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OBJECTIVITY VERSUS RELEVANCE IN STUDIES OF SCIENTIFIC ADVANCE

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A conceptual framework is suggested within which various techniques for studying scientific advance may be viewed. The two axes are *relevance* of the technique to a "true" measure of the rate of scientific advance, versus *objectivity* of the technique. It is suggested that a situation exists somewhat analogous to the Heisenberg uncertainty principle; the most objective technique, a simple publication count, is the least relevant to a true measure of scientific advance, while the most relevant technique, interviews with an eminent and knowledgeable scientist in the field, is the least objective. Between these two extremes lie a group of scientometric techniques which should be capable of producing analyses which are both satisfactorily relevant and satisfactorily objective.

Introduction

For many decades scientists and scientific historians have been struggling to develop techniques for the measurement of various aspects of science. In this paper we focus on measuring the rate of advance of a science.

Some of these past techniques have been purely descriptive, counts of papers, scientists, citations and so forth. Others of these past techniques have been highly interpretive, attempting to capture the social and philosophical milieus which surround scientific advances. Most studies have both descriptive and interpretive aspects. For example, one of the first studies with substantial quantitative underpinnings was the 1917 COLE and EALES count and analysis of the literature of comparative anatomy, spanning the 300 year period from 1543 through 1860.[1] COLE and EALES were able to clearly relate counts of national research publication to the political events of the time. In the 60 years since COLE and EALES' work, hundreds of papers and books have related scientific progress to its surrounding socioeconomic milieu.

Fig. 1 attempts to put this vast field into a rational perspective by summarizing the main techniques which may be used for measuring the contributions of a science

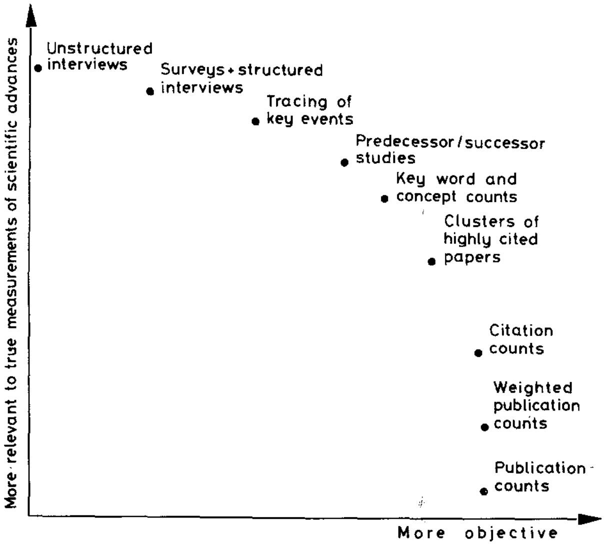

Fig. 1. Techniques for measuring the advance of a science or technology (supplementing directly measurable technical parameters)

or technology. Underlying the figure is an analogy to the Heisenberg uncertainly principle in quantum physics. Within the limitations of the current state-of-the-art, those science policy studies which are most relevant to measuring the true rate of contribution of a science have the greatest uncertainty as to objectivity, while those which are the most objective have the greatest uncertainty as to relevance. Between these extremes lie combinations of techniques from which a satisfactorily relevant and satisfactorily objective study of research advances can be designed.

For example, an unstructured interview with the most knowledgeable research scientist in a field would probably give an assessment of the science which is precisely relevant to the true rate of its advancement. On the other hand, this asssessment would be highly subjective and difficult to compare, for example, with the assessment of an equally qualified scientist in another field.

At the other end of the spectrum is a count of scientific publications – truly objective, since an equivalent count can be carried out on any other field simply by defining a field in a bibliometrically reasonable way. Yet one can argue with considerable force that the publication rate in a science is not necessarily proportional to the rate of advance of that science.

Between these two extremes lies a set of measurement techniques which are perhaps not as directly relevant as the interview with the top man in the field, but certainly are more objective.

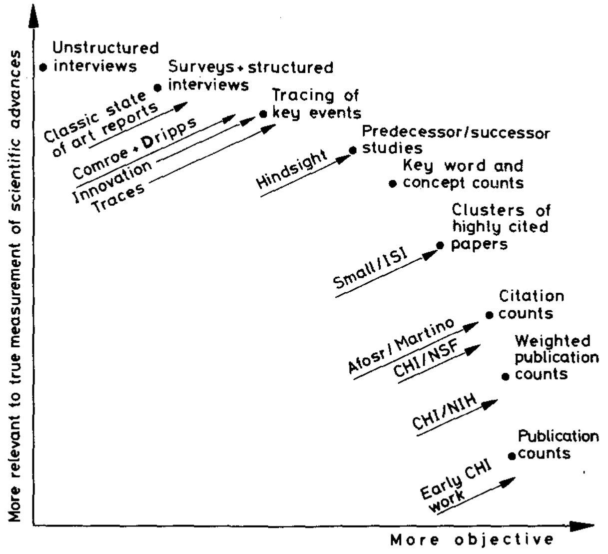

Fig. 2. Studies of R and D contributions

Classification of studies

Fig. 2 superimposes upon Fig. 1 some of the more well known studies in the field.

Unstructured interviews

Starting at the least objective techniques, a typical state-of-the-art report is the very excellent 600 page, single spaced report entitled "Chemistry and the Economy" produced by the American Chemical Society in 1973.[2] This study was based largely on interviews conducted by and with knowledgeable scientists and executives in the chemical industry; the report sought to document past accomplishments of chemistry, to describe the United States' chemistry resources, to discern the directions and implications of future developments, and to suggest ways in which the chemical education system may contribute to meeting social and economic needs. It is a very thorough and excellent report, but hardly the basis from which one can make quantitative assessments.

Structured interviews

Somewhat more quantitative is a recent and extensive study by COMROE and DRIPPS[3] which sought to develop statistical evidence demonstrating the contribution basic research provides to modern clinical medicine.

Their subject was clinical advances in treatment of cardiovascular and pulmonary diseases since the early 1940's. First, they selected the top ten advances in the field by asking physicians and specialists to list advances, to vote on the lists, and to arrive at a consensus.

COMROE and DRIPPS then identified the bodies of knowledge necessary for each of these ten advances, with the aid of 140 different consultants, identifying 137 essential bodies of knowledge. They then examined some 4000 scientific papers to establish the history of the 137 essential bodies of knowledge which were crucial to the ten advances. Ultimately, they found that some 41% of these articles were not clinically oriented. COMROE and DRIPPS felt that they had clearly demonstrated that the clinical advances in cardiovascular and pulmonary diseases were strongly dependent on predecessor basic biomedical research.

The COMROE and DRIPPS study has some limitations, as all studies of this kind do. There was no quantitative scaling of the impact of the advances, or of the research upon which the advances were based. They also did not include some parameters relevant to policy issues which are often touched upon in a modern analysis – the type of organizations which produced the research, who supported them and what was the mechanism for the support.

Tracings

Two studies rating higher on the objectivity scale are the original TRACES study[4] done at IIT Research Institute and the follow on Innovation Study performed at Battelle.[5] These are somewhat more objective than the COMROE and DRIPPS study because citation and historiographic techniques were used to establish formal links between the different bodies of knowledge which led to the advance and because an explicit attempt was made to quantify some of the policy relevant aspects of the research leading to the advance – especially organization type, source of support, intellectual milieu in which the advances were conceived, and a classification of the research according to a scale ranging from basic to applied.

Predecessor/Successor studies

The next technique, which is somewhat less directly related to the direct measurement of advances, is the predecessor/successor study, of which the HINDSIGHT study is the most famous.[6]

In the HINDSIGHT study the U.S. Department of Defense tried to measure the payoff of investment in science and technology. They chose proven utility in an end item as the criterion for measuring payoff, and found a very large payoff – ten to one – from applied R and D investments. In their study they took a predecessor and successor military hardware system: for example, a cargo airplane and its successor ten years down the line. They then measured the cost-effectiveness of the successor system compared to the predecessor, and tried to relate the difference between the two systems to R and D activities. They found a very large payoff from the applied R and D investment, and also found that old science (pre–1940) was literally priceless in value to the DOD. However, that conclusion was tempered by the finding that the DOD's investment in contemporary basic research had little direct consequence to these technological advances in weaponry.

Key words and concepts

A class of study which has not yet been applied to the science policy area is that of key word and concept counts. These are popular in the information science area, including studies of the technical content of titles of scientific papers, and the appearance of new key words. One possibility in studying the advance of science would be to look for the appearance of new terms and concepts in the key papers, and to see if these new terms, which presumably would be related to concepts and methodologies which have become accepted in the field, are directly related to identified research advances.

Clusters of papers

Another set of techniques which is becoming very useful for science policy are those allowing the identification of clusters of highly cited and interrelated papers, generally as co-citation clusters. In the co-citation technique, developed by SMALL,[7,8] two papers are said to be linked if they are jointly cited by a successor paper. In essence, co-citation establishes a link between published papers, based upon the perception of these papers by current scientists. Co-citation clusters do seem to represent the very forefront of scientific knowledge in the recent past, and a number of studies have suggested that a co-citation cluster of one to two hundred papers is often the precise locus of a scientific front, in one sense the "villages of science" of which the subfields and fields are constructed.[9]

Citation counts

The technique of counting citations to individual papers preceded the more recent co-citation developments. Citation counting is still controversial, but it is rapidly becoming accepted as one means of ascribing impact, importance or value to an individual scientific paper. It was first suggested by GARFIELD[10] and applied a number of years ago by MARTINO at the U.S. Air Force Office of Scientific Research (AFOSR to show AFOSR programs were supporting papers that were relatively highly cited.[11] Computer Horizons, Inc. has used the technique recently, in a more sophisticated way, to study the citation rates for all U.S. papers published in chemistry journals in 1972. The object of our study was to see whether the National Science Foundation (NSF) was supporting highly cited papers in chemistry.[12]

This study was carried out by taking all of the U.S. papers in a few hundred chemistry journals and dividing them into citation frequency quartiles. The fraction of the papers in each quartile which were supported by various agencies was then noted. A most interesting observation was that the set of chemistry papers which are highly cited from within chemistry is not the same as the set of chemistry papers which are highly cited from outside of chemistry. The set of chemical papers which are highly cited by scientists within chemistry were heavily supported by NSF; the set of chemical papers which are highly cited by scientists outside of chemistry were not particularly heavily supported by NSF. Further analysis revealed that the set of chemistry papers highly cited by scientists outside of chemistry were largely papers in such areas as pharmacodynamics and biochemistry, which were being very heavily cited by biomedical research fields. The highly cited papers in those fields of chemistry were heavily supported by U.S. National Institutes of Health.

Weighted publication counts

The weighted publication counts developed by Computer Horizons, Inc. is a technique of particular use in studying large collections of publications. In a weighted publication count each paper in a journal is given an influence based on the weighted number of time each paper in that journal is cited. Using the citation properties of the journals rather than citation counts for individual papers allows one to economically deal with very large data sets, and to construct profiles of research activity. Two of Computer Horizons, Inc. papers outline this technique for biomedicine[13] and physics.[14]

Publication counts

Finally, perhaps the most objective technique, and perhaps least relevant to the measurement of scientific advance is that of a publication count. At a very aggregate level this is a useful technique. It was used, for example, in the 1972, 1974, and 1976 *Science Indicators* studies.[15,16] This technique provides a measure of scientific activity in a field, and is useful as a basic activity indicator. However, the jump from count ing publications to ascribing scientific advancement to such counts is very questionable without the use of citation weighting or some other quality surrogate.

Future possibilities

As the field of scientometrics develops there should be further progress in enhancing both the relevance and the objectivity of its analytic techniques. Such enhancement should lead to far greater policy impact for the studies based upon these techniques.

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