or more citations. Only 16% of the 37 nondoctorates received citations. In two groups, rated "high" and "low" in on-the-job performance, 68% of the "high" group and 41% of the "low" group received citations. The percentages of the men receiving one or more citations in the 1961 Index are presented in Table 1.

These data may be interpreted in terms of known field differences, in doctorate attainment rates, publication practices, and employer categories. On this basis, these data indicate that doctorate attainment and academic employment with opportunity to do research in an experimental science are favorable conditions for receiving citations. The low count in geology is attributable in part to lower publication rates, and in part to lack of geology journals in the 1961 Index. The lower frequency of publication in mathematics largely accounts for the low percentage in that field.

Table 1

Percentage of Fellowship Applicants Receiving One or More Citations

Field	Number of cases	Percentage cited
Biology	380	58
Chemistry	457	52
Engineering	140	21
Geology	80	15
Mathematics	117	29
Physics (including astronomy)	301	69
Psychology	31	45

Other Citation Variables

In the same study, four variables in addition to the number of citations were considered. One of these, the number of cited references, was also obtained by direct count from the Science Citation Index. The other three are ratios: number of citations per cited reference; references cited divided by an index of productivity; and number of citations divided by the productivity index. A high citation count may result from infrequent citing of each of many publications, or from frequent citing of a few publications. A count of the number of cited reference ignores this distinction, but the ratio of citations to references points it up. The other two ratios attempt to reduce the effect of total productivity: i.e., to emphasize the quality rather than the quantity content of the citations information.

The intercorrelations among the five criterion elements derived from the Citation Index and their correlations with the productivity index provide further information about the meaning and potential utility of these elements in evaluation research. Such intercorrelations were obtained in five of the fields. Since the various fields have different patterns of relations between production and citation, some variations in these correlations could be expected, and were, in fact, found. However, the general pattern of intercorrelations may best be illustrated by the typical intercorrelation values obtained among the six variables. Median values computed from the five field samples are presented in Table 2.

Table 2

Intercorrelations Among Citation and Productivity Variables

Variable	1	2	3	4	5	6
1. Number of References	1.00					
2. Number of Citations	.96	1.00				
3. Citations/References	.75	.85	1.00			
4. References/Productivity	.85	.83	.55	1.00		
5. Citations/Productivity	.82	.83	.71	.90	1.00	
6. Productivity Index	.33	.30	.22	.10	.08	1.00

Since these correlations were obtained in the terminal fellowship applicant groups, they may be somewhat lower than those which would be obtained from a more general sample of scientists or former fellowship applicants. This is known to be the case for the correlation between productivity and citations. The report by Pelz (1956) gave a correlation of .50, a figure typical of those later obtained in the first-year and intermediate applicant samples. The correlation of .96 between counts of citations and counts of cited references indicates that these two variables are probably interchangeable, despite the logical difference in their meaning. The ratios have the disadvantage of having to be computed for each individual; this effort can be justified only if the ratios can be shown to have higher relevance, reliability, or validity in the context of a given study.

Validities

Validities of fellowship selection variables (Graduate Record Examination scores, undergraduate science grade average, and faculty ratings of over-all scientific ability) were computed against the five variables derived from citations information. This was done separately in five fields; biology, chemistry, engineering, mathematics, and physics. Neither job function nor employer category were controlled in this pilot study. A composite of selection variables predicted the citation counts with a validity of about .25. With the exception of biology, where the ratios were slightly better predicted, the number of citations was most predictable. Mean faculty ratings proved the best predictor with a little help from the Advanced GRE Test score.

It is of special interest that the citations are more predicatable by a few points, and uniformly so, than productivity. Correlations of citation counts with on-the-job performance ratings lie in the .25 to .35 range.

Thus it seems likely that citation counts contain some variance that measures quality as well as quantity of output.

Enriching the Picture

In the second and more thorough follow-up study involving first-year and intermediate fellowship applicants, the distributions and predictability of counts were again studied. In view of the results of the study of the terminal samples, only counts of citations by others were made; no counts of cited references and calculations of ratios were made. In this study, citation counts were obtained for all subjects (99%) for whom there was no substantial doubt concerning the matching between fellowship records and the citation indexes. Thus, information about nonrespondents to follow-up questionnaires could be gathered, which illustrates an important advantage of the citation counts: their depenaence of follow-up by questionnaires and of on-the-job performance reports. Bibliographic information from the questionnaire is helpful, however, in ensuring that the cited references are, indeed, those of the subject.

In this study, citation counts were obtained primarily from the 1964 rather than the 1961 Index. This choice was indicated partly by the greater likelihood that these subjects would have completed graduate study and achieved citable publications by 1964, and partly by the 1964 Index's more extensive coverage of the literature. However, it is theoretically possible to increase the relevance, reliability, and validity of the counts if they are based on more than one source year. Therefore, in biology, chemistry and physics separate counts were made based on the 1961 Index, and the counts from the two sources were combined. Since only a very small proportion of the subjects had completed graduate study by 1960, the counts based on the 1961 Index were much lower than those based on the 1964 Index. Otherwise, the distributions of counts from the two source years are similar. The correlations between 1961 and 1964 counts are typically in the .45 to .60 range and are higher for intermediate applicants and for 1955 applicants since these groups are more likely to have completed graduate study in time for 1961 counts to be meaningful and reliable. Validities in the various samples were uniformly higher for the 1964 counts. However, inclusion of the 1961 counts increased the validities slightly in several of the samples. It is apparent that combining counts from several source years can increase reliability, provided that the subjects have had time to progress in their careers far enough to have completed and published some research. Since this is not uniformly the case for the subjects in the study, distributions and validities will be presented only for the counts based on the 1964 Index.

Distributions of Citations

Distributions of citation counts for the subjects in the present study are presented in Table 3, which is divided into four horizontal sections representing various analytic groups of 3504 subjects. In the top section, subjects are grouped by application year, level, and sex. In the second section, they are grouped by field; in the third section, by questionnaire return status and employment categories. Finally the distributions for awardees and nonawardees are present. All distributions show the strong reverse-J curve previously noted for groups which include persons receiving no citations. In addition it is found that those groups with larger proportions of individuals having no citations also have smaller proportions of citation-receiving subjects with high citation rates. Not surprisingly,

Table 3

Distribution of Counts in 1964 Science Citation Index, in Follow-up Samples

Sample		Sample size	Number of Citations: None	1	2	3	4	5	6-8	9+	Uncer-tain match	Subjects with one or more citations
All subjects combined	N	3504	2315	292	197	118	84	70	134	259	35	1154
	%	100.0	66.1	8.3	5.6	3.4	2.4	2.0	3.8	7.4	1.0	32.9
1955 1st year men	N	844	564	59	56	24	21	11	38	63	8	272
	%	100.0	66.8	7.0	6.6	2.8	2.5	1.3	4.5	7.5	0.9	32.2
1955 1st year women	N	128	113	6	5	0	1	2	0	1	0	15
	%	100.0	88.3	4.7	3.9	0.0	0.8	1.6	0.0	0.8	0.0	11.7
1956 1st year men	N	935	659	75	47	26	19	17	28	54	10	266
	%	100.0	70.5	8.0	5.0	2.8	2.0	1.8	3.0	5.8	1.1	28.4
1956 1st year women	N	150	137	6	3	1	1	1	1	0	0	13
	%	100.0	91.3	4.0	2.0	0.7	0.7	0.7	0.7	0.0	0.0	8.7
1955 intermediate men	N	771	426	79	45	40	24	22	43	85	7	338
	%	100.0	55.3	10.2	5.8	5.2	3.1	2.9	5.6	11.0	0.9	43.8
1955 intermediate women	N	78	62	7	1	2	1	1	2	2	0	16
	%	100.0	79.5	9.0	1.3	2.6	1.3	1.3	2.6	2.6	0.0	20.5
1956 intermediate men	N	553	311	59	39	25	17	16	22	54	10	232
	%	100.0	56.2	10.7	7.1	4.5	3.1	2.9	3.9	9.8	1.8	42.0
1956 intermediate women	N	45	43	1	1	0	0	0	0	0	0	2
	%	100.0	95.6	2.2	2.2	0.0	0.0	0.0	0.0	0.0	0.0	4.4
Biology	N	712	443	60	41	25	20	15	27	71	10	259
	%	100.0	62.2	8.4	5.8	3.5	2.8	2.1	3.7	10.0	1.4	36.4
Chemistry	N	749	434	58	55	41	26	21	34	74	6	309
	%	100.0	57.9	7.7	7.3	5.5	3.5	2.8	4.5	9.9	0.8	41.3
Engineering	N	585	462	48	25	10	8	5	12	7	8	115
	%	100.0	79.0	8.2	4.3	1.7	1.4	0.9	2.0	1.2	1.4	19.6
Geology	N	177	144	12	6	5	1	2	1	0	6	33
	%	100.0	81.4	6.8	3.4	2.8	0.6	1.1	0.6	0.0	3.4	18.6
Mathematics	N	319	272	20	6	6	3	2	2	6	2	45
	%	100.0	85.3	6.3	1.9	1.9	0.9	0.6	0.6	1.9	0.6	14.1
Physics	N	800	434	80	60	27	26	23	55	87	8	358
	%	100.0	54.3	10.0	7.5	3.4	3.3	2.9	6.9	10.9	1.0	44.7
Psychology	N	162	126	14	4	4	0	2	3	8	1	35
	%	100.0	77.8	8.6	2.5	2.5	0.0	1.2	1.8	4.9	0.6	21.6
Employed by academic institution	N	953	518	85	59	41	32	31	59	128	0	435
	%	100.0	54.4	8.9	6.2	4.3	3.4	3.3	6.2	13.4	0.0	45.6
Employed by business or industry	N	603	406	49	29	27	10	10	23	48	1	196
	%	100.0	67.3	8.1	4.8	4.5	1.7	1.7	3.8	8.0	0.2	32.5
Employed by all levels of government	N	232	130	19	24	14	7	5	13	20	0	102
	%	100.0	56.0	8.2	10.3	6.0	3.0	2.2	5.6	8.6	0.0	44.0
Other employment categories	N	182	168	11	0	0	1	0	0	2	0	14
	%	100.0	92.3	6.0	0.0	0.0	0.5	0.0	0.0	1.0	0.0	7.6
Questionnaire non-returnees	N	1534	1093	128	85	36	34	24	39	61	34	407
	%	100.0	71.3	8.3	5.5	2.3	2.2	1.6	2.5	4.0	2.2	26.5
Awardees	N	943	500	96	65	45	26	19	59	122	11	432
	%	100.0	53.0	10.2	6.9	4.8	2.8	2.0	6.3	12.9	1.2	45.7
Non-awardees	N	2561	1815	196	132	73	58	51	75	137	24	722
	%	100.0	70.9	7.7	5.2	2.9	2.3	2.0	2.9	5.3	0.9	28.2

larger proportions of subjects with one or more citations are found among the older persons: the 1955 and intermediate applicants as compared with the 1956 and first-year applicants. In the case of differences between first-year and intermediate applicants some selection due to academic attrition has also occurred. In these otherwise unselected groups, citations are very much more frequent among men.

Field and Employer Variations

Citation rates are higher in biology, chemistry, and physics than in other fields, confirming the results observed with the terminal subjects. These groups are more often employed in the academic world and so have more opportunity for publishable and citable research activity. In this respect government employment is also favorable, although the proportion of subjects receiving many citations is higher in the academic group. Although the chances of being cited are lower for those employed by industry, about one-third of the present sample so employed received citations. Evidence presented elsewhere (Creager, 1962, 1965) indicates that a greater proportion of the lower ability applicants, as rated by the fellowship evaluation panels, are absorbed by industry in positions of lower technical responsibility. The reason for the very low citation ratings in the "other employment" category is that most of these people were unemployed or working in nonscientific jobs.

Quality Group Predicts Citations

In view of the earlier evidence for quality variance in citation counts (e.g., the higher citation rates for Nobel prize winners and electees to the National Academy of Sciences) the markedly higher percentages receiving citations among fellowship awardees (46%) than among nonawardees (28%) can be taken as further evidence of successful panel evaluation of fellowship applicants in terms of rated ability. The panel evaluation results in placing each applicant into one of six "Quality Groups," with Group I consisting of those considered most qualified to receive a fellowship. The distribution of citations received in the 1964 Index by the panel-determined quality group is of interest:

Quality Group:	I	II	III	IV	V	VI
% With one or more Citations (1964)	48.1	43.0	36.1	31.3	21.8	12.5

The correlation is clear though far from perfect.

Ph.D.s Get Cited More

It is not surprising that citation and attainment of the doctorate are related, as shown in Table 4 where frequencies and percentages of subjects in the total sample are cross-tabulated in terms of doctorate attainment and cited versus not-cited categories. One is rather unlikely to be cited if he has not attained the doctorate. Nevertheless a small group of nondoctorates were cited. The restriction of citation indexing to first-named author and the greater likelihood that published research in experimental science will be under the leadership of a doctorate-holder lead one to expect the positive relationship between doctorate and citations. The nondoctorates who are cited include those cited for work done during graduate study, and a few excellent and enterprising individuals who left graduate school and are in situations favorable for publishable research. More interesting is the large group of doctorate-holders without citations. This group includes capable people not in research settings and unproductive people who nevertheless manage to complete doctorates. Many of those not cited attained the doctorate too recently to have published articles that could be mentioned in the 1964 Index. Except for this, citation counts could compensate in part for imperfections in criteria of doctorate attainment if both kinds of criteria are included in a follow-up composite criterion. The point-biserial correlations between the doctorate attainment dichotomy and the citation counts typically lie between .30 and .40 in the various samples used in validation.

Time Spent in Research

In several of the foregoing sections, there has been frequent mention of the amount of time spent in research activity that might lead to publishable and citable results. The present data provide an opportunity to examine this question quantitatively for 1831 respondents who answered the questionnaire item regarding time spent in various functions on the job. Information supplied by the respondent was coded into nine patterns defined by percentage of time spent in teaching, research, administration, and other activities. Table 5 presents the number and percentage of subjects in each functional pattern who have one or more citations in the 1964 Index.

Table 4

Doctorate Attainment as a Factor in Citations

Citation Group	Doctorate Attainment Group								
	Doctorates			Nondoctorates			Total		
	Number of subjects	% of citation group	% of doctorates	Number of subjects	% of citation group	% of non-doctorates	Number of subjects	% of citation group	% of total
Cited	1049	90.9	50.1	105	9.1	7.4	1154	100.0	32.9
Not cited	1045	44.5	49.9	1305	55.5	92.6	2350	100.0	67.1
Total	2094	59.8	100.0	1410	40.2	100.0	3504	100.0	100.0

Table 5

Citations as a Function of Time Distribution

Activity Pattern	Number of subjects	Subjects with one or more citations	
		Number	Percent
A. 99-100% time in research & development	419	192	45.8
B. 60-98% time in research & development with remainder in administration	188	96	51.1
C. 60-98% time in research & development with remainder in teaching and/or other	272	161	59.2
D. 50-50 split in time between research-development & teaching activities	109	64	58.7
E. 50% time in research & development with remainder in various combinations of teaching, administration, and other activities.	137	60	43.8
F. More than 50% time teaching with some research & development	108	25	23.1
G. More than 50% time teaching with some administration	94	10	10.6
H. More than 50% time teaching with remainder in various combination of research, administration, and other activities	136	40	29.4
I. All other combinations	368	92	25.0
Total	1831	740	40.4

These data support the expectation that those with more time spent in research and development are more likely to receive citations. However, the relationship is not uniform; proper interpretation requires taking account of employer category and of the proportions of persons with high ability associated with the various functions. The supplemental data for these considerations are presented in Table 6.

If time spent in research were the main determinant of citation rate, Pattern A, in which full time is spent in research and development, would have the highest citation rate. The proportion of Pattern A subjects at the higher ability levels is close to that for the total sample, but a much higher proportion is employed in industry and government where results are more likely to be disseminated in house publications, technical memoranda, patent disclosures, and administrative reports. This picture is even more striking in Pattern B, where research functions are primary but where there is also appreciable administrative activity. Here the citation rate is higher, but the proportion of persons who have high-level ability is the same. It is likely that many of these people are in research administration in contrast to business administration; they are in a position to summarize and selectively disseminate industrial and governmental research results in the citations source journals.

Concerning the other patterns, it may be noted that a greater proportion of the high-level people appear in academic settings and spend at least half of their time in research (e.g. Patterns C and D). These people

Table 6

Employer Categories and Quality Group Level by Time Distribution Pattern

Time percentage distribution pattern	Percentage of cases in given time Pattern Category who are found in:			
	Academic jobs	Industrial jobs	Gov't jobs	Quality Groups I or II
A. 99-100% time in research & developm't	26	51	23	30
B. 60-98% time in research & development with remainder in administration	16	61	23	29
C. 60-98% time in research & development with remainder in teaching &/or other	64	22	14	40
D. 50-50 split in time between research-development & teaching activities	100	0	0	43
E. 50% time in research & developm't with remainder in various combinations of teaching, administration, & other activities	64	25	11	34
F. More than 50% time teaching with some research & development	100	0	0	23
G. More than 50% time teaching with some administration	98	2	0	15
H. More than 50% time teaching with remainder in various combinations of research, administration & other activities	100	0	0	31
I. All other combinations	34	52	14	27
Total	53	34	13	31

have high citation rates. It does not appear that some teaching load is detrimental to achieving citable research publications; indeed, it may be favorable for those with the ability to do both and for those in a position to relate the two functions in their professional life. This is more likely to be the case in the large doctorate-granting institutions. Those in smaller institutions, and primarily in teaching positions, at the undergraduate level, have much lower citation rates. Among former fellowship applicants, the proportion of the high-ability applicants who arrive in this combination of employment and function is relatively small. Finally, persons in the last pattern, who spend approximately equal portions of time in a variety of activities include the technician-level personnel, especially useful in industry and in other settings where carrying out detail is required more than is broad planning and supervision of research.

Correlations of Citations

To supplement the evidence obtained from distributions of citation counts for various groups of scientists and from other factors affecting citation counts, correlational analyses were undertaken. The correlations of citations with other follow-up criterion variables are presented in Table 7. The ability of the several predictor measures, separately and in the Summary Score composite of selection variables, to predict citation counts and the productivity index is shown in Tables 8 and 9. The correlations of Quality Group with these two criteria are also shown.

The previously noted relationship between citation counts and doctorate attainment and that between counts and productivity are well illustrated in Table 7. Correlations with overall rating and with income tend to be

Table 7

Correlations Between 1965 Citation Counts and Other Criterion Elements

Sample	N	Ph. D. attainment	Overall rating	Income	Productivity index
1st year - 1955	427	$\underline{\underline{40}}$	$\underline{\underline{27}}$	07	$\underline{\underline{52}}$
1st year - 1956	471	$\underline{\underline{37}}$	$\underline{\underline{26}}$	$\underline{13}$	$\underline{\underline{45}}$
Intermediate-1955	409	$\underline{\underline{24}}$	$\underline{\underline{31}}$	$\underline{\underline{21}}$	$\underline{\underline{49}}$
Intermediate-1956	282	$\underline{\underline{23}}$	$\underline{\underline{25}}$	11	$\underline{\underline{42}}$
Academic - 1955	437	$\underline{\underline{24}}$	$\underline{\underline{33}}$	$\underline{\underline{24}}$	$\underline{\underline{49}}$
Academic - 1956	442	$\underline{\underline{24}}$	$\underline{\underline{28}}$	$\underline{\underline{22}}$	$\underline{\underline{44}}$
Industrial-1955	293	$\underline{\underline{40}}$	$\underline{\underline{20}}$	$\underline{17}$	$\underline{\underline{49}}$
Industrial-1956	227	$\underline{\underline{39}}$	$\underline{19}$	14	$\underline{\underline{54}}$
Governmental-1955	106	$\underline{\underline{36}}$	$\underline{27}$	19	$\underline{\underline{48}}$
Governmental-1956	100	$\underline{\underline{43}}$	21	$\underline{27}$	$\underline{30}$
Biology - 1955	182	$\underline{\underline{26}}$	$\underline{\underline{29}}$	$\underline{\underline{29}}$	$\underline{\underline{38}}$
Biology - 1956	160	$\underline{\underline{31}}$	$\underline{\underline{28}}$	$\underline{\underline{35}}$	$\underline{\underline{36}}$
Chemistry - 1955	185	$\underline{\underline{29}}$	$\underline{\underline{46}}$	18	$\underline{\underline{57}}$
Chemistry - 1956	171	$\underline{\underline{32}}$	$\underline{\underline{40}}$	$\underline{\underline{26}}$	$\underline{\underline{57}}$
Engineering 55+56	249	$\underline{\underline{32}}$	$\underline{18}$	08	$\underline{\underline{45}}$
Geology 55 + 56	109	19	$\underline{25}$	01	$\underline{37}$
Mathematics 55+56	134	$\underline{25}$	$\underline{37}$	15	$\underline{\underline{41}}$
Physics - 1955	192	$\underline{\underline{38}}$	$\underline{\underline{37}}$	$\underline{\underline{30}}$	$\underline{\underline{62}}$
Physics - 1956	160	$\underline{\underline{38}}$	$\underline{22}$	20	$\underline{\underline{50}}$
Psychology 55+56	73	08	27	$\underline{31}$	$\underline{\underline{44}}$

Note. - Decimal points have been omitted. Coefficients significant at the 1% level are underlined; those significant at the .1% level are double-underlined.

Table 8

Correlations of Income, Productivity, and Citations with Five Predictor Variables

Sample	N	Verbal			Quantitative			Advanced			Grade point average			Reference rating average		
		In[a]	Pr[b]	Ci[c]	In	Pr	Ci	In	Pr	Ci	In	Pr	Ci	In	Pr	Ci
1st year																
1955	427	-02	14	27	22	03	18	14	22	25	03	13	16	00	11	14
1956	471	09	17	15	27	16	17	18	23	25	03	14	10	06	19	06
Intermediate																
1955	409	-01	00	12	23	03	18	10	01	10	05	07	09	08	22	16
1956	282	07	01	02	13	-02	05	13	07	15	01	-06	05	05	05	09
Academic																
1955	437	-01	09	21	21	06	21	14	20	22	04	01	07	09	15	11
1956	442	09	13	10	21	08	13	17	23	23	03	-03	00	03	09	04
Industrial																
1955	293	10	13	16	20	00	09	17	23	14	12	09	14	07	01	12
1956	227	20	06	05	11	00	02	17	18	18	04	03	11	09	04	08
Government																
1955	106	02	-08	18	14	03	28	12	04	17	-03	-02	16	08	03	19
1956	100	00	03	14	38	09	21	34	35	38	03	02	16	14	07	07
Biology																
1955	182	06	08	25	23	14	29	08	18	19	-05	08	12	01	04	04
1956	160	11	22	26	20	20	24	17	19	28	04	-01	07	13	08	15
Chemistry																
1955	185	-10	12	30	05	12	25	20	27	28	-06	05	13	00	15	23
1956	171	03	07	05	-01	10	17	11	43	35	-07	04	11	07	14	20
Engineering	249	05	08	09	06	04	02	03	17	13	10	08	04	10	08	05
Geology	109	14	14	11	03	21	15	11	33	08	00	03	07	05	05	08
Mathematics	134	16	26	16	29	13	09	17	34	20	-24	05	05	-19	19	20
Physics																
1955	192	-05	21	18	07	24	30	09	29	31	00	14	14	10	20	29
1956	160	02	04	05	17	13	12	26	26	18	-06	10	01	-02	10	-07
Psychology	73	-12	01	-03	-03	12	23	09	03	33	-11	04	-13	00	09	-04

Note.- Decimal points have been omitted. Coefficients significant at the 1% level are underlined; those significant at the .1% level are double-underlined.

[a]Income

[b]Productivity Index

[c]Citations Counts (1964)

Table 9

Correlations of Income, Productivity, and Citations with Summary Score and Quality Group.

	N	Summary score In[a]	Summary score Pr[b]	Summary score Ci[c]	Quality group In	Quality group Pr	Quality group Ci
1st year							
1955	427	10	20	27	08	20	24
1956	471	17	25	20	12	24	17
Intermediate							
1955	409	14	13	19	06	24	24
1956	282	11	04	13	05	10	15
Academic							
1955	437	15	19	24	11	22	25
1956	442	15	17	16	11	15	15
Industrial							
1955	293	19	17	20	17	18	16
1956	227	17	11	15	11	10	10
Government							
1955	106	11	02	26	01	-01	25
1956	100	29	23	31	11	19	13
Biology							
1955	182	09	16	23	15	13	30
1956	160	19	18	27	09	15	25
Chemistry							
1955	185	07	24	35	02	25	31
1956	171	06	27	28	-01	20	25
Engineering	249	09	14	10	09	10	07
Geology	109	12	25	14	05	16	06
Mathematics	134	03	31	22	04	32	17
Physics							
1955	192	09	31	36	11	27	37
1956	160	15	22	09	11	15	10
Psychology	73	01	09	16	13	10	12

Note.- Decimal points have been omitted. Coefficients significant at the 1% level are underlined; those significant at the .1% level are double-underlined.

[a]Income
[b]Productivity Index
[c]Citations Counts (1964)

higher in those categories where the "publish-or-perish" philosophy is more likely to prevail. Correlations with ability measures made several years before extensive publication are consistent with the hypothesis that citation counts have evaluative content. In groups where the counts are more reliable, the correlations with citations are higher than those with productivity.

Summary and Conclusions

The availability of the Science Citation Index provides those engaged in educational research with a useful tool. Counts of citations of published work not only measure quantity of publication, but contain a qualitative factor, often preferable in evaluation studies. This report has presented data bearing on the nature of citation counts, with special reference to potential hazards that arise from several factors that can affect them. In spite of these hazards, the usefulness of the counts in statistical evaluation of groups can be recommended where awareness of the hazards is accompanied by adequate controls in the design and execution of the study. Definition and control of experimental groups must include control of the academic fields in which subjects work and publish. Many other factors affecting citation counts are somewhat, but imperfectly, correlated with field. It is therefore highly desirable that additional controls for employment situation effects and for other factors which influence the counts be considered in the plan and execution of an evaluation study.

It may well be that the more able persons are more apt to go into those employment categories where productive and citable research is most likely. Data presented in Table 4 tend to support this assumption. To the extent that this is the case, the lower citation counts in some employer categories are not attributable to situational opportunity, but are partly a function of ability. Further research is needed to clarify the need for control of such selective input to the situations in which citation counts are being obtained for their evaluative content.

Where possible, it is desirable to build up the reliability of citation counts by basing the counts on more than one source year. In any case the decision to employ citation counts in an evaluation study must be based on their relevance to the aims of the study and the possibility of incorporating the necessary controls. Extra caution in using citation counts is required when the counts are to be used as a selection variable, since individual careers may be affected. In such cases considerably tighter control of the factors affecting the counts must be exercised than in the *ex post facto* evaluation of groups in a follow-up study.

Similar cautions are noted by Bayer and Folger (1966) in their study of some correlates of citation counts for 467 U.S. biochemistry doctorates. This study reports low but significant correlations between citation counts and quality of graduate education, and provides additional relevant references.

With these various precautions in mind, there would seem to be no reason why insightful use of this tool should be denied to educational research. Since published citations are available only in the science fields, the use of citation counts is necessarily limited at present to studies involving those fields. The extensive educational literature, as well as that in the arts and humanities journals would be somewhat more difficult, but not impossible, to index. If citation indexes in the nonscience fields are supported and thereby become available, the value of this research tool will be greatly enhanced.

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