Information Processing & Management Vol. 20, No. 5/6, pp. 575–582, 1984
Printed in the U.S.A.

0306–4573/84 $3.00 + .00

ASSESSING SCIENTIFIC PERFORMANCE

JOHN M. WEINER†, STEPHEN M. STOWE, RICHARD C. HONOUR and G. DENMAN HAMMOND
University of Southern California School of Medicine, 2025 Zonal Avenue, Los Angeles, CA 90033, U.S.A.

(*Received for publication* 9 *August* 1983)

Abstract—A method for assessing scientific performance is proposed and illustrated. Advantages over existing methods are: (1) increased objectivity; (2) increased emphasis on *what* was rather than *who* contributed; and (3) increased accuracy in theme identification. The procedure is based on relationships displayed numerically in the published documents. These relationships are extracted and organized as a graphic display representing the conceptual structure for a subject. Individuals or groups contributing to the knowledge of the discipline can be identified. The extent of their contributions also can be documented.

The method is illustrated using published documents in Pediatric Oncology for the period 1979–1982. The contributions of a major clinical investigations group, the Childrens Cancer Study Group, are analyzed. The results show increasing contributions by the Group as the conceptual structure changes from the simplest measure of survival to ones requiring sophisticated follow-up and clinical evaluation procedures.

INTRODUCTION

Traditionally, innovations in scientific knowledge have been linked to significant contributions by individuals[1]. The accounts of their scientific creativity have been dramatized and fictionalized to imply a cadre of superior beings possessing unique qualities necessary for innovation and creation[2, 3]. The implication from such stories is the existence of *a priori* special qualities possessed by the individual which, when applied to a scientific subject, will yield a revolutionary reorganization of the concept structure for that subject[4, 5].

This emphasis on the individual could exist unchallenged except for a recent process of scientific investigation involving groups of individuals and different disciplines. The multidisciplinary research group evolved in response to the need to solve problems requiring diverse sets of knowledge and expertise. The explorations in space and the therapeutic trials in chronic diseases are examples of this new group approach to scientific inquiry[6–9].

The search for individual contributors requires a network of informants. Members of the network have the responsibility for finding candidates, and such candidates must pass the screen of consensus opinion. Clearly, the winner must have reported important new work, but the time at which this work is recognized as new and important does not have to be current. That is, the recognition process uses hindsight, often of many years duration, in order to classify the work. This lag allowed the development of consensus and agreement regarding the contribution and its influence on subsequent scientific progress[10].

The need for a more objective and timely method for selecting significant contributors in science was met by an approach which focuses on citing behavior among the scientists[11]. The assumption employed is that workers in a field recognize and acknowledge primary contributors by citing their works. The citational analysis methods identify those contributors by developing a number of graphic displays. A simplified example from GARFIELD[12] is shown in Fig. 1. Authors are identified by Arabic numerals. The theme described in the article is identified by a key descriptive word. The authors are grouped into clusters dealing with techniques used and/or themes studied. Distance between authors reflects the degree to which the involved authors were cited together. Nodes or primary locations on the map are formed when a number of authors, independently and separately,

†Author to whom correspondence should be addressed.

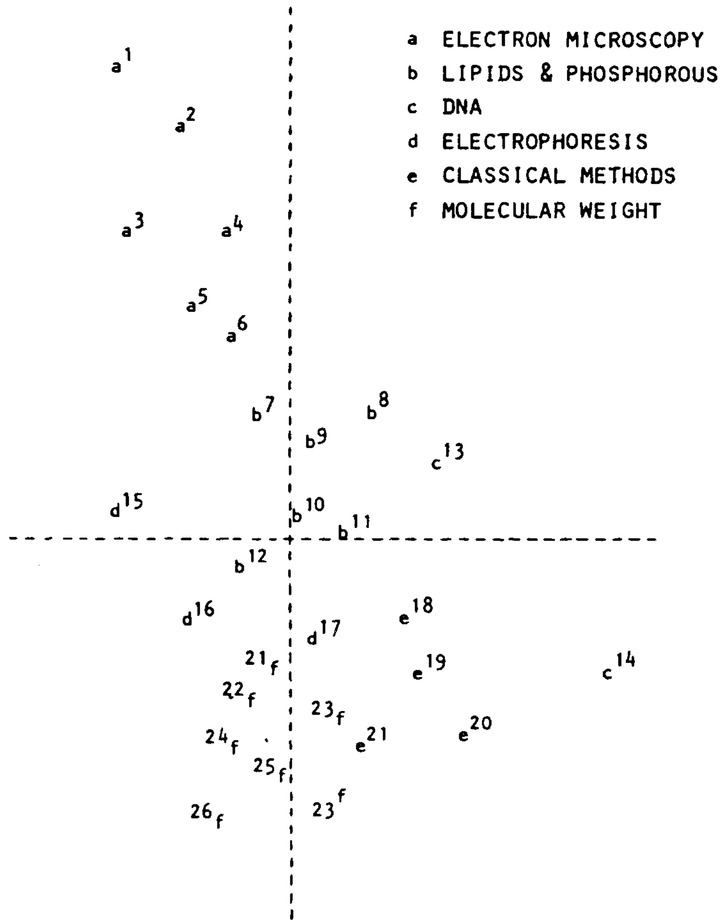

Fig. 1. Example of analytic display using citational methods for extracting and analyzing scientific contributors.

cite other authors. By adding the time factor, namely, the earliest reference to the theme by frequently cited authors, the source of the idea can be identified. A map of such source ideas can be used to identify the scientists providing significant change to existing conceptual structures[13].

The most frequently cited author was excluded from the graph in Fig. 1, because the distance between points shrinks to zero with the inclusion of that author. This exclusion points up a cogent problem with the method. That is, the most frequently cited author provided a method rather than a significant reorganization of existing knowledge. With that method available, investigators could pursue their own analytic interests. The method offered no conceptual improvement, but did offer a useful technique. As such, the citing behavior analysis failed to differentiate between contribution to conceptual structure and investigator recognition of technique.

There is another model of cognitive behavior which could be used to decide contributors to science. That model involves the identification and organization of informational elements leading to the presentation of informational displays[14, 15]. Studies using the model have included data obtained by analysis of the text, of the numeric displays within the documents, or some combination of text and displays. The simplest form, in the sense of ease in training technicians, is the numeric display analysis. This form establishes the existence of studied relationships. These relationships form the essential input to the analysis and give a physical representation of the concept structure. Relationships are author described associations between two or more characteristics. Examples of the bivariate linkage or relationship would be survival and therapeutic regimen or age and sex. In each situation, the author links the two terms and describes the conditions under which the relationship was observed.

The relationships expressed in numeric displays have an important subjective element. In order to present a a numeric relationship display, the author, editor, and reviewers must agree regarding the importance of the display[16]. Only those displays considered to be relevant to the subject are included in the published document. By selecting a numeric relationship for display, the experts reviewing the document also must agree that the associated concepts are important. This transformation process between the physical elements depicted by the numeric relationship and the cognitive elements considered in the concepts is dynamic.

The relationships method has been applied to a number of information processing and utilization situations. Its role in summarizing and critiquing scientific progress was studied in late effects of anti-cancer treatment[14], in design of non-Hodgkin's lymphoma protocols[17], and in decision making situations[18]. The method has been studied in techniques designed to rapidly learn a new body of knowledge[19] and in analysis of complex text[20]. The relationships method also has been studied as an alternative to current indexing methods and was shown to be superior[21]. Each of these studies showed the increased objectivity and replicability of extracted data available from the method. In comparison with expert generated subject reviews, the relationships method yielded a more complete description of the appropriate concept structure[14, 18]. Given its applicability in evaluating specific subjects, it is of interest to determine the method's role in evaluating issues related tangentially to the subject matter structure. One such issue is the identification of scientific contributors. To explore this, the contributions of the Childrens Cancer Study Group (CCSG) to the discipline of pediatric oncology were studied.

METHODS

Documents published in peer reviewed journals, scientific organization proceedings, and scientific books dealing with pediatric oncology were selected for the period 1979–1982. Those documents were separated into those with and those without numeric relationship displays. Those articles with numeric relationships shown in graphic or tabular form were retained and analyzed. The variates making up each relationship and the statistical test result (significant, non-significant, or not tested) were computerized. These data were analyzed and organized into concept structures[22].

The structures considered in this analysis deal with survival. Authors studied survival using four variates: (1) Survival (i.e. living vs dead); (2) Time Survival (i.e. length of time patient survived); (3) Survival Relapse Free (i.e. living free of disease vs dead); (4) Time Survival Relapse Free (i.e. length of time patient survived disease free).

RESULTS

The Childrens Cancer Study Group contributed an increasing proportion of articles with numeric relationships to the total 551 published from 1979 through 1982. As shown in Fig. 2, the total number of articles reached a peak of 188 in 1980. The 1982 total declined to 77, a decrease to 41% of the peak volume. The CCSG reported about 15% of the total articles in 1979 and 1980. This level increased to over 30% for 1981 and 1982.

There were 59 numeric relationships with measures of survival reported in the 551 articles studied. The variates involved were classified in terms of reporting source (i.e. CCSG or other) and structural category in medicine. The structural categories are: personal, disease, treatment, outcome, and study condition factors. The distributions shown in Table 1 are similar, suggesting that CCSG approached survival studies in a comparable fashion to other groups and institutions. This is important, in that the CCSG tends to be described as being primarily concerned with therapies. While this description is generally accurate, modern therapeutic investigations include characteristics defining personal, disease, and outcome factors. As seen in Table 1, there were four variates used from the personal factors set. Two of those were studied by CCSG and two were not. Similarly, 18 of the 40 variates representing the category of "disease factors" were reported by the CCSG. Overall, the

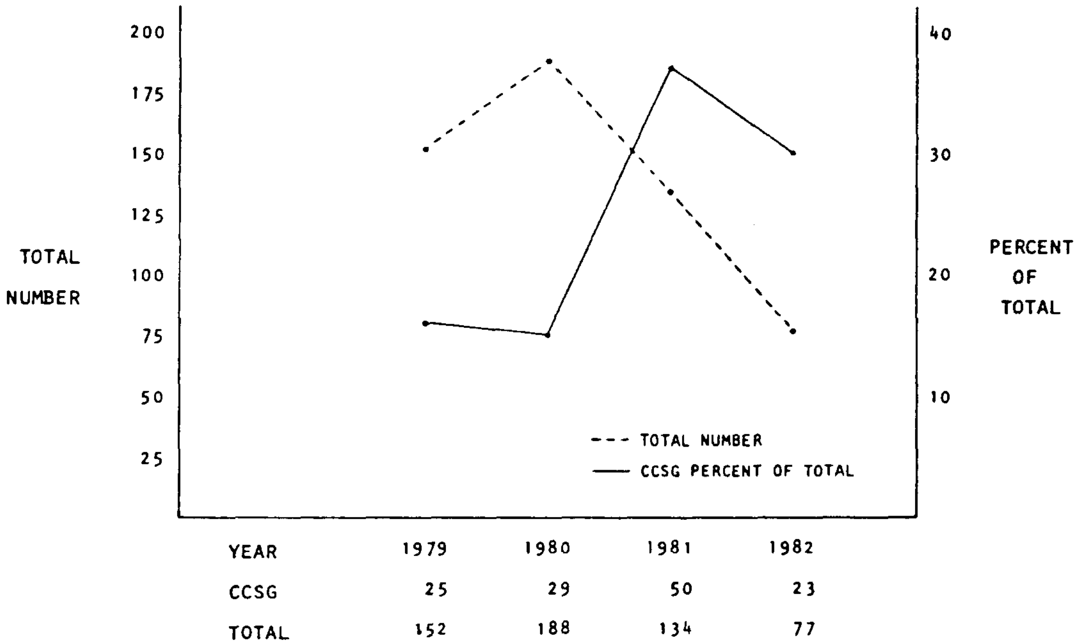

Fig. 2. Total number of articles in pediatric oncology data base and the CCSG contribution.

Table 1. Reported relationships involving measures of survival

Factor	Contributor CCSG	Others	Total
Personal	2	2	4
Disease	18	22	40
Treatment	4	5	9
Outcome	2	2	4
Study	0	2	2
Total	26	33	59

CCSG reported data for 26 of the 59 relationships displayed numerically in one or more articles.

Another analytic view is summarized in Fig. 3. The concept structure dealing with Survival involved four measures of survival. These are shown on the horizontal axis of the figure. There were 34 relationships represented by numeric displays in the total document set involving survival measured as living vs dead. Ten of the 34 were reported in CCSG documents. There were 18 CCSG relationships in the 51 dealing with Time Survival. When survival was measured taking disease control into account, CCSG contributions to the concept structures increased to 89% and 93% respectively.

The concept structure for Time Relapse Free Survival is shown in Fig. 4 in order to illustrate the CCSG contributions. There were two personal factors and nine disease factors. All were reported by CCSG in relationship to the survival parameter. Of the four treatment factors, three were reported by CCSG. Thus, of the 15 relationships shown, CCSG reported on 14 of them.

DISCUSSION

This study describes a text analysis model in identifying scientific performance as determined by contribution to the discipline's conceptual structure. The structure is determined from an analysis of relationships expressed numerically in scientific articles. The hypothesis considered is that investigators study relationships which make up the concept structure assumed to be meaningful in their field.

This analytic method differs in concept and application from the co-citational approaches described by GARFIELD [12], SMALL [11] and others [23–26]. The methods employed in preparing co-citational maps still require subjective referral patterns. The difference in co-citational methods is in the more impersonal approach in identifying potential con-

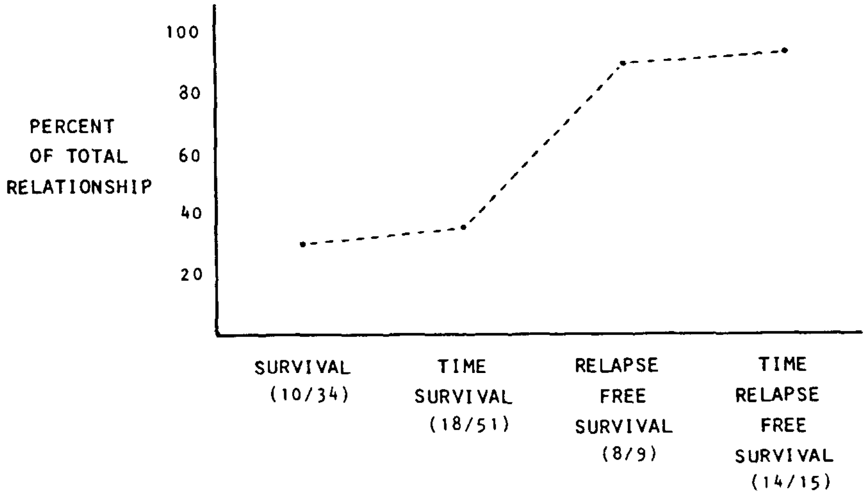

Fig. 3. Relationships studied by CCSG in describing survival in cancer.

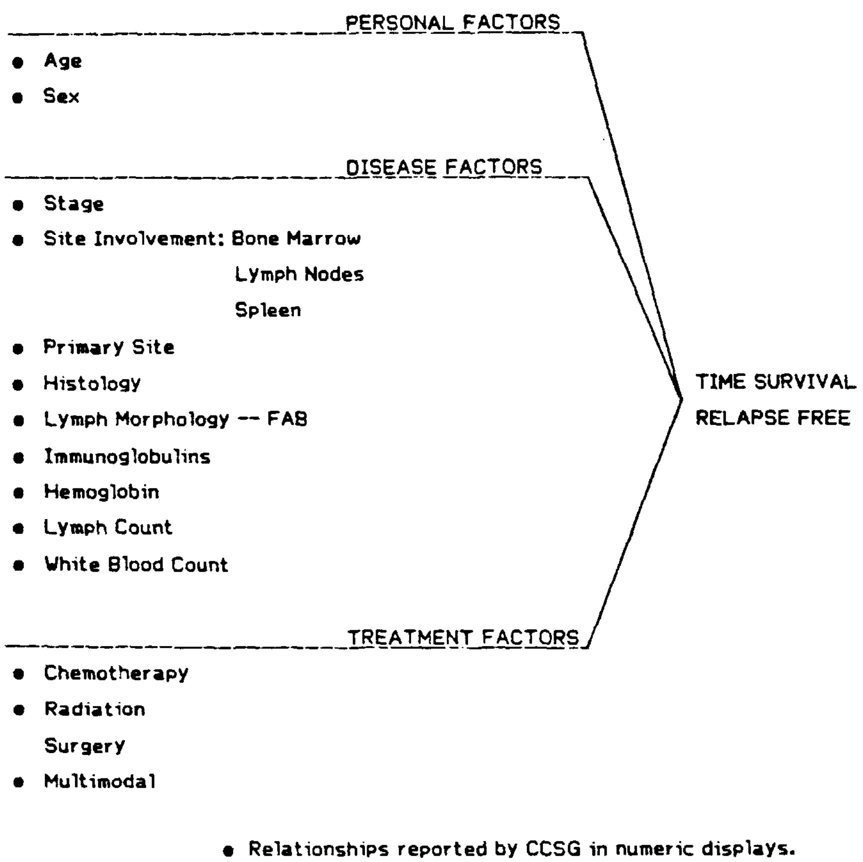

Fig. 4. Contributions to oncology—time survival relapse free.

tributors. The identification is made by the citing behavior of the authors of scientific documents. Because contributors are nominated within the context of a scientific article, the identification process is considered to be more objective.

A citation does not mean acknowledgment of contribution. Instead, the citation might be used to identify the individual committing an error of judgment or process. The methods of analysis of citing behavior employed do not differentiate between citations for or against the cited author. As such, the map of primary contributors does not depict accurately those who did contribute vs those who did not. A more important, albeit rarer, error would be the identification of a contributor who in actuality was repeating statements from a true but unidentified contributor. The citation process allows for all of these possibilities.

Another failing in the citing behavior analyses is the theme labeling. If key words are extracted from a document, these words may represent new labels for existing procedures rather than new labels for new procedures. The contributor who introduces new concepts may not introduce new labels. Another individual may pick up the new concepts and change the labels in order to better understand the innovation. This second scientist could easily become the primary contributor, since the key words originated with him. As such, the method could identify the advertising specialist and leave the inventor in obscurity.

The ultimate failure in the citing behavior analyses stems from the difficulties faced by an expert in keeping up with the literature in his field. The increase in numbers of new journal titles, of new proceedings, and of new book titles all translate to reading more in order to keep up. In one survey, we found 4500 titles dealing with a pertinent theme in pediatric oncology. These titles were published during a four year period. The expert would be required to inspect approximately 100 documents per month on this one aspect of the total specialty. Similar large numbers can be found for over half of the topics making up pediatric oncology. Another feature of the problem is that the necessary articles may not be published in accessible journals. Further, the individuals performing the studies may not be members of related disciplines[27–29]. Of necessity, the list of authors cited in a scientific article will tend to be limited.

The analysis of relationships method differs in important ways from the citing behavior methods. The most cogent of these is the way in which the subject matter contribution is found. The citing methods find the theme by first finding the individual. The relationship methods find the theme by identifying the pattern of variates used in describing it. The contributing individuals can be identified in a straightforward fashion after the pattern of variates is established. A second important difference is in the manner of identifying the theme. The relationship methods extract linked variates as presented by the author. These linkages are organized in order to display the pattern of studied relationships. This pattern represents the subject matter as perceived by those studying it. The citing methods require the assignment of a single word or phrase to the article's content. This summarization process is difficult and the results of such could be variable in spite of training and expertise. The third important difference is focus. The citing methods focus on *who* (i.e. the authors cited), while the relationships methods hone in on *what* (i.e. the relationships studied). A "who" emphasis implies an indirect approach to identifying significant contributions, since the contributions must first be determined and evaluated. While experts in a field undoubtedly identify both theme and contributor simultaneously, a formal translation of that process requires separation of the two.

Using the method of numeric relationships in analyzing the contribution of CCSG provided some interesting findings. As was seen in Fig. 2, the CCSG's contribution to the total number of articles reporting relationships in numeric form doubled through the time period studied. Over 30% of the scientific data (i.e. numeric relationships) documents were prepared by the CCSG.

Most impressive findings were the large proportions (89% and 93%) of relationships studied by the CCSG when the measures—Relapse Free Survival and Time Relapse Free Survival—were considered. The measure—Time Survival—also showed the philosophy of CCSG studies. Fifty-one percent of the relationships reported numerically had been studied by the CCSG. The number of relationships studied by CCSG was smaller (29%) when the simplest of the survival measures was used. The increasing number of relationships with parameters requiring more skill and effort in their study is indicative of the quality of the contribution to the conceptual structure.

Reviewing the variates studied by CCSG also shows the depth and quality of supplied information. For the most part, the disease factor variates were ones which can be measured in any modern medical facility. As such, the survival findings are relevant to the population in any geographical setting. This form of technology transfer is one of the key issues in the National Cancer Institute's program for control of cancer. The data suggest that the scientific reports not only contributed to the understanding of cancer but did so in a practical, applicable way.

SUMMARY

Information processing techniques are being used to determine scientific contribution as well as other important issues. The co-citational methods currently are favored in spite of significant limitations. Two are: subjectivity in the citing practices of the authors and inaccuracy in theme identification. The latter problem is seen with methods designed to extract the "meaning" of the document in terms of a single word or phrase.

An alternative analytic approach has been reported. This method considers the numeric relationship in terms of the variates contributing to it. The method can be performed by trained technicians. Replicability of extracted relationships is enhanced by the restrictions provided by the author in developing the numeric displays. That is, the author eliminates the "guess work" dealing with the variates linked to form the relationships and provides the technician with the elements needed for extraction.

When this method was used in assessing the performance of the CCSG, the relationship approach showed that the more cogent parameters describing survival were studied by the CCSG. The contribution to pediatric oncology was important scientifically and practically. The CCSG has provided data and concepts for the scientists. It also has provided diagnostic and therapeutic techniques for the practitioners.

REFERENCES

[1] I. Asimov, *The New Intelligent Guide to Science*, pp. 314–321, 626–627. Basic Books, New York (1965).

[2] H. Zuckerman, Nobel laureates in science: patterns of productivity, collaboration, and authorship. In *Science As A Career Choice—Theoretical and Empirical Studies*. (Edited by Bernice T. Eiduson and Linda Beckman). Russell Sage Foundation, New York, 1973.

[3] J. A. Chambers, Relating personality and biographical factors to scientific creativity. In *Science As A Career Choice—Theoretical and Empirical Studies*. (Edited by Bernice T. Eiduson and Linda Beckman). Russell Sage Foundation, New York, 1973.

[4] R. K. Merton, Priorities in scientific discovery: a chapter in the sociology of science. In *The Sociology of Science* (Edited by Bernard Barber and Walter Hirsch), pp. 447–485. The Free Press of Glencoe, New York (1962).

[5] T. S. Kuhn, Energy conservation as an example of simultaneous discovery. In *The Sociology of Science* (Edited by Bernard Barber and Walter Hirsch), pp. 486–515. The Free Press of Glencoe, New York (1962).

[6] W. O. Hagstrom, *The Scientific Community*, Chap. 1. Basic Books, New York (1965).

[7] N. W. Storer, Relations among scientific disciplines. In *The Social Contexts of Research* (Edited by Saad Z. Nagi and Ronald G. Corwin), pp. 229–268. Wiley–Interscience, London (1972).

[8] A. J. Meadows, *Communication in Science*, Chap. 7. Butterworth & Co. Ltd., London (1974).

[9] W. D. Garvey, *Communication: The Essence of Science*, Chap. 1. Pergamon Press, New York (1979).

[10] J. R. Cole and S. Cole, *Social Stratification in Science*, Chap. 2. The University of Chicago Press, Chicago (1973).

[11] H. G. Small and B. C. Griffith, The structure of scientific literature, I. Identifying and graphing specialties. *Science Studies* 1974, **4**, 17–40.

[12] E. Garfield, Citation indexing—its theory and application. In *Science, Technology and Humanities*, pp. 62–80. Wiley, New York (1979).

[13] E. Noma, Untangling citation networks. *Inform. Proc. Management* 1982, **18**, 43–53.

[14] J. M. WEINER, S. M. STOWE, S. SHIRLEY and N. J. GILMAN, Information processing using document data management techniques. *Proc. 44th Amer. Soc. for Inform. Sci. Annual Meeting* 1981, **18**, 291–294.

[15] E. HOFFMANN, Defining Information—II. A quantitative evaluation of the information content of documents. *Inform. Proc. Management* 1982, **18,** 133–139.

[16] A. S. RELMAN, Journals. Chapter 5. In *Coping with the Biomedical Literature* (Edited by K. S. WARREN). Praeger, New York (1981).

[17] S. M. STOWE, G. D. HAMMOND, R. CHARD, J. A. HORNBERGER, R. C. HONOUR, R. SPOSTO and J. M. WEINER, Monitoring clinical research. Accepted for publication in the *Amer. J. Clinical Oncology*.

[18] S. S. FULLER, R. E. WEINER, N. J. GILMAN, J. M. WEINER and D. STANLEY, The literature of decision making—an analytical approach. *Proc. 45th Amer. Soc. Inform. Sci. Annual Meeting* 1982, **19**, 100–102.

[19] J. M. WEINER, S. M. STOWE, S. S. FULLER and N. J. GILMAN, The size of the document set and conceptual structure identification. *Proc. 45th Amer. Soc. Inform. Sci. Annual Meeting* 1982, **19**, 327–329.

[20] J. M. WEINER, Text analysis and basic concept structure. Accepted for publication in *Inform. Proc. Management*.

[21] R. S. HOROWITZ, S. S. FULLER, N. J. GILMAN, S. M. STOWE and J. M. WEINER, Concurrence in content descriptions: author vs medical subject headings (MeSH). *Proc. 45th Amer. Soc. Inform. Sci.* 1982, **19**, 139–140.

[22] J. M. WEINER, *Issues in the Design and Evaluation of Medical Trials*. G. K. Hall & Co., Boston (1980).

[23] P. LENK, Mappings of fields based on nominations. *J. Amer. Soc. Inform. Sci.* 1983, **34,** 115–122.

[24] M. E. D. KOENIG, Bibliometric indicators vs expert opinion in assessing research performance. *J. Amer. Soc. Inform. Sci.* 1983, **34**, 136–145 (1983).

[25] S. M. LAWANI and A. E. BAYER, Validity of citation criteria for assessing the influence of scientific publications: new evidence with peer assessment. *J. Amer. Soc. Inform. Sci.* 1983, **34**, 59–66.

[26] H. D. WHITE and B. C. GRIFFITH, Author cocitation: a literature measure of intellectual structure. *J. Amer. Soc. Inform. Sci.* 1981, **32**, 163–171.

[27] J. M. WEINER, S. SHIRLEY, N. J. GILMAN, S. M. STOWE and R. M. WOLF, Access to data and the information explosion—oral contraceptives and risk of cancer. *Contraception* 1981, **24**, 301–313.

[28] J. K. STROSS and W. R. HARLAN, The dissemination of new medical information. *J. Amer. Medical Assoc.* 1979, **241**, 2622–2624.

[29] J. K. STROSS and W. R. HARLAN, The dissemination of relevant information on hypertension. *J. Amer. Medical Assoc.* 1981, **246,** 360–362.