MEASURES OF EXCELLENCE OF ENGINEERING AND SCIENCE DEPARTMENTS: A CHEMICAL ENGINEERING EXAMPLE

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THE PURPOSE OF this study was to determine how such measures[1] of departmental and research quality as number of citations of current research papers, number of citations of the research of a lifetime, number of Ph.D.'s graduated, funds expended for research, number of papers published, and others, correlate with one another and with the quality or visibility of departments as measured by peer evaluations such as those conducted by Cartter [1] and more recently by Roose and Andersen [2]. The number of citations by others correlates best with the other measures in the present study.

Numerous studies of citation analysis have been reported relatively recently [3, 4, 5, 6, 7, 8]. Also, the Institute for Scientific Information (ISI) has conducted a citation study for the National Science Foundation of all professors in the 78 leading chemistry departments listed in the Roose-Andersen report [2]. Several questions arise regarding the use of citations as measures of the quality of the research of an individual or group. First, does the number of citations provide a reasonably valid measure of research quality? Second, should one be concerned primarily with citations of recent work or of the work of a lifetime in assessing the value of the contributions that one has the potential for making in the future? Third, do citation counts correlate with other measures of quality, both objective and subjective? Fourth, can one compare the quality of individuals or groups in different disciplines on the basis of citation counts?

In the present study a simple random sample of 21 departments of chemical engineering in the U.S. universities was selected. Citations were counted in the *Science Citation Index* (SCI) (*11*)

TABLE 1

Spearman Rank Order Intercorrelation Coefficients for Departments of Chemical Engineering
N = Number of Departments Correlated in the Measure

No.	N	Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	21	Citations by others		.99	.95	.93	.91	.87	.85	.82	.87	.74	.81	.76	.63	.50	.31
2	21	Total citations			.95	.93	.93	.87	.84	.81	.87	.72	.83	.74	.62	.47	.27
3	21	Citations/professor				.89	.87	.82	.79	.71	.79	.83	.82	.68	.60	.42	.32
4	21	Papers with 5-9 citations					.93	.84	.86	.71	.71	.71	.73	.74	.42	.30	.10
5	21	Self-citations						.82	.86	.79	.57	.71	.69	.77	.40	.36	.16
6	21	Lifetime citations							.70	.59	.78	.54	.79	.57	.65	.48	.25
7	21	Number of papers								.67	.65	.84	.44	.94	.17	.43	.25
8	17	Research expenditures									.77	.59	.58	.65	.58	.45	.28
9	9	Papers with 10+ citations										.50	.72	.49	.56	.29	.13
10	12	Papers/professor											.42	.78	.15	.38	.36
11	21	Citations/paper												.30	.66	.27	.19
12	21	Papers with 0-4 citations													-.02	.44	.22
13	16	1970 Rating of Graduate Programs														.58	.58
14	21	Ph.D.'s graduated															.93
15	21	Ph.D.'s./professor															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

for 1965-9 (cumulative), 1970, 1971, and through June of 1972. The departments were ranked by number of citations, etc., and the rankings were compared with the unpublished Roose-Andersen rankings (that were supplied by Andersen) by use of the Spearman rank-order intercorrelation coefficients between all pairs of rankings. Results are in Table 1. All correlations are significant at least at the five percent level of confidence.

RESEARCH CITATIONS

THE NUMBERS OF citations to research by professors in different ChE departments varies much more than do other measures. In the 21 departments studied, the average number of lifetime citations[1] per professor varied in different departments from 275 in one department to 8 in another department with a mean of 79 for all professors in all departments; average number of citations[1] of 1967-9 articles per professor varied from 40 to 0.9 with a mean of 13 per department; number of papers published per professor in different departments varied from 6.5 to 0.63 with a mean of 3.6. The variation among individual professors is much greater than among departments. For example, lifetime citations vary from 0 to 1,100 and those of 1967-9 articles from 0 to 162. Thus, it seems that the recognition, as measured by the number of citations to works of professors in different departments, varies much more than does the rate at which they publish articles, and departments with professors who publish more, on the average, seem to be the source of work that is used (cited) more. These data dispel the myth that those who publish prolifically, publish less significant work; quantity and quality are correlated highly positively.

Our low correlation coefficient, 0.17, between the number of articles and peer recognition (Roose & Andersen (RA) study (2)) contrasts with the 0.67 obtained by Hagstrom [12] for biology, chemistry, mathematics, and physics departments. This suggests that there may be a difference, on the average, between the impact of science and applied science articles.

Departmental reputations as measured by the RA study [2], tend to correlate slightly better with lifetime citations than with '67-9 departmental citations.[1] That is, it is not only the work that is presently being done or has been done in the recent past, but also the work that has been done years ago, that contributes significantly to the reputation among peers of individuals and departments. Our results show the correlation coefficient between peer judgment (RA) and the first-author citations to be 0.65; Hagstrom [12] obtained 0.69. Also, our results for both first-author lifetime citations and total '67-9 citations are 0.65 and 0.62, respectively; Hagstroms and our results are on the same order but are somewhat lower than the 0.75 obtained in the recent study of 78 leading chemistry departments carried out by ISI [13]. On the other hand, our correlation between citations per article and the RA ratings is 0.66 whereas the ISI correlation is only 0.48. The ISI counting by computer was the most comprehensive, ours was next, and Hagstrom's was the least since he apparently used first-author data for only 1966.

CITATION OVERLAP

WE HAVE CONSIDERED essentially five different measures of excellence including various types of citation counts, research support, numbers of papers published, peer evaluations and Ph.D.'s produced. Clearly, the various types of citation counts overlap in items counted and therefore high correlation coefficients between these counts are not surprising. The other four measures are not so obviously related to one another or to citation counts. Therefore, we might wish to ask which of the ways of counting citations has the highest mean correlation with the four non-citation measures. On this basis citations by others and total citations per department correlate most highly with the other measures (0.70 and 0.69) and these are followed by citations per professor (0.63).

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It is somewhat surprising that number 15, Ph.D.'s graduated per professor has among the lowest correlation with the other measures. However, number 14, Ph.D.'s graduated per department, correlates quite well, on the same order as citation counts, with the peer evaluations of

TABLE 2

Data on Measures

No.	MEASURE	MAXIMUM	MINIMUM	MEAN	MEDIAN
1	Citations by others/dept.	428	7	151	89
2	Total citations/dept.	495	7	179	111
3	Citations/professor	40	0.9	13.4	11.4
4	Papers with 5-9 citations	23	0	8.9	6
5	Self-citations/dept.	74	0	27.4	21
6	Lifetime citations/dept.	3,847	58	963	772
7	Number of papers/dept.	118	5	46.4	39
8	Research expenditures/yr.	$664,K	$28,K	$265,K	$251,K
9	Papers with 10-plus citations	18	1	8.1	7.5
10	Papers/professor	6.5	0	3.7	3.6
11	Citations/paper	6.9	1.1	3.3	2.9
12	Papers with 0-4 citations	75	4	28	21
13	Withheld				
14	Ph.D's. Graduated/yr.	12	1	4.4	4
15	Ph.D's./professor/yr.	0.93	0.09	0.36	0.30
16	Lifetime citations/professor	1,194	0	78.6	32.5
17	Professors/school	21	5	12.1	11

the Roose-Andersen 1970 Rating of Graduate Programs. This implies that department size is important and larger departments are more visible to others in the field.

Maxima, minima, means, and medians of the measures in Table 1, plus numbers 16 and 17, are given in Table II. It is interesting to note that, on a departmental basis, the citation counts per professor show means and medians that do not differ greatly. However, number 16 in Table II, which refers to the lifetime citations per individual, shows a mean of about 79 and a median of 33. This indicates that, on an individual basis, the distribution of citations is highly skewed and that a relatively small number of highly talented people contribute work that is highly cited and which accounts for a large fraction of all of the citations of the entire group. Thus, the mean does not reflect the performance of the average individual because the average is so strongly influenced by those with outstanding citation records. The median seems much more representative of average individual performance.

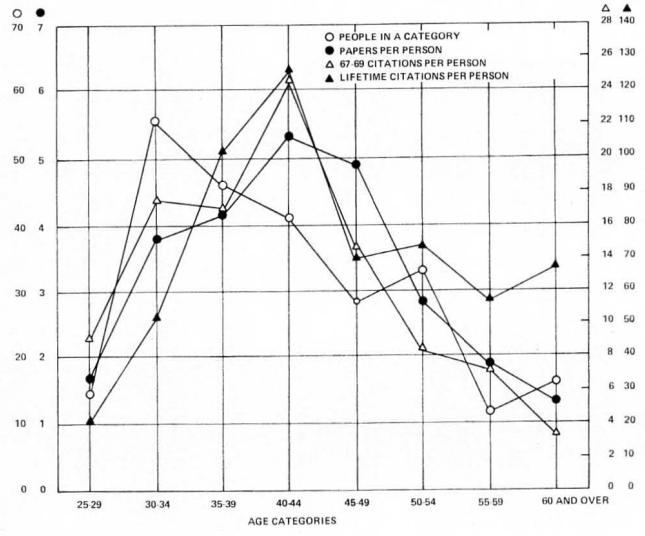

FIGURE 1
Relationship between age and productivity in Chemical Engineers.

It does not seem reasonable to compare the quality of departments in different disciplines by the measures discussed. For example, the average chemistry article is cited close to 10 times (one department was lowest with 5.3, another had 25.3 in the ISI study) whereas the average ChE article is cited about 3 times or less. Some data were obtained on various engineering departments to see if citation rates differ among them. It appears that civil and mechanical engineers cite somewhat less frequently (1/3 to 1/2) than do chemical engineers, and electrical engineers cite perhaps twice as frequently as do chemical engineers.

The relationship between age and productivity of chemical engineers is interesting. As shown in Figure 1, all measures of research productivity peak in the 40-44 age group; individuals in this group published an average of approximately 5 papers each during the two-year period, 1967-9, and these papers were cited approximately 5 times each; the lifetime citations for this group averaged about 126 per professor.

PERFORMANCE EVALUATION

EVALUATION OF THE performance of individuals and departments is difficult at best, but it is customary and necessary. Appointment, funding, promotion, ranking, selection, and tenure depend upon the results of evaluation. Objective data, such as those discussed here, are useful (if crude) measures that enable one to minimize unrealistic appraisals. It certainly seems that the number of citations should be included in any evaluation of the research performance of individuals or departments. Indeed, the dossier of every candidate for tenure or promotion should include a citation analysis of his published work.

DEFINITIONS

1. **Citations by others: Number of non-self citations of works published between 1967 and 1969 and listed in the** *American Chemical Society Directory of Graduate Research, 1971* **[10] (including those works in which the author studied is not listed first on the work).** *Science Citation Indexes:* **1965-9 cumulative, 1970, 1971, and the first half of 1972 were used for the random sample of 21 departments of chemical engineering in the U. S.**
2. **Total citations: Self-citations plus citations by others.**
3. **Citations/professor: Total citations of '67-9 works divided by number of faculty members.**
4. **Papers with 5-9 citations: Works published in the '67-9 period per department—with 5-9 total citations.**
5. **Self-citations: Authors' citations of their own '67-9 works (including those works on which their names do not appear first).**
6. **Lifetime citations: The number of citations, including self-citations, to all works on which a faculty member is first or only author.**
7. **Number of papers: Works published in the '67-9 period.**
8. **Research expenditures: Dollars spent per department for research per year, averaged for the '67-9 period.**
9. **Papers with 10-plus citations: Works published in**

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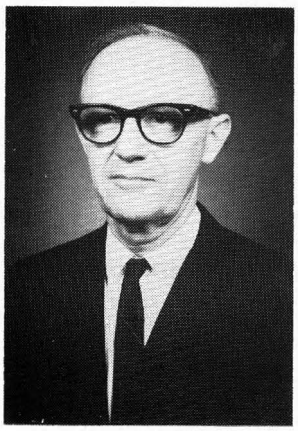

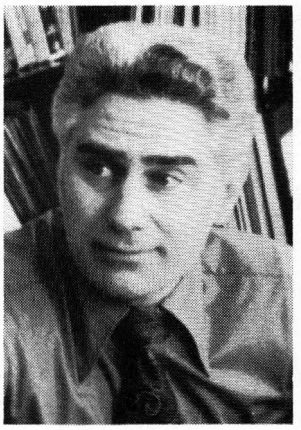

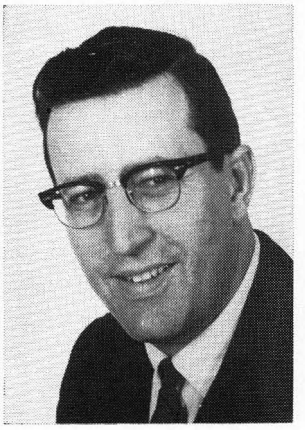

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William N. Gill took his Ph.D. at Syracuse University and remained there on the faculty until 1965 at which time he joined the Department of Chemical Engineering at Clarkson College of Technology as Chairman. In 1971 he became Provost of the Faculty of Engineering and Applied Sciences and Professor of Chemical Engineering at the State University of New York at Buffalo. He has written about 100 articles on theoretical and experimental studies in transport phenomena. Recently his main research activities have been in reverse osmosis, including hollow fiber systems, and the development of a new theory of unsteady convective diffusion in which a generalized dispersion model is derived from first principles. (CENTER)

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DIGITAL COMPUTATIONS: Liu

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propositions. What is perhaps the most encouraging of all is the interest in this course and the constructive criticism by the class.

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'67-9 and cited ten or more times.

10. **Papers/professor: Works published in the '67-9 period divided by the number of professors, publishing or not, in the departments in that period.**
11. **Citations/paper: Total citations divided by the number of '67-9 works (impact factor).**
12. **Papers with 0-4 citations: '67-9 works with through four total citations.**
13. **1970 Rating of Graduate Programs: Detailed data of Roose and Andersen study on rankings of departments of ChE kindly supplied by Andersen.**
14. **Ph.D.'s graduated: Ph.D.'s graduated per year during '67-9.**
15. **Ph.D's/professor: Ph.D.'s graduated per faculty member per year in '67-9.**
16. **Lifetime citations/professor: The number of citations, including self-citations, to all works on which a faculty member is first or only author divided by the number of professors, publishing or not, in the literature cited.**
17. **Professors/school: The number of professors, publishing or not, in the literature cited divided by number of schools (21).**

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