ILLINOIS UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

PRODUCTION NOTE

University of Illinois at Urbana-Champaign Library
Library Trends, a quarterly thematic journal, focuses on current trends in all areas of library practice. Each issue addresses a single theme in depth, exploring topics of interest primarily to practicing librarians and information scientists and secondarily to educators and students.

Editor: F. W. Lancaster
Publications Committee: Janice Del Negro, Betsy Hearne, Marlo Welshons

Library Trends is published four times annually—in summer, fall, winter, and spring—by the Graduate School of Library and Information Science at the University of Illinois, Urbana-Champaign, 501 E. Daniel Street, Champaign, IL 61820-6211.

Subscriptions: Institutional rate is $94 per volume (plus $7 for overseas subscribers). Subscriptions for an individual are $66 (plus $7 for overseas subscribers). Registered students may subscribe for $28 (plus $7 for overseas subscribers). Individual issues are $25.00 (shipping included); back issues other than those from the present year are $10 (plus shipping). Claims for missing numbers should be made within six months following the date of publication. All foreign subscriptions and orders must be accompanied by payment.

Address orders to: University of Illinois Press, Journals Department, 1325 S. Oak Street, Champaign, IL 61820. For out-of-print issues, contact ProQuest Information and Learning, 300 North Zeeb Road, Ann Arbor, MI 48106-1346. Postmaster: Send change of address to University of Illinois Press, 1325 S. Oak Street, Champaign, IL 61820-6903.

Copyright © 2002 by the Board of Trustees of The University of Illinois. All rights reserved. Printed in the U.S.A. ISSN 0024-2594. Postage paid at Champaign, Illinois.

Authorization to photocopy items beyond the number and frequency permitted by Sections 107 and 108 of the U.S. Copyright Law is granted by the Board of Trustees of the University of Illinois, provided that copies are for internal or personal use, or for the personal or internal use of specific clients and provided that the copy pay a fee of 10 cents per page directly to the Copyright Clearance Center (CCC), 222 Rosewood Dr., Danvers, MA 01923. The CCC code for Library Trends is 0024-2594/88 $0 + .10. To request permission for copies for advertising or promotional purposes, or for creating new works, please contact the Graduate School of Library and Information Science, Publications Office, 501 E. Daniel Street, Champaign, IL 61820-6211.

This journal is abstracted or indexed in Library and Information Science Abstracts, Current Contents, Current Index to Journals in Education, Information Science Abstracts, Library Literature, PAIS, and Social Sciences Citation Index.

Procedures for Proposing and Guest Editing an Issue of Library Trends

We encourage our readers to submit ideas for future Library Trends themes; issue topics are developed through recommendations from members of the Publications Committee and from reader suggestions. We also encourage readers to volunteer to be issue editors or to suggest others who may be willing to be issue editors.

The style and tone of the journal is formal rather than journalistic or popular. Library Trends reviews the literature, summarizes current practice and thinking, and evaluates new directions in library practice. Papers must represent original work. Extensive updates of previously published papers are acceptable, but revisions or adaptations of published work are not sought. Although Library Trends is not formally peer reviewed, articles are invited for submission and are critically reviewed by both the guest editor and the journal editor.

An issue editor proposes the theme and scope of a new issue, draws up a list of prospective authors and article topics, and provides short annotations of each article’s scope or else gives a statement of philosophy guiding the issue’s development. Please send your ideas, inquiries, or prospectus to F. W. Lancaster, Editor, GSLIS Publications Office, 501 E. Daniel Street, Champaign, IL 61820-6211.
Current Theory in Library and Information Science

William E. McGrath

Issue Editor
# Current Theory in Library and Information Science

## CONTENTS

<table>
<thead>
<tr>
<th>Title</th>
<th>Authors</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>William E. McGrath</td>
<td>309</td>
</tr>
<tr>
<td>The Progress of Theory in Knowledge Organization</td>
<td>Richard P. Smiraglia</td>
<td>330</td>
</tr>
<tr>
<td>Explanation and Prediction: Building a Unified Theory of Librarianship, Concept and Review</td>
<td>William E. McGrath</td>
<td>350</td>
</tr>
<tr>
<td>Informetric Theories and Methods for Exploring the Internet: An Analytical Survey of Recent Research Literature</td>
<td>Judit Bar-Ilan and Bluma C. Peritz</td>
<td>371</td>
</tr>
<tr>
<td>Solving Problems in Library and Information Science Using Fuzzy Set Theory</td>
<td>William W. Hood and Concepción S. Wilson</td>
<td>393</td>
</tr>
<tr>
<td>Surveying the Use of Theory in Library and Information Science Research: A Disciplinary Perspective</td>
<td>Lynne (E. F.) McKechnie and Karen E. Pettigrew</td>
<td>406</td>
</tr>
</tbody>
</table>
Ranking of Nations and Heightened Competition in Matthew Core Journals: Two Faces of the Matthew Effect for Countries
*Manfred Bonitz* 440

*Wolfgang Glänzel* 461

Similarities and Dissimilarities in Coauthorship Networks: Gestalt Theory as Explanation for Well-ordered Collaboration Structures and Production of Scientific Literature
*Hildrun Kretschmer* 474

Towards Research Performance in the Humanities
*Henk F. Moed, Marc Luwel, and A. J. Nederhof* 498

A Theory of Information Genetics: How Four Subforces Generate Information and the Implications for Total Quality Knowledge Management
*Bor-sheng Tsai* 521

The Institutionalization of Scientific Information: A Scientometric Model (ISI-S Model)
*Peter Vinkler* 553

About the Contributors 570
Introduction

WILLIAM E. McGRATH

Whatever theory is, it is many things to many people. In physics and other exact sciences, the meaning of theory is well understood, with much agreement. In the arts and humanities, there are as many theories (perhaps better denoted as opinions) as individuals, with universal disagreement. In Library and Information Science (LIS), there is little formal theory to agree or disagree on. Yet there is extensive reference to theory in LIS literature, whether from a well-informed intent to place LIS on a more rigorous foundation, or from a naive effort to sound more scientific. In an extensive content analysis of 1,160 articles in six LIS journals, Pettigrew & McKechnie (2001), found that 396 “incorporated theory in either the title, abstract or text” (p. 66).

In traditional librarianship, particularly in cataloging and classification, theory was often regarded as a set of rules or a prescription established by custom and convention rather than from rigorous investigation (Smiraglia, this issue), sometimes characterized as “how we should do it” rather than “as we do do it.”

Any of the following have been used as the meaning of theory: a law, hypothesis, group of hypotheses, proposition, supposition, explanation, model, assumption, conjecture, construct, edifice, structure, opinion, speculation, belief, principle, rule, point of view, generalization, scheme, or idea. Perhaps the most authoritative dictionary definition is that from the *Oxford English Dictionary*, 2nd ed, def. 4. a.:

A scheme or system of ideas or statements held as an explanation or account of a group of facts or phenomena; a hypothesis that has been confirmed or established by observation or experiment, and is propounded or accepted as accounting for the known facts; a statement
of what are held to be the general laws, principles, or causes of some-
thing known or observed.

See also Pettigrew & McKechnie (2001) and McKechnie & Pettigrew (this
issue) for references to other formal definitions.

To this author, theory is an explanation for a quantifiable pheno-
non. It may be a set of relationships among variables for a fixed unit of
analysis (McGrath, 1996) in which one variable may be explained by oth-
ers (e.g., Kerlinger & Pedhazur, 1973 on elucidating theory with multiple
regression). But Glazier & Grover (this issue) go well beyond this conven-
tional paradigm, incorporating it and other paradigms into a more com-
prehensive "multidimensional" framework.

For some researchers, theory does not necessarily require more than
one variable, particularly for the mathematicians and statisticians who can
see predictable patterns within a variable apart from any known influence.
Those patterns may be empirical, with equations fitted to curves. Or the
patterns may be graphed as rank distributions such as Bradford’s, Zipf’s,
and Lotka’s, in which the theory is in the regularity of the ranking. Or the
theory may be based strictly on mathematical or probabilistic data distri-
butions such as the normal, lognormal, power functions, Poisson, negative
binomial, and related distributions.

Many theories cited and used by LIS researchers originate in other
disciplines. Bothamley (1993) has over 4,000 entries for theories in arts,
economics, history, linguistics, philosophy, psychology, sociology, statistics,
geology, physics, and mathematics. Pettigrew & McKechnie (2001) list ap-
plication to LIS of many theories from the sciences, social sciences, and
humanities.

The oft-heard remark that something is “only a theory” seems to sug-
gest that theory, by definition, is something less than credible, meaningful,
or valid and that only something “factual” can be believed. The papers in
this issue are far more than factual. All are attempts to extract or impose
meaning from highly complex phenomena from the universe of informa-
tion, its processing, and use.

No attempt was made to impose any definition on the authors of this
issue. And indeed its authors surely have their own.

The papers in this issue can be grouped into two categories. The first
contains those papers about theory. These papers discuss concepts, mean-
ings, and definitions of theory. The group also contains surveys of theory
and literature reviews. The distinction between them is blurry and some
may contain all of these approaches. The second group, in general, con-
tains original research. These papers bear little resemblance to each oth-
er and all are unique. They are all difficult and require careful reading
to recognize their relevance to LIS or their potential for practical appli-
cation. With exceptions, papers about theory contain a substantial num-
ber of references, while those offering specific theories contain relative-
ly fewer references. For all papers, I have tried to indicate briefly what the "theory" means for LIS.

**ABOUT THEORY—DEFINITIONS, SURVEYS, AND REVIEWS**

Glazier & Grover attempt a broad, all-inclusive, and general definition of theory, an update on their earlier paper Grover & Glazier (1986). Whereas in their earlier paper they outlined what appeared to be a hierarchical approach to theory, from observation of phenomena to definition, concept, proposition, hypothesis, theory, paradigm, and world view, they place this scheme into a more comprehensive one they call "Circuits of Theory." The broader scheme incorporates this familiar objective and deterministic view of science into a world view where phenomena and explanation are inevitably tempered by the self, personal knowledge, social knowledge, or society in a cyclic process of change and evolution. Thus, their revised model is both objective and subjective, both deterministic and subjectivistic. Their intent is to encourage an inclusive and creative approach to research.

Smiraglia traces the history and progress of theory in knowledge organization from early rationalism based on reasoned principles and rules pertaining to cataloging and classification, to pragmatism based on observation of knowledge entities, to modern logical-positivism and qualitative methods based on empirical research. He states that no single, formal theory of knowledge organization exists. He posits, however, that (1) Lotka's Law (most names occur few times, and a few names occur many times) underlies the structure of databases, (2) Lotka's Law holds for copies, editions, translations, and other bibliographic entities, and (3) the Law holds from one collection to another, which he calls external validity. He concludes that "rationalism and historicism can help us to uncover the ineluctable truths of the natural order of knowledge entities" (p. 346).

McGrath takes the position that theory is explanatory and predictive, basically positivist. He likens the need for theory in LIS to the development and unification of fundamental forces in physics and astronomy: From Copernicus's description of solar orbits overthrowing the Ptolemaic system to Kepler's discovery of elliptical orbits, to Newton’s Laws explaining the principles of gravitational attraction, to Faraday's linking of electricity and magnetism to the unification of electromagnetism with the weak force, and the current effort to link the electroweak force to the strong force and ultimately with Einstein’s theory of relativity into a grand unification theory. In the far more modest field of librarianship, McGrath suggests that theories of individual functions of publishing, acquisitions, storage and preservation, structure of knowledge, library collections, and circulation can be integrated into a grand unified library theory. He then reviews recent explanatory and predictive research in each of these areas of librarianship, citing them as examples of the kind of research that could be used to build a unified theory of librarianship.
Methods used in research are critical to the building of theory. Bar-Ilan and Peritz provide an extensive survey and review of informetric methods used to study the Internet. Many of the methods they cite are from mathematical and statistical theory. An understanding of these methods and their application to the Internet, they believe, is appropriate for establishing a sound theory of the Internet. Their survey begins with literature on data collection methods. These include surveys, monitoring, and logging; crawling (retrieval of Web pages); retrieval by sampling; and exhaustive retrieval from databases, search engines, and other retrieval tools. They then review the literature of informetric methods, models, and laws used to analyze the Internet. These include citation analysis (a popular subject in informetric research in general), cocitation and coword analysis, content analysis (the method used for data collection by McKechnie and Pettigrew in this issue), evaluation using existing and new methods, identifying and calculating indicators (Web impact factor, or WIF, for example), and various models (hubs and authorities, for example, as well as fractals). They continue with a review of fitting models to the literature of scientific topics; a review of power laws and Zipf-type laws, both common in the general informetric literature but here applied to the Internet; and finally a review of the literature of obsolescence applied to the Web where documents are changed, removed, or relocated. They provide a summary table of characteristics and measurements of the informetric literature reviewed according to various categories.

In mathematics and statistics, “theory” is often used to describe a group of procedures or tools that otherwise would be thought of as “method.” Examples are probability theory, game theory, information theory, chaos theory, queuing theory, catastrophe theory. They are methods used to model certain kinds of data. Hood and Wilson note, that “Some aspect of the real world may be modeled by a mathematical theory.” “How useful this is,” they continue, “depends on how well the mathematical model captures the essence of the reality” (p. 394). The better the fit, the better the model or theory. They review the literature of one such method that has been used in LIS, Fuzzy Set Theory (FST), a tool employed to analyze data that do not fall readily into discrete categories. FST can be used in information retrieval where, for example, relevance in a “set of relevant documents” is fuzzy rather than dichotomous as in the traditional Boolean approach. Other examples are when and if to bind periodicals, when and if to insert detection strips in periodicals, expert systems, document retrieval, relational databases, thesauri and catalogs. They cite additional literature of applications in LIS as well as the literature of the theory itself. They conclude that, despite its theoretical appeal, FST has not yet found widespread application in LIS.

McKechnie and Pettigrew, continuing their earlier work (Pettigrew & McKechnie, 2001), cross tabulate applications of theory published in six LIS journals. Their tabulations include topics in humanities, social sciences, or
science, as well as by affiliation of author (private sector, government, LIS, humanities, social sciences, sciences), type of article (descriptive, empirical research, historical, modeling argument, review, method, theory), and sources of theory (from LIS, humanities, social sciences, sciences). The result is a useful picture (counts and percentages) of how and in what context theory is used in the current literature of LIS. They discuss the implications of differences in the number of theory articles associated with humanities, social sciences, and science, and the “surprising” finding that “many non-LIS scholars are publishing in LIS journals” and the “disappointing” finding that “LIS theories had not made substantial inroads in other disciplines” (p. 414). The large number of theories found in the surveyed articles, they conclude, is enriching LIS, but they encourage authors to list primary sources of theory, and to provide better explanations of theory and how it has been used.

For periodical collections in libraries, there is hardly an issue more critical than deciding which titles to keep, which to buy, and which to terminate in times of budget restraints. Evaluation of periodical titles is a difficult process. While many methods of evaluation have been used, most libraries probably still use old-fashioned rules of thumb and subjective criteria. More often than not, a journal’s subscription price will dictate a decision. On the other hand, information scientists have devised a number of mathematical methods or indicators based on usage and citations to journal titles. Perhaps the best-known and most widely studied indicator is the impact factor (ratio of citations to articles published) and its variations. Rousseau, in his article, discusses several methods for evaluation, focusing on the mathematical issues associated with the calculation of impact factors and related measures such as the immediacy index (how quickly a journal is cited after publication). Rather than expressing these indicators in terms of formal theory, he confines theoretical issues to their “precise [mathematical] formulation,” with no input-output or explanatory model. This approach, he suggests, may help fellow scientists to construct just such an overall model.

**Original Theories**

Each of the following papers presents a unique and original theory. Nothing ties them together in any thematic way, although there are some coincidences. They are theory rather than about theory.

An interesting phenomenon found in the use of scholarly and scientific literature that has implications for libraries is the Matthew Effect (first discovered by Robert Merton, the well-known sociologist of science), named after the Biblical passage in St. Matthew. According to this theory, a large number of citations to scientists’ publications generate even more citations to the detriment of scientists who receive few citations. The effect also holds for individual articles as well as for journals. Bonitz, continuing earlier work
on the Matthew Effect, examined a large number of journal citations and found that the effect also holds for countries, the MEC. He cites a clarification of the Matthew Effect as not “the rich become richer and the poor poorer,” but “the employment of your given talents is rewarded and their neglect punished” (p. 444). He then describes two aspects of the MEC. First, ranking of nations based on the effect can be regarded as a measure of the overall efficiency of scientific performance of a country. Second, the effect is concentrated in a small number of journals he calls Matthew core journals. Scientists should endeavor to publish in those journals, and libraries would profit by holding them.

What has coauthorship to do with librarianship other than to record it in catalogs and indexes? Glänzel studied trends in coauthorship for the period 1980–1998 in three scientific fields, biomedical research, chemistry, and mathematics. Using data from the Science Citation Index, he found that (1) coauthorship of individual papers has increased, but declined to offer a theoretical explanation for the increase; (2) the theory of coauthorship affecting individual author productivity was not supported; (3) the theory that coauthored papers are cited more frequently than single-authored papers was strongly supported. (The latter relationship apparently holds only for individual papers and not the journals in which they are published.) Glänzel suggested that coauthorship should be added to bibliographic coupling, coword, and cocitation analysis when studying the network of science communication and in the design of information retrieval strategies, particularly for identifying core documents. Glänzel refers to these relationships as theories supported or not supported by the findings, which suggests that further research may or may not support these theories.

In another study on coauthorship, Kretschmer applies gestalt theory from psychology to the similarities and dissimilarities of authors to each other based on counts of the number of papers coauthored. (The method used in gestalt theory may be an alternative to cluster analysis and multidimensional scaling.) The more papers two scientists coauthor, the more similar they are to each other in their research concentration. Conversely, the fewer they coauthor, the more dissimilar to each other. Ketschmer likens similarity to “birds of a feather flock together” and dissimilarity to “opposites attract,” and to the Yin and Yang of Chinese philosophy. Readers familiar with gestalt theory should have no difficulty with this paper. Readers unfamiliar with it will be helped by the definition of a gestalt as a holistic configuration of the parts of a relationship. Each gestalt can be graphed as a 3-dimensional array of coauthor relationships. Though the interrelationships may vary, they can always be represented in a single holistic graph that, when stable, exemplifies the conciseness principle. This principle could be used in the design of search algorithms in databases, as in Glänzel’s paper.

Moed, Luwel, and Nederhof develop a general framework in which librarians can be called upon as bibliometric professionals for the collec-
tion of data regarding research performance and productivity in the humanities and social sciences, the dynamics of which differ significantly from the sciences. The authors develop a methodology for performance indicators, with a review of earlier studies, then provide an example from the field of Belgian Law with a critical discussion of the methodology. The framework was based on results obtained from surveying Flemish scholars regarding their perceptions of the quality or importance of books, theses, journal articles, reports, lectures, and other items of productivity to be used in judging research output. The framework contains as many as eighteen categories, but is considered preliminary, needing operationalization. It may also be regarded as structure and therefore theoretical.

Tsai develops an elaborate theory of information-generating forces and subforces and, like McGrath (this issue), invokes the vocabulary of physics but there the similarity ends. He adopts a genetic metaphor in describing the sub-forces of query, command, statement, and term-term bond denoted as Q-C-S-T or Q-T-S-C chaining which can, apparently, interact with each other in any sequence inseparably but whose symmetry can be broken, producing a need for change or readjustment. The model can be portrayed in 3-dimensional graphs reminiscent of Kretschmer’s gestalts (see above), suggesting an unrecognized connection. The broken symmetry can be restored and recombined as in a Möbius strip, or re-sequenced by “clip-jointing,” a simulation of cocitation. Multiple Möbius twists and repeated clip-jointing results in genetic sequencing while the original configuration is lost and must be reconstructed by information specialists. Tsai follows with a Fuzzy Commonality Model (FCM) for describing data generated by the Q-C-S-T process. In still another analogy, he likens libraries to the Q-C-S-T process, with library administration as the command center (C), technical services providing statements (S), public services for user queries (Q), and publication of library services for term-term bonding (T). (This analogy could be regarded a component of or even an alternative to McGrath’s unified theory approach.) In the final section of his paper, Tsai describes software written to analyze, mine, map, and repackage information, and lastly he describes its application to a total quality knowledge management (TQKM) system.

Modeling the growth of science has been a preoccupation of information scientists ever since the publication of Price’s *Little Science, Big Science* (1963). A large literature seems to have settled on a standard model of either linear or exponential growth. Vinkler, in his paper, asserts that models based on annual cumulative or relative growth can only give a simplified picture. These models seem to hold only for short periods. “There is no general law ‘governing’ the publication growth of disciplines for longer periods,” Vinkler asserts (p. 555), emphasis original). Instead, he offers the “Institutionalization of Scientific Information Model” which “integrates the production, evaluation, modification, and aging of processes of scientific in-
formation" over time through "various evaluation and modification processes toward a cognitive consensus of distinguished authors" (p. 557) The model is elaborate and detailed and is based on generated information, its evaluation, and its impact. Vinkler's intent is to model the institutionalization of science disciplines by this process. A discipline's information is fully institutionalized when it becomes common scientific knowledge. References (citations) are regarded as proof of impact when assessing research results and when making library subscription decisions.

The contents of these papers are far richer than what has been summarized here. Some require careful and patient reading to comprehend them, but the effort is rewarding for those who try.

Originally, this author had envisaged a collection of theoretical essays more representative of the broader aspects of LIS. What has been achieved is a collection of worthy papers, an international representation, albeit of narrower scope. Still needed is a deeper understanding of theory and the fundamental sociologic forces driving LIS and a volume of literature to elucidate this need.

REFERENCES
A Multidisciplinary Framework for Theory Building

Jack D. Glazier and Robert Grover

Abstract
In 1986, the authors proposed a taxonomy of theory for library and information studies research. The purpose of this paper is to propose a revised model for theory building, called Circuits of Theory, that includes both the taxonomy and the critical contextual modules researchers consider in their work. These modules surround the taxonomy and encompass the concepts of individual as well as social knowledge, both discovered and undiscovered. This work has been done not to replace the original taxonomy, but—as the title implies—to revise it in light of a broader vision.

Introduction
More than fifteen years ago, the authors (Grover & Glazier, 1986), proposed a taxonomy of theory intended to outline the relationships between multiple levels of phenomena, theory, and paradigmatic perspectives. The taxonomy initially was based on data drawn from an ethnographic study of city managers (Grover & Glazier, 1984), an extensive study of qualitative methods and methodologies (Grover & Glazier, 1985), and a review of the library and information science and social science literature. The purpose of the taxonomy was defined as “. . . a framework for generating and testing theory in library and information science” (Grover & Glazier, 1985, p. 253). It served as a means of highlighting the hierarchical relationships among the concepts of research, theory, paradigms, and phenomena.

This taxonomy (see Figure 1) came at a time when the discipline of library and information science was in the throes of self-definition and on
the threshold of broader recognition among the social sciences. Much of the interest generated centered on the deterministic relationship between theory and research. The taxonomy was represented in graphic form intended to stimulate conversation about the roles and the nature of theory in the social sciences. Since that time, there has been an ongoing conversation about the relationships among experience, theory, research, and practice in the discipline of library and information science.

This paper is the result of continued thinking on this topic. In this paper, we propose a broader framework for research that includes both the primary deterministic concepts embodied in the earlier taxonomy and recognition of the wide range of subjective factors that influence thinking and creativity. Construction of such a framework leads to an approach to theory building and research that more accurately mirrors the role of disciplines, the influence of social factors on the construction of personal and social knowledge, and the research process. In other words, the framework presented here reflects today's postmodern approach to research.

It is the task of this paper to explore new ways of thinking that better reflect the social and psychological contexts of research, research design, and theory building in which the earlier taxonomy is embedded. This is accomplished by developing a framework, called "Circuits of Theory" (see Figure 2), that hosts the taxonomy and broadens the emphasis of the role of the accompanying context to mirror more closely the world of experience.

It is important to keep in mind that the content of the taxonomy has not been changed. Over time it has continued to accurately reflect the deterministic relationships between the perception of phenomena, the design of research, the analysis of data, and the process of theorizing. In
its previous form, the taxonomy was, for the most part, considered alone—with only limited attention paid to the primary contextual variables that affect the predisposition of those involved in the research. Evidence of predisposition is available in the form of observable individual and societal behaviors and their relationships to both existing and undiscovered knowledge as well as to the phenomena in which this evidence is embedded. This combined approach of determinism and subjectivism yields a framework that is inclusive of multiple approaches to data collection and analysis and embraces opposing world views. The intention is to encourage inclusive and creative thinking about research and theory building.

**Review of the Earlier Taxonomy**

Theories may be described as generalizations that seek to explain relationships among phenomena. This concept remains consistent with the authors' earlier work on the topic (Grover & Glazier, 1986) as that work was based on the work of both Odi (1982) and Mullins (1973). It is argued here that "theory" is a multiple-level component of the research process, comprising a range of generalizations that move beyond a descriptive level to a more explanatory level. In addition, Glaser & Strauss (1967) proposed that the role of theory is (1) to enable explanation and some degree of prediction of behavior, (2) to help both researchers and practitioners understand and have some control over as many situations as possible, (3) to provide a perspective of behavior, and (4) to guide research.

The earlier taxonomy (see Figure 1) was intended to help readers gain a conceptual understanding of the nature of research as a process within a theoretical context. While it may have appeared to be hierarchical and lin-
ear in nature, this was not the intent of the authors. What may be considered hierarchical was, in fact, an artifact of the taxonomy's dialectical character, embodied in the multiple processes that move the researcher from sense data to theory.

Throughout this paper, the term dialectical is employed to describe the interactive relations that exist between elements of the taxonomy. It is understood as a non-linear process. In the taxonomy, the dialectical process begins with an existing substantive theory. This existing theory can be thought of as the thesis. The newly discovered information, then, becomes the antithesis. As the antithesis, the newly discovered information is applied to the existing theory as the synthesis. Finally, the synthesis becomes a new theory. The theory level on the taxonomy is contingent upon the degree to which a theory can be generalized. Hence, the resulting synthesis or new theory may or may not be generalized to the formal level.

*Phenomena, Symbols, and Definitions*

These processes begin with an exploration of the relationships among phenomena, defined as “Events experienced in the empirical world” (Grover & Glazier, 1986, p. 230). Next is the process of assigning symbols, either iconic or digital, to phenomena. Symbols are defined as “Digital or iconic representations of phenomena, usually words or pictures” (Grover & Glazier, 1986, p. 231). The accompanying process of assigning symbols to represent phenomena also includes defining those symbols in a meaningful form for analysis or communication. This process of assigning meaning is referred to as “definition” and is described as “A precise, generally agreed upon, description of phenomena using symbols” (Grover & Glazier, 1986, p. 231).

*Concepts, Propositions, and Hypotheses or Research Questions*

Conceptualization marks a change in the process from working with phenomena in their natural contexts to working with data that have been bound by symbols and definitions and often removed from their natural context. Concepts can then be defined as “Symbols or combinations of symbols (words or phrases) which describe speculated relationships among phenomena” (Grover & Glazier, 1986, p. 232).

Following conceptualization is the assembly of propositions. A proposition is “A logically and syntactically consistent statement of a concept which can be stated as a hypothesis for testing” (Grover & Glazier, 1986, p. 232). The hypothesis is a reconfiguration of a proposition in the form of an assertion and is formally defined as “A proposition which has been stated for purposes of verification, i.e., professional level theory” (Grover & Glazier, 1986, p. 233). Research questions are propositions reconfigured into a question to be answered in the research process.
Theories

Substantive theory. The first theory level, substantive theory, is defined as “A set of propositions which furnish an explanation for an applied area of inquiry” (Grover & Glazier, 1986, p. 233).

Formal theory. The next level of theory is referred to as formal theory. Formal theory is defined as “A set of propositions which furnish an explanation for a formal or conceptual area of inquiry, that is, a discipline . . .” (Grover & Glazier, 1986, p. 234). Together formal and substantive theories are commonly referred to in the social sciences as “middle range” theory. Most research for professions begins with a problem followed by a study capable of generating substantive level theory. Another scenario is to borrow theory from the appropriate discipline, apply it to a professional problem, and recast the theory at the substantive level.

Generalizations at the “middle range” level are typically more “data connected” than grand theory or paradigms. That is to say, the broader theoretical concepts (i.e., grand theory or paradigms) are more methodologically and analytically distant from the data gathering processes and, in turn, the phenomena themselves. Given this “loosely coupled” relationship, there is a concern that the system will be prone to more ambiguity. Conversely, while these broader concepts initially appear to introduce some degree of systemic vagaries, they also have a propensity to interject into the system equally important directional and contextual qualities. From this perspective, these broader concepts also offer important insights into relationships among theory and phenomena.

Grand theory. The term “grand theory” is used here somewhat differently from the earlier taxonomy. Grand theory is defined as a set of theories or generalizations that transcend the borders of disciplines to explain relationships among phenomena.

Paradigm. A paradigm is “. . . described as a framework of basic assumptions with which perceptions are evaluated and relationships [and values] are delineated and applied to a discipline or profession” (Grover & Glazier, 1986, p. 234).

World view. Finally, the most influential of the theoretical categories is the world view. It is defined as “an individual’s accepted knowledge, including values and assumptions, which provide a ‘filter’ for perception of all phenomena” (Grover & Glazier, 1986, p. 235). Each of the preceding categories facilitates an individual’s ability to develop and define their world views. The category of “world view” introduces an individual’s perspective in contrast to that of the other terms, which are understood from a social perspective. Thus, within the framework, both individual and social perspectives are addressed.
Reexamining Theory

Since the publication of the original taxonomy, new global, contextual, sensitive ways of thinking about the world, perception, research, theory, and theory building have led to changes in vocabulary as well as perspective. Both the earlier taxonomy and the new Circuits of Theory continue to be "meta-theoretical" in nature. Meta-theorizing is defined as a "... systematic study of the underlying structure of sociological theory" (Ritzer, 1992, p. 511).

The general structure of library and information studies theory has increasingly been patterned after social science theory, in large part due to library and information studies' client-centered approach to public service. This is but one part of the increasing complexity of what might legitimately be referred to as the discipline of information studies. Configuration of information will continue to be specialized to meet the needs of specialized disciplines and individuals in the hard sciences, social science, business, and law. In order to meet these needs, the discipline of information studies must be familiar with the forms of research within these other disciplines.

Moving from perception, interpretation, and analysis to theory, one important difference between the early taxonomy and the new Circuits of Theory is that the original did not place enough emphasis on the differences between the individual and societal perspectives in relation to knowledge both existing and undiscovered. While both the early taxonomy and the new Circuits of Theory emphasize the role of the individual, the Circuits of Theory goes further by linking the individual, society, and both discovered and undiscovered knowledge in an articulated open system.

A Circuits of Theory

This Circuits of Theory (see Figure 2) comprises three dialectically related modules and the taxonomy of theory within the existing social environment. Because of its generality, the social environment is not defined per se, but is represented in the Circuits of Theory by the concept of phenomena. All of these modules come together to compose our social system. They interact with one another in the research process, such that phenomena are isolated and analyzed within the context of the research environment. The modules themselves are as follows: (1) Self, (2) Society, and (3) Knowledge, both discovered and undiscovered.

While these three modules of the Circuits of Theory stand out visually, the operational nexus is the taxonomy of theory. The difference between the three modules of the Circuits of Theory as a group and the taxonomy is that the modules represent the contextual variables that surround and contribute to the utilization of the taxonomy. However, the taxonomy remains the nucleus around which the operational dynamics of the Circuits of Theory are concentrated. Following are descriptions of the operational dynamics of the taxonomy and each of the three modules.
The Taxonomy

The earlier taxonomy remains intact as the centerpiece of the Circuits of Theory. It is the linkage that integrates the many aspects of the complexities associated with modeling social action. It is nested in an environment composed of individuals, society, knowledge, and "phenomena." Some aspect of a phenomenon stimulates an individual's perception. Perception, then, isolates and extracts those aspects of a phenomenon that served as the stimuli. Such an extraction is the first step in the processes of interpretation based on an individual's experience and perceptive skills. The aspect of phenomenon that is extracted is further screened and labeled through the use of symbols. These symbols are interpreted, defined, and organized into conceptual categories. These concepts then form propositions in preparation for verification in the form of analytical testing. The testing is carried out through empirical research.

In the taxonomy, empirical research begins with the formation of research questions to be answered about the concepts or hypotheses for testing the concepts within a narrow set of predetermined parameters. While the testing of the hypotheses is carried out based on the view of the researcher and remains intact until testing is completed, the results of the initial testing are frequently later verified through replication or additional testing. When research questions are employed, answers based on data drawn from phenomena are used to make sense of the problem that precipitated the research questions. Verification again is frequently employed but is mechanically somewhat different from that associated with the hypothesis.

Verification frequently occurs when research questions are altered according to the data being gathered and analyzed. Rather than a linear approach, this approach is cyclical. As new data come in, the researcher analyzes, interprets, and dialectically merges them with the existing information. This dialectical process of merging new with existing information continues to repeat itself in a cyclical pattern until an adequate explanation of the phenomenon is derived.

The final step is generalizing the findings. As noted above, the Circuits of Theory includes the taxonomy as a hierarchy of theory to guide the structuring of generalizations by researchers and theorists. The levels can be viewed as linear in nature or as inclusive, with each broader level including the levels below it. For an explanation of these levels of theory, see the descriptions provided above or the authors' earlier work (Grover & Glazier, 1986) on the topic.

The Self

The three modules of the Circuits of Theory constitute an inseparable series of closely interrelated segments of this complex system. The first of these is the intricate, enigmatic module of the self. The individual self includes the functions of perception, interpretation, conceptualization, and integration.
The individuality of the self is a key aspect to understanding the processes of research and theorizing. However, the self does not exist in isolation, but operates in the context of cultures and sub-cultures within society. This concept has been fundamental to the work of scholars representing the various paradigms, including American pragmatism, symbolic interactionism, and library and information studies (James, 1969; Mead, 1934; Cooley, 1922; Shera, 1970; Greer, 1987). The concept of the self as employed here relies on these traditions.

The nature of the self is to integrate individual knowledge into the broader arena of social knowledge through perception. Perception is the means of receiving stimuli from phenomena as they appear in the environment to sensation (through the use of the senses). It includes within its arsenal the analytical tool of introspection, the first part of the process that results in accepting incoming data consistent with an individual's belief and values systems. It is these incoming, initial data that, after being selected, collected, analyzed, and integrated with other data and information, will eventually yield new knowledge. As a result, they are the locus in the Circuits of Theory where the self, society, and knowledge intersect. They are also the initial step in the taxonomy where phenomena and the individual first meet.

All of this is included in the process of perception. It is also the initial point of interpretation in which data are converted into symbols that are then given meaning through definition and conceptualization. These are the first steps toward the process of the discovery that comprises research and analysis.

From within the self, perception is guided by our belief and values systems, which serve as the unconscious lens through which stimuli are filtered at the point of initial sensation. This is also where, as Boulding (1956) argues, the role of the self becomes that of a unifying element in which these filters shape consciousness and individual knowledge. As a result, the self, as the center of all of this activity, unites the conscious and unconscious into a unified whole that is able to construct individual and social knowledge.

Individual knowledge includes knowledge gained through socialization as members of key institutions, such as family, education, and church, which profoundly influence the formation of systems of individual and social experience, norms, values, and beliefs. These systems, including the development of principles, conventions, and a knowledge base, constitute an individual's world view.

Since research is a process that is largely an individual undertaking, influenced by individuals and their assumptions, values, and beliefs, the impact of self on the research process is undeniable and plays a prominent part in the new Circuits of Theory. As a result, understanding the role of the self and its relationship to individual, society, and social knowledge is critical.
Society

The second module, which includes both the social and social knowledge, must be understood in terms of how society relates to existing knowledge. Social groups create their own reality by the mutual acceptance of group norms, values, beliefs, and knowledge. Holzner & Marx (1979) define “social knowledge” as knowledge screened and accepted by social groups or by society at large. Thus, the social knowledge module is that in which researchers build on existing or create new knowledge through the generation of individual knowledge and its acceptance as a legitimate part of social knowledge. Individual knowledge is merely opinion without the legitimation provided by its acceptance as a part of social knowledge.

Accepting and legitimizing individual knowledge and ultimately social knowledge relies on acceptable data gathering techniques and processes, a necessary element in society's recognition of the reliability and validity of new knowledge. Disciplines and professions define the conventions for accepting or rejecting new knowledge. Hence, the legacy of the social knowledge module is less about existing knowledge and more about these conventions. Teaching these conventions and the idealism that there still exists the potential of undiscovered knowledge is an essential part of undergraduate and graduate education.

Library and information studies (LIS) education is dedicated to the study, understanding, and use of social knowledge as it relates to the social module of the Circuits of Theory. LIS doctoral education is directed toward developing new ways of studying, understanding, using, and extending research and knowledge in the field. It is also about linking individual knowledge through the process of social acceptance to social knowledge—the whole of social knowledge becomes the sum of its parts in the form of individual knowledge.

Knowledge

The third module is that of knowledge, both existing and undiscovered. While the previous two modules included accompanying and integral aspects, the knowledge module is a fully integrated module that comprises existing knowledge and its shadowy partner, undiscovered knowledge.

Existing knowledge is defined here as phenomena that have been captured and have undergone some degree of analysis. Conversely, undiscovered knowledge is unknown knowledge in the form of “uncaptured” phenomena that possess the potential of discoverability. The fulfillment of this potential of discovery is contingent on both existing and future mechanical and/or theoretical technology. The linkage between existing knowledge and undiscovered knowledge has to do with basic empiricism and epistemology. Empiricism is how individuals respond to external stimuli from phenomena. It is through empiricism that existing knowledge is generat-
ed and verified. Epistemology is the belief system that permits individuals to accept the actuality of the existence of undiscovered knowledge.

Individual knowledge includes aspects of social knowledge gained through an individual's educational experiences at various levels, from primary through higher education. People are socialized to believe in the predominance of social knowledge over individual knowledge through much of the formal educational experiences provided by society.

However, contrary to a social knowledge bias that tends to be learned through early education, there is also a considerable body of knowledge that is unique to an individual. This individual knowledge may conflict with social knowledge at times, especially when the acceptable knowledge of one group conflicts with that of another. For example, professional knowledge may conflict with political or religious knowledge. A professional school empowers students to practice a profession, but professional education may conflict with individuals' personal knowledge and values, which have often been the product of socialization through participation in other social groups and institutions, for example, church, education, politics, leisure time activities, etc. It becomes a question of which takes precedence—the individual, the group, or the institution.

**APPLYING THE CIRCUITS OF THEORY TO THE RESEARCH PROCESS**

Today, a considerable amount of research in LIS is based on action research with little attempt to apply theory. The structure that the new Circuits of Theory supplies will enable researchers to construct theories that help with generalizations beyond the conclusions drawn from empirical data. It is worth a reminder that when one reaches a conclusion one has already engaged in the generalization process by reflecting on data and discerning patterns. While the generalization process is similar in moving from data to conclusions and from conclusions to theory, use of the taxonomy enables a systematic approach.

For example, a researcher might identify a psychological (discipline level) theory that has implications for professional intervention in the information search process. The theory could be operationalized through application in data gathering associated with client interviews and observations. The data gathered would be compiled, analyzed, and compared to the psychological theory that might then be revised into a substantive level theory for use both at the reference desk and in professional education. Further study might reveal unanticipated nuances to the theory, which might result in refinements to the original theory relating to information gathering and the mind.

The three modules of the Circuits of Theory identify contextual variables from which the meaning of new knowledge emerges as influenced by the self, society, and existing knowledge. The Circuits of Theory portrays
research as a complex dialectical process with numerous interactions between the modules of the Circuits of Theory.

Sample Study

City manager study (Grover & Glazier, 1984). Five city managers were studied to discover their information use patterns. The study generated a substantive theory usable by professionals, such as information specialists. It was found that each city manager operated similarly based on his/her past experiences (individual knowledge module), local context (society module), and individual reaction (self module), and on the knowledge known and unknown (discovered and undiscovered knowledge module).

Conclusion

Several common themes emerge throughout this paper as it relates to research, theory building, and the environment that envelops the research process. First, it is argued that research and theory building is surrounded by a complex of social and psychological contexts. Second, these contexts comprise three basic modules. Each module is malleable—is without clear-cut boundaries—and is linked to the others phenomenologically. The initial module, the self, represents each individual that undertakes the long journey associated with the research process. While this journey is thought of as deterministic and rational, it is also shaped by the subjective experiential categories that organize the very self from which this entire process emanates. This initial module is embedded in each of the remaining three modules.

The self is an inextricable part of the next module, society. While the concept of society provides a home in the form of the context for each of the other modules, it also has its own identity. Society and social knowledge are more than the sum of the individuals and individual knowledge that are a part of it. Society is the source of accumulation and legitimation of individual knowledge in the form of social knowledge. The third module, knowledge, discovered and undiscovered, is the linking module among the preceding two, the self and society. It is the repository of existing individual and social knowledge as well as potential knowledge based on what is already known and recognized as grand theory and paradigms. As a result, the responsibility of social legitimation resides here.

Finally, there is the taxonomy of theory. The taxonomy of theory is central to the entire Circuits of Theory. It is here that initial research and theory building takes place as well as the critical process of replication that prepares the way for paradigmatic changes. Since the categories of the taxonomy have been detailed earlier, that process will not be repeated here.

The taxonomy is placed within the context of the new Circuits of Theory as the central point around which the three key modules are arranged. Each module is analyzed above in terms of its functions and relationships
to the other modules individually and systemically. It is these complex, inter-linking, shifting relationships that are the focus of the new Circuits of Theory.

These relationships are not linear but cyclical in their pattern of interaction. They dialectically define and redefine one another based on the shifting nature of the system as a whole. The interactions of self, society, and knowledge, within the context of the research process, create a dynamic environment that encourages change and innovation. Resistance to change in the context of this Circuits of Theory and in general in a society that has historically been grounded on discovery, innovation, and change is systemically alienating and creates systematic aberrations in the form of contradictions, inequality, and exploitation.

The relationships spoken of above unify information studies research, analysis, theory building, and knowledge integration into a single whole. Relationships as understood here are based on dialectical interactions brought about when modules possessing subjective and objective qualities interact in a world of varied substances and experiences. A framework or system designed to favor a subjective approach to nature without considering the objective, or an objective approach that does not consider the subjective, lacks understanding, versatility, and vision. Hence, this framework or Circuits of Theory is not intended to favor one to the exclusion of the other; or, in this case particularly, the qualitative to the exclusion of the quantitative.

Further Research and Study

As the Circuits of Theory has been constructed, as many contingencies as possible have been anticipated. It is, of course, impossible to anticipate all the possible contingencies that might arise, let alone resolve them. However, here are some of the contingencies that emerged in the process of writing this paper and that need additional research. First, is the nature of the concept of phenomena. Second, is the nature of the concept of knowledge both in its discovered and undiscovered forms. Is it knowledge when we have yet to discover it and lack the technology to bring it to the surface? This question brings about a third contingency, the nature of the relationship between phenomena and knowledge, both discovered and undiscovered. These are just a few of the contingencies that have been obstacles in the preparation of this paper. The authors lay them at the feet of the research community in general.

Notes
1. Odi described theory as "an internally connected and logically consistent proposition about relationship(s) between phenomena" (p. 313).
2. Mullins (1973) contended theories may be a single topic developed in parts by many persons or on many topics by one person.
3. This terminology is adapted from its original use by Weick (1976) as it related to the organizational literature, and is thus employed in a different sense than Weick intended.
REFERENCES
The Progress of Theory in Knowledge Organization

RICHARD P. SMIRAGLIA

ABSTRACT
We understand “theory” to be a system of testable explanatory statements derived from research. In knowledge organization, the generation of theory has moved from an epistemic stance of pragmatism (based on observation of the construction of retrieval tools), to empiricism (based on the results of empirical research). In the nineteenth century, Panizzi (1841), Cutter (1876), and Dewey (1876), developed very pragmatic tools (i.e., catalogs and classifications), explaining as they did so the principles by which their tools were constructed. By 1950, key papers at a University of Chicago Graduate Library School conference on “Bibliographic Organization” recorded the role of bibliographic organization in civilization (Clapp, 1950) and deemed classification the basis of bibliographic organization (Shera, 1950). In 1961, the International Conference on Cataloguing Principles in Paris brought together key thinkers on the design of catalogs. Wilson (1968) expounded a system for bibliographic apparatus, and provided the framework for empirical theoretical development. In 2000, Svenonius asserted that knowledge organization is accomplished through a bibliographic language (or, more properly through a complex set of bibliographic languages), with semantics, syntax, pragmatics, and rules to govern their implementation. Logical positivism notwithstanding, rationalist and historicist stances have begun to come to the fore of late through the promulgation of qualitative methods, most notably those employed in classification, user-interface design, and bibliometric research.
INTRODUCTION

We understand “theory” to be a system of testable explanatory statements derived from research. The term is difficult, because it has a colloquial usage that is quite a lot less precise than its use in academe. Colloquially, we understand theory to mean “ideas” or “principles.” We attribute vagueness and an air of indecipherability to the term. The usage in academe is quite different. Here, we mean, quite precisely, statements, derived as a result of rigorous research and testing, that explain phenomena and relationships among them. Theory does not exist in a vacuum, but rather in a system that explains the domains in which we operate, the phenomena found in those domains, and the ways in which they might be affected by manipulation or change. Theory is derived from the controlled observation of phenomena, whether this has taken place in the positivist empirical paradigm or in the qualitative paradigm. Theory is the basis of research, serving to supply hypotheses for empirical research, and to confirm observations in qualitative research. The power of theory is its explanatory capability. We can use theory to analyze, predict, and manipulate phenomena.

In knowledge organization, there is quite a lot of theory of the colloquial sort (that is, stated principles) and even a fair amount of consensus on these statements. But, there is also, increasingly, a formal theoretical base. Knowledge organization, at least as it is practiced inside the domain of library and information science, has been largely (up to now) the province of the construction of tools for the storage and retrieval of documentary entities. That is, tools, such as catalogs, indexes, and databases, have been constructed to allow the rapid manipulation of and retrieval from large collections of surrogate records that represent documents, which in turn represent recorded knowledge. Order within these tools may take a variety of forms depending on the knowledge domain (or domains) represented, the anticipated usage of the tools, and their structure. Classification uses symbolic notation to order related concepts in appropriate groupings. Controlled vocabulary is created to alleviate linguistic variation in the documents and their surrogates that might otherwise obscure relationships among concepts. So-called “known items,” documents identified by some combination of creator and title, are listed in alphabetical arrays using both names of creators (subarranged by title of work and date of creation, etc.) and document titles.

All of these tools have been constructed according to bibliographical judgment and pragmatic concerns about the documents themselves and their anticipated usage. In the second half of the nineteenth century, principles were expounded for the construction of catalogs that have, more or less, governed the development of bibliographic retrieval tools to the present day. The twentieth century increasingly saw the compilation of codes of rules to govern the construction of both document surrogates (i.e., bibliographic records) and the retrieval tools themselves. Svenonius (1981)
and Smiraglia (1987), among others, called for the application of empirical research methods to describe the phenomena of knowledge organization and to inform the further development of retrieval tools. The automation of bibliographic retrieval at the end of the twentieth century was informed, to some extent, by such empirical research. At the turn of the twenty-first century, scholarship in knowledge organization has begun to embrace qualitative research methods alongside the empirical, and, in a limited way, historical perspectives have been turned to in order to comprehend the social context of knowledge phenomena. Finally, rationalism has seen the increasing use of ontological and epistemological tools to comprehend the underlying structures of knowledge.

In knowledge organization, then, the generation of theory has moved from an epistemic stance of pragmatism (based on observation of the construction of retrieval tools), to empiricism (based on the results of empirical research). Logical positivism notwithstanding, rationalist and historicist stances have begun to come to the fore of late through the promulgation of qualitative methods, most notably those employed in bibliometric research. Another major balancing force has been the introduction of epistemology and ontology into the design of classification (Hjørland, 1998; Marco & Navarro, 1993). This paper is a review of these themes. Its purpose is not so much to present an exhaustive review of theory in knowledge organization, as to demonstrate the epistemological progression from rationally derived principles, to empiricism, to historicism.

**HISTORICAL BACKGROUND: PRAGMATISM AND RATIONALISM**

Panizzi (1841), Cutter (1876), and Dewey (1876), in the nineteenth century, developed very pragmatic tools (catalogs and classifications), explaining as they did so the principles by which their tools were constructed. Their efforts were influential: The principles they expounded can still be observed in the structure of modern online retrieval systems. Each, in his own way, raised the development of pragmatic retrieval tools to the level of a professional art form, introducing the concept of bibliographic judgment into the continued maintenance and development of tools for cataloging and classifying library collections. For each, the convenience of the public was always to be held in mind, over and against the inventory of the collection, on the one hand, or the ease of the cataloger, on the other. This was a remarkable development, which when interjected into the nascent program of education for professional librarians, saw the growth of pragmatism and rationalism in the construction of tools for knowledge organization over the next three-quarters of a century. The evolution of these objectives laid the groundwork for the research in the mid-twentieth century that would lead to better empirical understanding. This, then, can be seen as the beginning of the development of formal theory in knowledge organization.
Strout (1956) told the whole history of catalogs from antiquity to modern times. Thus, we can trace developments back in time—for instance, one can postulate Hyde as Panizzi's predecessor, Maunsell as Hyde's, and so on, back to Callimachus in the great library at Alexandria. However, our point here is not to review the whole history of catalogs, but rather to establish a beginning for the theory of knowledge organization that prevails today. For this reason, we begin at this point in the mid- to late nineteenth century, when developments began to appear with great rapidity. And, of course, there were other leaders of that period, most notably Charles Coffin Jewett (1853). But here we posit the coincidence of Panizzi, Cutter, and Dewey as pragmatists as the beginning of our current backdrop of theory about the order of catalogs, relationships among subjects, and the order of knowledge itself.

Antonio Panizzi was hardly the first to develop a major catalog, nor was he even the first to develop a finding aid in the English-speaking world. That honor goes, of course, to Thomas Hyde's 1674 catalog for the Bodleian Library. Hyde's catalog has been called the first great alphabetical catalog, and was designed specifically to assist students in conducting research. Hyde's major contribution was to raise the collocating function to the level of principle, by insisting on the collocation of an author's works under a single form of name, with references from variant names and name forms. Also, in Hyde's catalog, representations of a single work that had appeared under different titles were also caused to collocate. As de Rijk (1991) has confirmed, Hyde's was a catalog in which divergent forms of names and titles of works were both expressed and reconciled.

It was Panizzi, however, for whom the construction of a catalog became more than the task of recording physical details of books. Rather, Panizzi recognized the importance of making a distinction between the retrieval and use of specific intellectual entities—that is, works—and the usual inventory of books. With Panizzi, the function of identifying and collocating works and their variant instantiations became a principle, and a very pragmatic principle at that. Panizzi was emphatic that to be useful, a catalog had to allow a reader to identify and choose among works. His famous defense of his catalog includes this very pragmatic assertion ([1848] 1985, p. 21, emphasis original):

No catalogue . . . can be called 'useful' in the proper sense of the word, but one in which the titles [i.e. entries] are both 'accurate,' and so 'full' as to afford all that information respecting the real contents, state, and consequent usefulness of the book which may enable a reader to choose, from among many editions, or many copies, that which may best satisfy his wants, whether in a literary or scientific, or in a bibliographical point of view.

In other words, no catalog that merely lists items can be considered useful. Rather, it is the intellectual content—that is, the works—for which readers
consult a catalog. To be useful, then, the catalog must clearly identify works in such a way that a user is assisted in making an informed selection—a very pragmatic principle, rationally derived, which advanced the construction of the catalog from that of inventory of documents to modern tool for the retrieval of works.

Charles Ammi Cutter, librarian of the Boston Atheneum, provided rules for the construction of dictionary catalogs. The dictionary catalog was to be one in which name, title, and subject entries for books were integrated in a single alphabetical sequence. The direct successors of codes of rules by Panizzi and the Smithsonian’s Charles Coffin Jewett, Cutter’s rules often are seen as the direct progenitors of the modern Anglo-American cataloguing rules. Indeed, many cataloging practices that are encoded in today’s rules for descriptive cataloging can be traced directly to Cutter’s code.

Cutter’s rules were originally issued as the second part of a special report of the Bureau of Education (then a division of the Department of the Interior), titled Public libraries in the United States of America: Their history, condition, and management. Published thusly in 1876, these rules enjoyed widespread acceptance and fueled the growth of the public library as an educational institution. As public libraries spread, Cutter’s rules gave pragmatic instruction to librarians across the U.S. landscape for the construction of local dictionary catalogs. Asserting a principle of context, Cutter suggests that the given catalog might be considered short, medium, or full—depending on the level of detail considered critical to the users of the collection in question.

Cutter’s rules were prefaced with a statement of the objectives of the dictionary catalog. These statements, called “Objects,” frame the entire construction of the catalog within the pragmatic judgment of the cataloger. Ultimately, the cataloger is given generic directions for the creation of a description of a book, and for the selection and formation of access points that will, in many cases, lead to the collocation of entries for the work within that book. There is an expectation that, given specific instructions and a pragmatic philosophical framework, catalogers will be able to apply their own professional judgment and yield consistent results.

The popularity and widespread usage of Cutter’s rules is apparent from the publication history—the fourth, and final edition was published in 1904, containing many appendices intended to inform the cataloging of nonbook materials. Ultimately, Cutter’s pragmatism was expressed in his suggestion (1904, p. 6) that the cataloger always weigh local needs against the convenience of the users. While Cutter dictates that this decision must always yield to the requirements of users, still it is a critical, pragmatic instruction to take both sets of sometimes conflicting needs into account.

Melville Dewey, the father of much of American librarianship, is the third individual whose influence caused the spread of pragmatic tools for the organization of library collections. Most famous for his Decimal Classifi-
cation (1876), which is now in use worldwide, it is perhaps more important at this juncture for us to consider Dewey’s powerful political influence on the development of the profession of librarianship. It is to Dewey that we owe the professionalization of bibliography, the beginnings of education for librarianship, the development of professional associations for librarians, and in 1908 the publication of the first joint Anglo-American cataloguing rules. But it is also to Dewey and his Library Bureau that we owe the spread of the card catalog utilizing 3-by-5-inch holed cards in wooden cases of standard sizes. Together with his Decimal Classification, the spread of the card catalog (now in dictionary form thanks to Cutter’s influence) standardized the organization of knowledge in libraries all across the English-speaking world and particularly in American public libraries. This standardization ensured more than professional economies of scale. Perhaps Dewey’s greatest contribution was to give generations of users the capability to find relevant materials treated in the same way in nearly any library.

As we noted earlier, the history of catalogs and cataloging has been written elsewhere. Here our point is to note the historic coincidence of the efforts of Panizzi, Cutter, and Dewey. All three were pragmatic managers of large libraries, and authors of the principles of catalog and collection management. Above all, they left a critical legacy to the practice of the organization of documents (and, thereby, of the works and recorded knowledge contained therein). They were the progenitors of the twentieth-century move toward standardization and codification. Their pragmatic guidance insisted on the judgment of the cataloger, the convenience of the user in retrieving what was sought, and the consistent ordering of bibliographic entities—be they citations for works, subject headings in the dictionary catalog, or volumes themselves ordered to facilitate browsing by the public.

From time to time, the pendulum would swing away from their pragmatic guidance, but ultimately, pragmatism was the theoretical norm through the twentieth century. For example, Panizzi had called for the entry of pseudonymous works under the authors’ pseudonym, so as to yield a direct result for the searcher. The pragmatism of the idea is clear—a user should be able to seek a work under the citation by which it is popularly known in the marketplace (or in the culture). However, a more academic approach was used—entry under the real name—from Cutter’s time until the second revision of the second edition of the Anglo-American cataloguing rules in 1988. At last, at the end of the twentieth century, the flood of romance fiction written by authors using several pseudonyms at once resulted in a compromise measure that allows for collocation of works under an author whose real name has become synonymous with his/her pseudonyms, but for entry under the pseudonyms (even under several) for those that have not.

Key papers at a 1950 University of Chicago Graduate Library School conference on “Bibliographic Organization” recorded the role of bibliographic organization in civilization (Clapp, 1950) and deemed classifica-
tion the basis of bibliographic organization (Shera, 1950). Clapp defined bibliographic organization as: “The pattern of effective arrangements which results from the systematic listing of the records of human communication” (p. 4). Asserting the social role of the organization of knowledge, Clapp set about to list the areas in which empirical research would be critical for developing the discipline. These were: (1) Types (suggesting the taxonomic study of kinds of bibliographies); (2) Gaps (where possible these should be closed); (3) Duplication (which should be eliminated); (4) Informativeness (it would be necessary to combine comprehensive and selective lists); (5) Physical location; (6) Cooperation, or the coordination of energies; (7) Classification (the tools of library organization should be generalized to all bibliography); and (8) Mechanical devices (a challenge to develop cheaper, more compact, and more flexible bibliographical apparatus) (pp. 17–21). Similarly, Shera asserted the importance of classification as the very basis of bibliographic organization. However, he also pointed to the failure of a century of library classification to resolve the key problems of organizing knowledge, saying: “There can no longer be any doubt that library classification has failed, and failed lamentably, to accomplish what it was designed to do” (p. 72). Shera outlined four basic historical assumptions about the utility of classification: (1) There exists a universal order of nature that should reveal a permanent conceptual framework of the entirety of human knowledge; (2) Schematization of that universal and permanent order is a hierarchy; (3) There is a principle of differentiation derived from likeness or unlikeness of the properties of phenomena; and (4) These properties partake of the substantive nature of the phenomena. He related what he calls the “failure of traditional approaches to classification” to the lack of social epistemology, or social context of a given knowledge domain (pp. 72–73). Like Clapp, Shera also posited a research agenda, which includes: (1) Studies of existing classifications; (2) Development of new schema, based on new principles; (3) Experimentation in the construct of conceptual frameworks; (4) Content analysis of research literatures; (5) Careful scrutiny of subject headings; (6) Measurements of effectiveness; (7) Analysis of dispersion; and (8) Precise measurement of costs (p. 93). As though to demonstrate Shera’s point, the Chicago conference also witnessed the introduction of Ranganathan’s Colon Classification, from which the notion of faceted indexing would be derived and expanded. The 1961 International Conference on Cataloguing Principles in Paris brought together key thinkers on the design of catalogs. Lubetzky (1961) provided the impetus for restating Cutter’s principles in a way that would begin to shift the focus of the catalog from its role as inventory of books to a new role as pathfinder among works. Verona’s concept (1961) of literary unit vs. bibliographical unit would underlie this shift in roles, as would Osborn’s pragmatic approach (1961) to the construction of tools for bibliographic retrieval. Hickey summarized much of this theory in 1977, at the brink of the paradigm...
shift from paper-based systems to electronic, automated systems. Taken together, these key statements of rules and principles can be seen to constitute a core for theory of knowledge organization.

Wilson (1968) was the first to analyze and summarize these accomplishments in a single text, expounding a system for bibliographic apparatus, and providing the framework for empirical theoretical development. Wilson stated underlying philosophical points, for example, descriptive and exploitative domains, in which the bibliographical apparatus (as created by Panizzi, Cutter, Dewey, et al.) plays a key role. According to Wilson, the descriptive domain (in today's parlance the word “domain" might better be rendered as “concept space") is the domain in which descriptive bibliographic activity takes place. In the descriptive domain, catalogers, bibliographers, and indexers strive to create listings of various depths and degrees of detail to record the existence of writings available to searchers. In the exploitative domain, scholars seek answers to their questions, and especially they seek to make the best possible use of recorded knowledge. That is, they seek to exploit what is already known, so as to create new knowledge.

Here Wilson provided, for the first time, a means by which the efficacy of the bibliographical apparatus can be measured. Whatever in the descriptive domain facilitates activity in the exploitative domain can be said to be efficacious. Likewise, whatever hinders activity in the exploitative domain can be said to be detrimental. By inserting specific activities (e.g., searching) or entities (e.g., access points) and measuring retrieval success, researchers could operationalize variables, and begin empirically to test such theoretical statements as had heretofore had the status of "principles." This contribution moved the field of knowledge organization forward as a research discipline, allowing practice to be informed by the results of scientific investigation, and paving the way for an accumulation of observations over time that might contribute to true theory.

**The Beginnings of Empiricism**

Clapp (1950) and Shera (1950) posited research agendas, essentially marching orders for the world's scholars in bibliographic retrieval and classification. Other calls to action were to follow, in particular papers by Gorman (1980, 1982) and others, at the time of AACR2's first edition being published. In 1981, Svenonius reviewed current research in bibliographic control and found it wanting, particularly in regard to problems of heading integrity and file structure:

> Questions of efficient file design need researching, such as how is linkage information to be accessed, should all linkage information be contained in an authority file, and how are authority and bibliographic files to be interfaced? (p. 101)

Gorman (1982) called for similar research, suggesting a design schema for the online catalog in which physical items would be represented by unique
bibliographic records, and all access points (names, works, subjects, etc.) would be represented in unique authority records. Explicit links could then be created in several directions, both among related authority records and between authority records and the bibliographic records that represent bibliographic entities. Similarly, Taylor, in a 1988 review of progress in authority control research, pointed out the need for continued research in bibliographic relationships:

The questions Svenonius asked about how linkage information is to be accessed, whether all linkage information should be contained in an authority file, and the means for interfacing authority and bibliographic files have been examined to some extent, although the answers are not yet clear. (p. 51)

Taylor suggested further study of file design, concluding:

Perhaps these questions remain unanswered because Svenonius's remaining question, that of efficient file design, has yet to be examined. . . . The conflicts we now have of some linkage information being held in the authority file and the remainder being held in the bibliographic file [should] be resolved. (p. 51)

In a 1992 review Svenonius stated:

Library catalogs . . . must be able to distinguish uniquely bibliographic entities at a variety of aggregate levels. . . . Further experimenting is needed to identify the necessary and sufficient data elements needed to distinguish various kinds of bibliographic entities. . . . (p. 11)

She went on to say:

A library catalog in addition to distinguishing unlike bibliographic entities must also collocate and otherwise relate like entities. The failure to do so is a failure in recall. . . . An entity in the bibliographic universe is not an island unto itself but is connected to other entities in a variety of constellations and relationships. In order for a user to navigate the bibliographic universe to a desired end, a map is needed to show how entities are clustered and where the pathways are between and among them. Such a map would depict the collocating relationships specified by the second objective of the catalogue and it would show other bibliographic relationships as well. (pp. 11–12)

These papers represent a call to arms from the major scholars of bibliographic control in the last quarter of the twentieth century, issued to the up and coming researchers in the field. Questions of file design, record construct, and entity-relationship definition were critical to the advancement of the catalog as a tool of the modern age. Furthermore, empirical evidence of the incidence of bibliographic phenomena, and of searching behavior would be critical to inform the rapid development of increasingly technologically complex systems for retrieval of not only bibliographic
data, but also full document texts, archival records, surrogates for museum artifacts, and so on. Empiricism, represented by scientific research in the positivist paradigm, was clearly called for if the cause of knowledge organization was to advance. And, chief among the problems of empirical researchers, therefore, was the lack of comprehension of the extent to which external validity (the ability to generalize a research result from one collection of documents to another, which would depend on the degree to which collections of documents were inherently alike or different) was key.

Many took up the challenge, and the research journals are filled with reports of research that examined the problems posed by these pivotal scholars. In four areas, to be described below, research has accumulated to a degree sufficient to posit theoretical statements. Let us now turn to these four areas to understand the role of positivism and pragmaticism in the growth of theory in knowledge organization.

**Author Productivity and the Distribution of Name Headings**

In 1926 Lotka asserted an inverse relationship between the number of authors writing in a given subject area and their productivity. Known as "Lotka's Law," this relationship can be stated thus: The total number of authors in a given subject, each producing $x$ publications, is inversely proportional to some exponential function $n$ of $x$. The practical result of Lotka's observation was to demonstrate that the total number of authors contributing a single publication would be just over 60 percent (p. 321). That is, only 40 percent of authors contribute more than one paper. Lotka was concerned bibliometrically with the attribution of author productivity as a measure of the influence of authors in specific subject areas. But research by Taylor, Potter, Papakhian, and others has demonstrated an ability to observe Lotka's law operating in the bibliographic universe.

These studies were conducted to examine name headings' frequency of occurrence in catalogs. Potter (1980) examined this frequency in two general catalogs, and discovered that roughly two-thirds (63.5 percent and 69.33 percent respectively) of all names occur only once (p. 9). Fuller (1989, p. 81) found a similar proportion, 61 percent, in the catalog of the University of Chicago. McCallum & Godwin (1981, p. 198) found that 66 percent of names occurred only once in the Library of Congress machine-readable catalog. Papakhian (1985, p. 285), replicating Potter's design in a sound recordings catalog, found that fewer than half (47.6 percent) of names could be said to occur only once, concluding that the presence of nonbook materials could be associated with an increase in multiple occurrence entries. This research was conducted to help the community understand the impact of changes in cataloging rules. Collectively, these results demonstrate a theoretical assumption that underlies the infrastructure of bibliographic databases. That is, most names will occur only once, and a very small number, which can be predicted by Lotka's Law, will occur many times.
Bibliographic Relationships

No document is an island, and the interrelatedness of documents and their contents, as well as the complexity of these relationships, has prevented the increasing sophistication of online retrieval systems. Beginning with Tillett (1987), who sought to classify and quantify the entire range of bibliographic relationships in the Library of Congress catalog, research has demonstrated the efficacy of comprehending bibliographic relationships. Smiraglia (1992) investigated the derivative relationship, which holds among all versions of a work, refining its definition to include several different categories of derivation. Leazer and Smiraglia studied the presence of derivative relationships in the OCLC WorldCat (Smiraglia & Leazer, 1995, 1999; Leazer & Smiraglia, 1996, 1999), affirming the taxonomy of derivative relationship types. Yee (1993) examined problems of relationships among moving image materials, including the substantial problems of associating bibliographic records for varying instantiations of films. Vellucci (1994, 1997) examined musical works and found that the categories of work relationships that Tillett (1987) and Smiraglia (1992) had suggested were present, and in large numbers. Smiraglia (1999) demonstrated the effectiveness of the taxonomy of relationship types by analyzing the extent of derivation among entities in theological collections. Research in bibliographic relationships reinforced the observation of Lotka's law, exploded unitary concepts of bibliographic entities by demonstrating their complexity and interrelatedness, and confirmed the importance of the role of works in the bibliographic universe.

Entity-Relationship Design

Traditional catalogs and indexes were conceived as linear files of bibliographic records (i.e., citations). However, with the introduction of syndetic structure from Panizzi onward, catalogs grew increasingly complex. Translation to the online environment yielded the early (unfortunately misnomered) “online card catalog.” Research that would apply the principles of database construction to the infrastructure of the catalog was needed. Authors examined catalog data conceptually to identify independent entities. Fidel & Crandall (1988) described the Anglo-American cataloguing rules from a generalized database approach, using the entity-relationship model to suggest a problem-based typology of rules that might underlie a theoretical framework of rules for bibliographic database design. Leazer (1992) documented intra-record data redundancy, as well as the apparent absence of a conceptual schema, for the MARC-based online catalog. Leazer (1993, 1994) described a conceptual schema for the explicit control of works in catalogs, taking into account both Tillett and Smiraglia’s taxonomies of relationship types. Green (1996) presented a conceptual design for a full-scale bibliographic database based on entity-relationship modeling. The
1998 report of the IFLA Study Group on the Functional Requirements for Bibliographic Records presented a framework that identified and defined the entities of interest to users of bibliographic records, the attributes of each entity, and the types of relationships that operate between entities. Collectively, this research has demonstrated the utility of the entity-relationship approach to the design of bibliographic databases.

**External Validity**

A lack of comparative data that might provide the grounds for external validity has hampered research in knowledge organization. However, there are now indications that catalogs containing bibliographic records for similar collections of materials exhibit similar characteristics. Potter (1980), McCallum & Godwin (1981), Papakhian (1985), and Fuller (1989) all discovered similar proportions of single-occurrence name headings in research library catalogs. These studies support the contention that catalogs of similar materials exhibit similar characteristics. That is, there is reason to believe that there are grounds for generalizing research results from studies conducted in a specific library to other similar library environments. Taylor & Paff (1986) found that changes of name and title headings required by the implementation of **AACR2** in the catalog of a medium-sized academic library were in line with projections made by Taylor in her 1980 study of a similar library (Dowell, 1982). The replication tested proportions of change in the new catalog against the proportions reported in the 1980 study and found no statistically significant difference in the proportions from the two independent samples:

The fact that there was no significant difference between the projections . . . may indicate that samples of the collections of libraries (at least of academic libraries) are drawing from essentially the same universe. (Taylor & Paff, 1986, p. 280)

Further, they found that certain patterns of headings occurrence were comparable in the two independent samples:

Is it possible that various types of heading occur in predictable proportions in the bibliographic universe? . . . It can be noted that, although the exact proportions varied somewhat, the pattern . . . found in all three libraries in the Dowell study . . . was repeated at ISU. This is not simply a representation of the relative proportions of these types of headings in the cataloging as a whole. (pp. 280–281)

Countless other studies, notably those examining bibliographic relationships, have gathered data on the inherent characteristics of the documents in specific library collections. These data have yet to be compiled, but taken together with the studies cited here, there is evidence that theoretical predictability about bibliographic phenomena might be possible.
Historicism

Epistemology is the division of philosophy that investigates the nature and origin of knowledge. Poli (1996) contrasted the tools of ontology and epistemology for knowledge organization, suggesting that while ontology represents the "objective" side of reality, epistemology represents the "subjective" side. Ontology ("being") provides a general objective framework within which knowledge may be organized, while epistemology ("knowing") allows for the perception of the knowledge and its subjective role. Olson (1996) used an epistemic approach to comprehend Dewey's classification, asserting a single knowable reality reflected in the topography of recorded knowledge. Dick (1999) described epistemological positions in library and information science. He suggested that experience (i.e., empiricism) provides the material of knowledge, and reason (i.e., rationalism) adds the principles for its ordering. Rationalism and empiricism supply the basic platform for epistemological positions. They have been the primary modes of theoretical development in knowledge organization to this point. At the turn of the twenty-first century, the field of knowledge organization has begun to turn increasingly to the tools of qualitative analysis to explain the complexities of phenomena surrounding knowledge and its documentary record. This can be seen as an attempt to move beyond the strictures of empiricism, to bring a historicist epistemology to bear on the problems of the organization of knowledge.

Hjørland's Epistemological Framework

Hjørland (1998) asserted a basic epistemological approach to base problems of information retrieval, particularly to the analysis of the contents of documentary entities. He began from a basic metaphysical stance, stating that ontology and metaphysics describe what exists (basic kinds, properties, etc.), whereas epistemology is about knowledge and ways in which we come to know. Hjørland listed four basic epistemological stances:

- Empiricism, derived from observation and experience;
- Rationalism, derived from the employment of reason;
- Historicism, derived from cultural hermeneutics; and,
- Pragmatism, derived from the consideration of goals and their consequences.

Hjørland described a domain-analytic approach to subject analysis, recognizing that any given document may have different meanings and potential uses to different groups of users. Hjørland & Albrechtsen (1999) delineated recent trends in classification research, demonstrating the utility of Hjørland's epistemological framework for deriving categories.

Marco & Navarro (1993) described contributions of the cognitive sciences and epistemology to a theory of classification:
The study of epistemology is, therefore, essential for the design and implementation of better cognitive strategies for guiding the process of documentary analysis, particularly for indexing and abstracting scientific documents. The ordering and classifying of information contained in documents will be improved, thus allowing their effective retrieval only, if it is possible to discover the conceptual framework (terms, concepts, categories, propositions, hypotheses, theories, patterns, and paradigms) or their authors from the discursive elements of texts (words, sentences, and paragraphs). (p. 128)

Epistemology, then, is concerned with the theory of the nature of knowledge.

Knowledge organization has been too long enamored of the rationalistic and pragmatist approaches. Indeed, rationalism expounds detail, and some of the hallmarks of knowledge organization theory are the rationalist works on descriptive cataloging. Most notable among these are the groundbreaking works of Seymour Lubetzky, who first sought to explain rationally, the purposes and construction of the modern catalog (summarized in Lubetzky, 1969). Domanovszky (1974) and Carpenter (1981) also offered rationalist constructs that advance the theory—that is, the system of principles that govern the construction—of the dictionary catalog.

However, the problem remains that too few conceptual arrays are based on either empirical knowledge of what exists in the universe of documentary knowledge entities, or on essential understanding of the cultural importance, historic origins, or social roles, of the entities we propose to systematize. Knowledge organization, as Hjørland (1998) and Hjørland & Albrechtsen (1999) have suggested, must proceed from more finely developed epistemological positions, and these are the empiricist and historicist points of view.

Research Moves Away from Empiricism

To inform our cognitive structures with epistemological perspectives from the historicist point of view requires new analytical tools. A few examples will demonstrate the power of the historicist perspective. For instance, cocitation analysis, reviewed extensively by White & McCain (1997), has demonstrated the complex relationships that exist among authors working within and between disciplines. Beghtol (2000, 2001) demonstrated the centrality of key concepts, such as “Genre” and “A Whole and its Parts.” Mai (2000a, 2000b) brought the tools of semiotics to bear on problems of indexing and classification. Smiraglia (2000, 2001) used semiotics to comprehend the social role of works and Hjørland’s epistemological stances to derive an expanded definition of the work. By understanding from an empirical perspective what has been observed from a historicist perspective, we can begin to rationally and pragmatically derive appropriate constructs for systems for information retrieval. The potential uses of epistemology for documentary analysis, then, are many; a few have been attempted. Whereas ontology
may be relied upon to frame the organization of knowledge, epistemology provides us with key perceptual information about the objects of knowledge organization. Each perspective can contribute to understanding; collectively, a balanced perspective can be achieved. To begin, empiricism can lead us to taxonomies of knowledge entities. Rationalism can demonstrate the cultural role of, and impact on, knowledge entities.

*Svenonius*

Svenonius (2000) represents, like Wilson (1968), a milestone summary and analysis of all that has come before. Svenonius asserted that knowledge organization is accomplished through a bibliographic language (or, more properly through a complex set of bibliographic languages), with semantics, syntax, pragmatics, and rules to govern their implementation. She cumulated the historical record of research in knowledge organization, and brought ontological tools to bear on the problems of the definition of phenomena. Like Wilson, she drew together the results of empirical research in every aspect of knowledge organization, stating principles where appropriate, and demonstrating lacunae in the empirical record. Also, like Wilson, she contributed a tool that may come to be used as a theoretical benchmark for future research. This is her set theoretic model "that regards the bibliographic universe as consisting of documents, sets of these (formed by attributes . . .), and relationships among them" (p. 32).

**THEORY IN KNOWLEDGE ORGANIZATION: CONCLUDING REMARKS**

"Theory," then, remains a system of testable explanatory statements derived from research. In knowledge organization, the generation of theory has moved from an epistemic stance of rationalism (construction of retrieval tools based on reasoned principles), to pragmatism (based on observation of the phenomena of knowledge entities), to empiricism (based on the results of empirical research). After nearly two centuries of formal work on the construction of catalogs and classifications, we are blessed with a well-spring of rationalist thought and large codes of pragmatic rules. At the same time, three decades of advancing formal, empirical research have yielded the beginning of a set of formal theories for the organization of recorded knowledge.

Two key contributions are those of Wilson (1968) and Svenonius (2000). Each expounded an entire system for the knowledge domain and its retrieval apparatus. Given the similarities between their approaches, one can also view these systematic presentations as standing at two points on the epistemological spectrum. That is, Wilson’s system followed a century of pragmatism, and seems to arise at the beginning of what would be the most intense period of empirical research into knowledge phenomena. Svenonius’ system arises at the point where research seems to have turned toward the historicist stance.
And so there is no single, formal statement of theory of knowledge organization. However, we can posit, based on this review, three simple theoretical statements:

1. A theoretical assumption underlies the infrastructure of bibliographic databases, such that most names will occur only once, and a very small number, which can be predicted by Lotka’s Law, will occur many times. As noted above, Lotka’s law has been observed in a variety of bibliographic environments. We are not certain why this law holds, or what, exactly, it represents. Smiraglia & Leazer (1999) have suggested that canonicity plays a role in this function. That is, some works enter an academic canon, and thereby gain value for the academic community, which in turn causes them to be variously translated, edited, and reproduced, thus contributing to the frequency of occurrence of author names in databases. It is also likely that some larger number of works are published, consumed by the culture, and then discarded (in a sense, such works are “digested”). However, it is equally likely that Lotka’s law reflects phenomena that are as yet unobserved. In sum, the pragmatic influence of this distribution is that 60 percent of records (names, etc.) in a file will be unique; another 40 percent will require extra effort to delineate the relationships among the knowledge entities they represent.

2. Bibliographic relationships reinforce the observation of Lotka’s law, exploding unitary concepts of bibliographic entities by demonstrating their complexity and interrelatedness. Bibliographic relationships are complex. These are the relationships among bibliographic entities, such as the equivalence relationship (that holds among copies of an item, e.g., a book and its microform reproductions) or the derivative relationship (that holds among variations on a work, e.g., editions and translations). Research has shown that for a small proportion of works in catalogs (about 40 percent, in line with Lotka’s law) there will be a complex set of interrelated entities that require explicit linkage to facilitate efficacious retrieval.

3. There is a beginning of evidence that there are grounds for external validity in the examination of knowledge entities. That is, we have begun to observe similar distributions from one collection to another among the bibliographic characteristics that describe knowledge entities. This means that empirical research can advance secure in the knowledge that results can be generalized from one subset of the bibliographic population to another.

Other theoretical statements, of course, might soon be possible. These will come to light as a result of the combined use of all four epistemological stances. For instance, much research has been undertaken on the na-
ture of subject searching in library catalogs. This research suggests that cognitive aspects of user behavior are at least as important as the subject characteristics of the documents represented. One might expect research to soon provide theoretical statements in this area. Another area rife for theoretical development is the extensive work of cocitation and coword analysis. This work describes relationships among scholars, essentially mapping intellectual relationships within knowledge domains as represented by citations and abstracts. What is needed are sociological (i.e., cognitive) explanations of the behaviors that lead to these intellectual relationships. Such explanations could give us real predictive power for the development of sophisticated systems for the retrieval of knowledge entities.

One thing is clear: A variety of epistemic stances are required to advance the pursuit of theory. Where pragmatism could only suggest what to do, and empiricism could only describe unique phenomena in isolated contexts, rationalism and historicism can help us uncover the ineluctable truths of the natural order of knowledge entities.

REFERENCES


Panizzi, A. ([1848] 1985). Mr. Panizzi to the Right Hon. the Earl of Ellesmere, British Muse-
um, January 29, 1848. Reprinted from Appendix to the report of the commissioner appointed to inquire into the constitution and management of the British Museum. In M. Carpenter & E. Svenonius (Eds.), Foundations of descriptive cataloging (pp. 18–47). Littleton, CO: Libraries Unlimited.


Explanation and Prediction: 
Building a Unified Theory of Librarianship, 
Concept and Review*

WILLIAM E. McGRATH

ABSTRACT
As INSPIRATION FOR DEVELOPING A comprehensive, unified, explanatory theory of librarianship, the author makes an analogy to the unification of the fundamental forces of nature, beginning with the Copernican revolution, followed by the discoveries of Kepler, Galileo, Newton, and Einstein, and the unification of electro-magnetism, light, the weak force, the electroweak force, the strong force, and the ultimate goal to include gravity, space, time, and relativity into a single grand unified theory. While the analogy may be naive and debatable, the linking of disparate domains suggests a process for linking the broad and classical functions of librarianship into a framework for a unified theory. The unified theory might consist of functions stemming from the world of publishing: Selection and deselection, acquisitions, the structure of knowledge and classification, storage and preservation, the library collection, and circulation. The author reviews recent Library and Information Science (LIS) research of the type that could contribute to development of unified theory. Dependent and independent variables are identified when apparent, with particular emphasis on the importance of units of analysis to theory. The recent literature is dominated throughout the framework by studies involving library circulation or its surrogates.

COPERNICAN REVOLUTION

When Copernicus showed that the known planets orbited the sun, not the earth, he began a centuries-long process of linking the fundamental forces of nature. His revolutionary theory changed the course of astronomy because it explained the movements of the planets far better than the
orthodox Ptolemaic system did. It was advocated by Galileo, augmented by Kepler's discovery of elliptical orbits, explained by Newton's laws of gravity, and ultimately refined by Einstein’s general theory of relativity.¹

The genius of the Copernican-Galilean-Keplerian-Newtonian achievement, or "celestial mechanics," as it is now called, is in its extraordinary ability to explain and predict. The movements of the planets, moons, comets, and other bodies can be explained in terms of gravitational force and the conic sections of classical geometry—the ellipse, parabola, and hyperbola—and their exact positions relative to each other can be predicted with great accuracy.

Similarly, the power to explain and predict also improved with the nineteenth-century reconciliation of electricity and magnetism by Michael Faraday, with light by James Clerk Maxwell, and more recently with the fundamental "weak" force, to form the "electroweak" theory. Current efforts are aimed at reconciliation of the "electroweak" force with the "strong" force and, ultimately, with gravity and general relativity to form a "super unified" theory incorporating all of the fundamental forces of nature (Ferris, 1991).

Hannaford (1980), in his discussion of libraries and scientific knowledge, refers to this as the hierarchical picture of explanation, "General relativity explains special relativity explains Newtonian mechanics explains observations of planetary motions" (p. 577).

**Phenomena of Librarianship**

What is the implication of these great achievements for libraries—apart from being repositories for the precious documents describing them? As scholars and social scientists in our own much humbler yet somewhat pretentious sphere, can we formulate theories to explain the various interacting forces of librarianship that would enable us to predict those phenomena? The answer is "perhaps," because such application is mostly by analogy, and the analogy is more inspirational than emulative. After all, library science is not natural science. Human behavior, far more complex than planetary motions, can never be described or predicted with the precision of celestial mechanics. But we should like to try, even though our theories may never be elegant or exact.

For this discussion, an informal and simple (some would say simplistic) definition of theory can be used: A set of variables that may explain and predict another variable. A unified theory is simply one that reconciles or incorporates other theories. For a more formal definition of theory in the context of librarianship, refer to the taxonomy of theory by Grover & Glazier (1986) and their broader update of the taxonomy in this issue (Glazier & Grover, 2002).

Consider some of the traditional areas of concern to librarianship: Publishing, acquisitions, storage, preservation, classification and organization of knowledge, and collections and circulation. While not necessarily
complete, few question these as basic to the profession. Most recently, Curran (2001) has reconfirmed them as those aspects of information that library and information scientists are most concerned with, adding origin, dissemination, properties, retrieval, and interpretation of information. No doubt, this list could be even further refined or expanded. Curran offers many questions pertaining to each area, the answers and alternatives to which the profession should continue to seek. His questions (how, who, what) are all valid when attempting to describe activities. We, those in the Library and Information Science (LIS) profession, should like to have a more precise, perhaps mathematical understanding of how these areas are interconnected, and how the activities or outcomes of each may be explained or predicted in terms of inputs from others. While recognizing that Curran and others may prefer the more detailed outline or one altogether different, this paper is confined to the more limited one. However, whatever the framework, it is important to note that there is a sense of flow or connectivity from one domain to another, just as there is in everyday practical processing and use of library materials.

Within the context of these activities, but beyond their mere description, what do we mean by "explanation" and "prediction?" What do we want to explain and what is there to predict in librarianship, and why should we want to predict it? One definition of explanation—a much more complex concept than can be explored here—is simply accounting for one phenomenon in terms of others. A good explanation is one that provides understanding. More specifically, it is one that, given a set of conditions, enables us to predict another with reasonable or satisfying confidence.

In every area—acquisitions, storage, preservation, classification of knowledge, collections, reference work, and so on—there is something that varies and is dependent on something else, so that we should be interested in building theories that would enable us to explain and predict those things that vary in each area. Intuitively, we know that each area is, to some extent, dependent on some other, either directly, in a linear flow, beginning to end, or in a more complex multidimensional way, in which communication, or the workflow, may take many paths.

Consider some typical activities in each of the functional areas listed above—how they might be explained by some other area, how specific theories could be built for each area, and then finally how they might ultimately be integrated into a unified theory. Figure 1, modeled after a diagram, "Explaining the Forces of Nature," published in the New York Times (Broad, 1984), and reproduced in McGrath (1995b, see note 1), shows these traditional areas of librarianship with hypothetical connections (dotted lines) between them to indicate relationships not firmly established in any explanatory or predictive sense.
Publishing

To some extent, librarians want to know what societal factors contribute to the variability of publishing each year: Demand, world events, economic conditions, and so on. Knowledge of those factors is necessary to construct a theory of publishing. Though such a theory is of interest for understanding the bigger picture, librarians accept information from the world of publishing as input to their considerations—the population of books, journals, and other materials, or portion thereof, to be acquired. Whereas publishing is the output of societal motivation and conditions, it is input to a theory of acquisitions.

Acquisitions

Publishing is a necessary condition for acquisitions to take place. Collection-building cannot occur unless there are published items to collect. The question, therefore, is “What are the conditions and criteria for selecting or not selecting specific books to add to the collection?” All of these conditions and criteria may be quantified in such a way that their affect on the number of items selected can be tested.

A proposed theory of collection building should consider—that is, should test—variables associated with publishing, selection, and censorship, as well as a host of other variables, including the education and knowledge of the selectors, the academic environment, nature of the community, size of the budget, and the required subject areas. The theory would include only those variables that significantly contribute to the variation of selec-
tion and collection building—that is, only those variables that hold up under testing. Even then, it is still a theory, because it is in the nature of science that an old theory can be modified, overthrown, or displaced, and that is certainly true in our context.

**Classification**

The classification scheme used by the library is a major property of the collection. The scheme reflects the librarians’ perceptions of how knowledge is organized or structured. The idea of structure comes closest to our cosmological analogy: Just as there have been many theories on how astronomical bodies relate to one another in an organized system, so also have there been many classification systems. And just as some of those cosmological theories, such as the Ptolemaic system, failed in their ability to predict, so have our classification systems failed to optimize accessibility. Just as the Ptolemaic system was taken on authority for fourteen centuries or more until Copernicus put it to a test, so have librarians taken most classification systems on authority and rarely, if ever, put them to the test of predictability. Human systems can never be deterministic in the sense that, for example, orbiting bodies depend on the force of gravity. Because society is mutable, no classification theory can ever be enduring. Nevertheless, we can still look for structure in knowledge. And even though structure may not be permanent, principles are permanent and are reason enough to look for more enduring structure. Buckland, in defining theory, says that “structure is theory” (1988, p. 37). From that, it follows that classification and the structure of knowledge is necessary for the development of a unified library theory.

The structure of knowledge is due in no small part to what is published. For any given library, it may depend on the portion of published knowledge acquired. It may also be due to other variables in the local environment—including demand, the nature of the community, and the library’s users.

**Storage and Preservation**

Storage and preservation are major functional concerns of every library. Storage problems involve available square footage, linear stack space, stack maintenance, retrieval and reshelving of materials, scheduling and training of stack personnel, shelf-reading, inventory, and much else. Preservation comprises the condition of materials, environmental questions, humidity, chemicals, temperature, lighting, acidity of paper, dust, protection against fire and moisture, and so on. All of these variables can be quantified, controlled, or otherwise described and are important properties of the library collection.

**The Collection**

Now we can see that a description of the library’s collection must include everything discussed up to this point: Publishing, acquisitions (which
entails selection), the classification scheme (based on some perceived structure of knowledge), and the problems of storage and preservation. How these components fit together to make a theory of collections seems obvious and trivial, but what may seem obvious may be merely a reflection of what we actually do in practice, the current way of doing things—which may not necessarily be the best way. After all, the Ptolemaic system, which Copernicus and Galileo showed to be wrong, was able to predict planetary positions with some success. Perhaps some components, such as classification, may be based on a coherent theory, but unless the theory includes all components it is not complete. Ideally, all of the variables and all of the components must be described, quantified, tested, and retested as a complete system before we should be satisfied. Hannaford (1980), equating “theoretical” and “scientific,” believes that collection development can be scientific. In two earlier papers, McGrath discussed the theory of collections in terms of the relationship between circulation and collections and the units in which data could be collected (McGrath, 1980), and in terms of the relationship between parts of collections, who uses them, and between other collections (McGrath, 1985).

Circulation

Let us now look at circulation, perhaps the ultimate first and last reason for the very existence of the modern library. Success of the library depends on its circulation. Conversely, circulation depends on the library and its classification, organization of materials.

The high volume of circulation requires that library administrators maintain appropriate records, reshelve returned books promptly, keep bookshelves orderly, and so on. But library circulation varies from hour to hour and day to day. The library administrator would like to be able to anticipate (to predict) this variation in order to allocate sufficient funds to pay shelvers and to schedule them when needed. If the conditions or variables that make circulation fluctuate were known, the administrator could provide better service. What makes circulation fluctuate? We do not know until we can test the variables we think may be correlated with circulation—that is, by formulating a theory of circulation and then testing it.

Circulation may be dependent on variables both internal and external to the library. In either case, we should like to know what they are. If internal, then we would need to examine all functional areas, such as acquisitions and cataloging, for conditions that might make circulation fluctuate. If external, then circulation becomes part of a larger sociological theory.

Grand Unified Library Theory

In a very broad and nonspecific framework, this essay outlines one possible approach to the development of a grand unified library theory in which the library is an integrated system where outcomes are describable
in terms of measurable relationships, regularities, and laws. The work required to uncover these relationships—the work of intellectual design and computation—might be prodigious and challenging, but the computations should be relatively trivial once the design is formulated.

The unified theory is sketched only in the broadest and briefest outline. There is much not addressed—the psychology of users and librarians, attitudinal studies, organizational behavior, interaction with other disciplines, scientometrics and informetrics, individual scholarly productivity, citation analysis, LIS education, welfare and status of librarians (including tenure, salaries, and prestige), and so on. To some critics, the most glaring omission might be inattention to the digital revolution. To this author, however, while the production of electronic databases, the World Wide Web, and the Internet is technology, their use can be described in terms of traditional library functions.

At a more mundane level, the need for bridging domains, whether it is called unified theory or something else, is recognized by the familiar sardonic complaint in libraries that acquisitions librarians do not talk with catalogers, who do not talk with reference librarians, who do not talk with circulation librarians, and so on. “No one talks with anybody,” yet the need for reconciliation, cooperation, and system integration is obvious and incontrovertible. A unified theory might provide the basis and incentive both for understanding and quantifying the flow of materials between the domains and for establishing firmer communication as well.

METHODS

Modern mathematical and computational tools, far more powerful than the pencil and paper used by Copernicus and Kepler three centuries and more ago, can measure the relationship between output or dependent variables and input or independent variables. Probabilistic statistical tools, such as canonical correlation, discriminant analysis, path analysis, the general linear model, multiple regression, and analysis of variance, are routinely used for testing and building theories in many scientific domains. The general idea of these tools is that they allow us to account for the variance in the dependent variables in terms of the variance of independent variables. Other methods may be used to describe the inevitable cyclic nature of information access. After all, the Laws of Newton and Kepler were derived from pure and accurate description of orbital motion and were held to be precise and deterministic. Mathematical tools, such as time series and spectral analysis—fundamental to the understanding of celestial signals and orbital mechanics—can be applied to these cycles (McGrath, 1996a).

Building a theory, of course, entails much more than application of quantitative methods. An understanding of the entire process is essential. Scriven (1968) provides just such an understanding in an essay on the concerns of science: Observation, description, definition, classification, measure-
ment, experimentation, generalization, explanation, prediction, evaluation, and control of the environment. McGrath (1986) showed how these concerns might apply to research in LIS as a coherent and continuous process.

**A Review of Recent Explanatory Research That Could Contribute to a Unified Theory**

Theory in LIS is something more than just an esoteric and abstract realm out of touch with the practical problems of day-to-day professional work, as may be inferred from the extensive review by Pettigrew & McKiechnie (2001). They found that of 1,160 articles in six LIS journals for the years 1993 to 1998, 397 discussed or employed theory while characterizing “the vast majority of information science” since 1950 as “atheoretical.” Earlier surveys reached similar conclusions (Peritz, 1980). Nevertheless, these reviews show that, despite the failure of much research to address theory, there is considerable recognition among grass-roots researchers that theory would help to strengthen our understanding of LIS relationships.

Following is a brief review of recent papers that exemplify the sort that can contribute to theory in each of the traditional categories outlined above. The journals are replete with studies of library and information activity, but relatively little—as Pettigrew & McKiechnie and others have found—cast in theory, and less that lend themselves to theory building. No attempt was made here to review all of the literature that might otherwise be considered relevant. In particular, the vast literature on digital libraries and online retrieval is left to other reviewers (e.g., see Bar-Ilan & Peritz, 2002).

There is much literature on the philosophy of LIS containing provocative and stimulating ideas that always seem on the verge of offering testable theories or of challenging empirical researchers to operationalize abstract themes. One such piece is the comprehensive and thoughtful treatise on metalibrarianship by Nitecki (1993), a tour de force, in which he explores not only the interdisciplinary character of librarianship, but the “relationships between the essential, minimal and basic elements in the communication of any recorded data, information, or knowledge” (Part 1, p. 2). In Chapter 11, “The Theory of Metalibrarianship,” Nitecki explores theory, metatheory, methodology, evolution of concepts, the “multiplicity of metalibrary relations,” and other ideas detailing a relational approach to librarianship.

A paper by Znadlo (1997) similarly challenges LIS to apply “philosophical” ideas to “useful things.” Many more such papers can be found in both Nitecki’s and Znadlo’s citations, as well as in others. However, as interesting as it might be, unless the philosophy of librarianship tells us how to develop an explanatory theory of librarianship, it has limited value to this review.

Criteria for inclusion in this review are papers published (approximately) within the last ten years that include (1) the use of quantitative methods, such as multiple regression and the analysis of variance, that enable
researchers to test independent variables that might account for variance in dependent variables or (2) correlation methods applied to two or more variables for which dependence or independence may or may not be identified by the researcher but which are potentially one or the other or (3) studies that do not necessarily apply quantitative methods, but express a research hypothesis or objective or model that may ultimately be tested by quantitative methods and thus have the potential for building theory.

An enormous number of studies have been devoted to frequency distributions of single variables. While these are always highly mathematical and interesting and theoretical, and while there are examples even among the papers in this issue of *Library Trends* (e.g., Rousseau), their authors are mostly concerned with the ability of a frequency distribution to forecast itself. These distributions are theoretical in that researchers attempt to fit a model to actual data. They are often highly successful and accurate, but are limited in their application to explanatory theory. The relationships between them and other variables are rarely analyzed. Other than to note their importance when considering normality and homogeneity of variance, important properties of distributions used in parametric testing, they contribute very little to the explanatory relationships of concern to this review. With a few exceptions, that genre is not included among the studies reviewed herein.

Many other interesting studies, some that used an explanatory approach with dependent and independent variables, were excluded from this review because they were outside of its main thread or failed to find significant relationships. Attitudinal studies, user satisfaction studies, and psychological studies in general were excluded, as were studies on librarians’ status, job satisfaction, and salaries. Thus, there is a bias toward what libraries, librarians, and users do instead of what they think or feel.

Papers about citation theory, except where citations correlated with other relevant variables, have been excluded. The literature of citation theory focuses primarily on the communication relationships among scholars and scientists or between and among disciplines—highly interesting but of indirect interest here.

There may well be studies that could have been included—papers published in the seventies, eighties, and earlier, for example. However, the purpose of this paper is not to provide an exhaustive review of all possible relevant papers or a history of theory development, but rather to provide examples of recent papers that might help to build theory.

The following studies, then, are illustrative of types that have the potential for building a comprehensive, grand theory. One could call these studies “normal” science after Kuhn (1962)—filling in the gaps of existing theory—except that existing theory is much more elemental or primitive, and LIS has far to go to build good explanatory theory.
Dependent Variables, Independent Variables, and Units of Analysis

When apparent, the author has tried to list the dependent variable, significant independent variables, and the units of analysis (the things described by variables) for each paper reviewed. Whereas the meaning and importance of dependent and independent variables in theory is understood by most researchers, the importance of units of analysis in research design is not always appreciated. Understanding the unit of analysis is crucial in building theory (McGrath, 1996b). The difference between variables and units of analysis can be quite confusing. A variable at one level, for example, might be a unit of analysis at another level. In some studies, the units of analysis were not always specified by their authors and had to be inferred.

Saxton (1997), using meta-analysis to evaluate consistency of findings and standards for reporting findings across independent studies—in this case, correlations with accuracy of reference service—makes several important observations, one of which is also critical to the development of theory. “Studies cannot be compared,” he says, “if they use different units of analysis (for example, libraries, librarians, reference transactions)” (p. 282). McGrath (1996b) also makes this argument but adds that, in the development of a unified theory, different units of analysis can be related to each other at different levels. For example, number of libraries can be a variable in a study where country is the unit of analysis, whereas in another study, number of books held by a library may be a variable, while library would be the unit of analysis.

For each study, where identifiable, the independent variables are italicized, the dependent variables are in uppercase and, when not otherwise indicated, the units of analysis are followed by the abbreviation “u.a.” in parentheses. Thus, in a study using demographic variables to predict the number of books checked out by users of a library, independent variables are, for example, age, sex, marital status, educational level; the dependent variable is NUMBER OF BOOKS CHECKED OUT; and the units of analysis are library users (u.a.).

Publishing

It has been said that, as pharmacies are the dispensers of the drug industry’s productivity, so are libraries the dispensers of the publishing industry and scholarly output. Such a limited perspective interferes, perhaps, with our ability to perceive the whole world of knowledge and to understand how best to use it. Much research can be found on the commercial and marketing aspects of publishing, but other than pricing and availability, relatively little—in the explanatory sense—on the interaction with libraries. Not reviewed here are the multitudinous studies on factors affecting the productivity of individual faculty, scientists, and scholars in general.

Petersen (1992), using multiple regression to find the most significant correlates of journal (u.a.) PRICES, found that for-profit publishers, those originating in Europe, and the journal’s impact factor were the best determinants.
Chressanthis & Chressanthis (1994), also using regression analysis, found that *the exchange rate between countries, the existence of illustrations, the number of pages, a composite of citation measures, journal age, economies of scale created by higher circulation, and the existence of "nonprofit motivation of publishers" all have an effect on journal (u.a.) PRICES.*

Kishida and Matsui (1997) developed a regression model in which they found that *population and the number of people attaining a university education best explained THE NUMBER OF MONOGRAPHS PUBLISHED in each country (u.a.).* Quandt (1996) used an iterative simulation model to describe the evolution of library subscriptions in which cancellations inevitably cause publishers to raise their prices. Though not about the determinants of price nor the number of subscriptions, his article may be helpful in designing such a study in two respects: One in which *price and profit are predictors of THE NUMBER OF LIBRARY SUBSCRIPTIONS to journals (u.a.); and another in which cost and importance to libraries are predictors of library (u.a.) decisions to SUBSCRIBE OR NOT.* Thus, his article is an example of bridging more than one level of our theoretical context: Publishing and acquisitions.

**Acquisitions (Book and Journal Selection)**

Whereas several studies on the predictors of price as a dependent variable were cited in the section on publishing above, *price becomes an independent (determining) variable when considering the purchase or deselection of books and journals.* For example, McCain (1992) found that *price, as well as mathematical content and cocitation rate, were significant predictors of THE NUMBER OF LIBRARIES HOLDING economics journals (u.a.).* *Longevity and cocitation rate were significant predictors in genetics.*

Shaw (1991) found a significant correlation between the *number of reviews of BOOKS and the number of libraries holding them.* Likewise, Serebnick (1992) found a significant relationship between the *number of reviews of book titles (u.a.) and THE NUMBER OF LIBRARIES HOLDING THEM.* Similarly, in a sampling of books (u.a.) reviewed in *Choice* magazine, Calhoun (1998) found a positive correlation between the *number of reviewed books appearing in vendor approval plans and those books subsequently purchased by libraries.* Either of these could be regarded as the dependent variable, but were not so indicated in the study.

Kreider (1999) found a significant correlation between *local citation frequency and the global citation frequency of journals (u.a.) appearing in Journal Citation Reports (JCR), suggesting that libraries should consider JCR data when evaluating their journal collections.* Either local or global citation frequency could be regarded as the dependent variable, depending on purpose.

Tsay (1998) found significant correlations between *frequency of journal use and citation frequency and between frequency of use and impact factor for some medical disciplines (u.a.) but not for others.* To comment, since Tsay...
did not indicate which comes first, *circulation* or *citation* (that is, which is dependent and which independent), librarians could use published *citation* data to predict *CIRCULATION* when selecting and, conversely, *circulation* to predict *CITATION* when deselecting holdings.

Crotts (1999) "develops" a model for allocating monograph budgets to *SUBJECT AREAS* based on *circulation*. Budget allocation for subject areas is an issue for which there is voluminous literature and many reviews going back to the seventies and eighties and earlier. His paper is cited simply to document the continued interest in and timeless nature of a classic model, as an example of bridging the two domains (collection development and circulation), and as continued potential for further development of theory. His design was not conceptualized in terms of dependent or independent variables, although it is reasonable to regard *CIRCULATION* as the dependent variable and subject areas (u.a.) as the units of analysis. For earlier contribution of circulation to theory and collection development, see McGrath (1980, 1985).

*Classification and Organization of Knowledge*

Few recent explanatory studies on classification and organization of knowledge were found. This does not necessarily suggest a research oversight, because there is a great deal of literature, including whole journals, devoted to classification and organization of knowledge. Nevertheless, there does seem to be a gap in the explanatory literature of classification.

Satija (2000) provides numerous definitions—one of Scriven's (1968) concerns—about classification concepts that would be necessary when operationalizing hypotheses in an explanatory design.

Leazer & Smiraglia (1999) perform a qualitative analysis of "bibliographic families," families of related works in the library catalog, intended to produce an explanation of some pattern [a dependent variable?]. Cataloger-generated maps of these families, they conclude, are inadequate to explain the pattern, and user behavior studies are needed to determine which maps are preferable. Smiraglia discusses the need for explanatory studies in this issue of *Library Trends*.

Losee (1993), in a study on the influence of classification and location on circulation, used a regression approach to predict the AVERAGE NUMBER OF BOOKS a patron (u.a.) circulates from the relative location of books, relationships among the number of areas in which books are found (measured by the number of stops a patron makes when browsing), and the distances across a cluster. Patrons made more stops than books found at a stop.

Rodman (2000) discusses the connection between call numbers and browsability on the shelf, or in an online catalog, when call numbers are not changed to fit into shelf list sequence. Though not an explanatory study, it does suggest a design in which "number of screens between like items" in an online catalog could be regressed against the NUMBER OF HITS during a search session (u.a.) or time period (u.a.).
Storage, Preservation, and Collection Management

Storage, preservation, and collection management are crucial components of a comprehensive theory, obviously because existence of a library collection (whether hard copy or digital) is a necessary condition for its use or circulation.

As a means for identifying low-demand titles (u.a.) for remote storage, Silverstein & Shieber (1996) looked at individual titles (u.a.) to see how many times they circulated (0, 1, 2, . . . , n times circulated). They concluded that “past use [is still] the best single predictor of future use” (p. 289). Though theirs was a frequency distribution study, not intended as explanatory, their data might be submitted to explanatory methods, such as analysis of variance. Independent variables were categorical: Last use, Library of Congress classification, publication date, language, and country.

For a similar purpose, Hayes (1992) fit an exponential J-curve equation to book (u.a.) circulation frequency data, and developed a cost-allocation model to levels of access and storage. The units of analysis were books (u.a.). The dependent variable was, variously, circulation and in-house use. As with Silverstein & Shieber, his study was not intended to be explanatory.

Lee (1993) addresses the problem of storage space, citing past research on remote storage, weeding, and rarely used material as possible solutions. As an aid to determine the most economic approach to storage, Lee proposes a model that incorporates both prediction of demand and cost analysis into a single model.

Two surveys of book deterioration (Bennett, 1992; O'Neill & Boomgaard, 1995) were not in themselves explanatory studies but may be helpful in defining variables such as the brittleness and acidity of book paper (u.a.) and other conditions that may be helpful in eventual correlation with other components of a unified theory.

Collections

What the library collection contains and how it is organized and used is an essential component of a unified theory (McGrath, 1985).

Exon & Punch (1997), replicating a 1981 study, tested the assumption of self-sufficient library collections by performing a correlation analysis between collection size of a library (u.a.) and interlibrary loan requests of other libraries. From the strong positive correlation found, they conclude that self-sufficiency is a fallacy. This can be interpreted to mean that libraries need each other and that their interdependence may be incorporated into the larger theory. In an explanatory study, number of interlibrary loan requests could be the dependent variable.

Circulation (Includes Catalog Access, Online Access, and Reference Service)

Circulation and usage may be the most studied function in libraries. The literature is voluminous, going back many decades, and has been ex-
tensively reviewed by many authors. These reviews can readily be found in the literature.

A perennial question is whether in-house use can be employed as a measure of circulation—that is, books officially charged out. The unit of analysis may be some unit of time, such as day, week, or month; or some other unit, such as subject or discipline; or type of material, such as book or journal.

Blecic (1999), investigating journal (u.a.) use in a medical library, found a significant correlation between in-house use of journals and their circulation, as well as between those two variables and journal (u.a.) citation by faculty. Similarly Walter & Darling (1996) showed an apparent correspondence between circulation of journals (u.a.), in-house use, interlibrary loan, and frequency of publication.

Lochstet & Lehman (1999) correlated reference question counts with door counts in which the units of analysis were weeks (u.a.). One would expect to find as high a correlation between these two variables (either of which could be dependent on the other), as one would expect between circulation and in-house use. There was indeed a very high correlation, 0.96, suggesting, at worst, a meaningless comparison or, at best, an error somewhere. At the very least, what is apparent is that virtually all gross counts of library use—whether in-house, official checkouts, reference counts, or door counts—are necessarily highly correlated, because the same users who are counted as they walk through the door (turnstile counts), are counted again when they ask reference questions, and still again when they check out books. What is needed to build theory are correlation studies between library use and variables that are truly independent of use. Circulation, in-house, and other measures of use are not independent of each other.

One such study, in the public library context, is that by Yilmaz (1998), who regressed circulation against age, sex, marital status, educational level, occupation, income level and “geographic past,” as well as social status and social role, in three socio-economic strata. Regardless of whether these variables were significant or not, they appear to be truly independent. Users (u.a.) were the units of analysis.

Cooper & Chen (2001) used a logistic regression approach to predict “relevance” of a catalog search session (u.a.), where relevance was defined as a discrete result—that is, WHETHER OR NOT A USER SAVES, PRINTS, MAILS, OR DOWNLOADS A CITATION. The prediction is based on “the time spent performing tasks during the session, and the counts, relative frequencies, and proportions of actions taken during the session,” which the authors call “surrogates for user behavior” (p. 826). The unit of analysis was search session (u.a.) rather than individual user (u.a.) because, presumably, individual users made repeated searches.

Most of the variables cited in this review were measured irrespective of their change over time. That is, they were measured at points in time, wheth-
er minute, day, week, or year. A complete theory of librarianship should, of course, consider change over time. Time adds another dimension to the structure of explanatory theory.

Two kinds of past-future use studies are (1) probabilistic frequency distribution studies, which count the number of times a thing happens and where low-frequency is usually more common than high frequency, and (2) forecasting studies in which the units of analysis are sequences of points in time, a univariate framework different from correlation studies, which are usually multivariate, and in which the units of analysis are taken as snapshots in time.

Kasukabe (1990), using multiple regression to study public library use in Tokyo, found that per capita collection (presumably holdings), population of community per thousand librarians, day time population, and proportion of administrative workers were all predictors of PER CAPITA CIRCULATION but differed at different points in time (u.a.). Since “per capita” appears to be a component in each of their variables, one suspects that the significant correlations were due to the colinearity thus introduced.

In two papers McGrath (1995a, 1996a) examined circulation per day (u.a.) over a period of several years. In one paper (1996a), he first converted daily circulation in a university library from the time domain to the frequency domain using spectral analysis, and was able to show at least two distinct and pronounced frequencies: A 122-day semester period and a 7-day period.6

In the other paper (1995a), he argued that circulation per day (u.a.) could be modeled using a combination of three sources: (a) Correlative predictor variables, (b) Normal cyclic influences (time or frequency domains), and (c) A complex or recursive process (from chaos theory) in which some part of circulation is due to previous circulation—for example, when the references in a borrowed book are later borrowed.

Naylor & Walsh (1994) fitted a time series equation to weekly (u.a.) pick-up data (books picked up off tables for shelving). Decroos et al (1997) also submitted two years of daily (u.a.) circulation data to spectral analysis. They “clearly detected” semester and weekly periodicity. These time and spectral papers suggest that they should be considered when building theory.

Kishida & Sato (1991) used the same approach as Kasukabe above, but without looking at the time component. Library collection (holdings) per capita, annual per capita acquisitions, number of libraries in each community (u.a.), proportion of professional occupations, and daytime population were all submitted to regression analysis as predictors of PER CAPITA BOOK CIRCULATION, but again it is not clear what effect the per capita component has.7 The explanatory (r-square) coefficients are very high, suggesting colinearity (self-correlation) due to the per capita component in each variable. Nevertheless, theirs is an interesting approach to the prediction of circulation in a public library context.

Table 1 recapitulates the dependent variables and units of analysis for
Table 1. Summary of Reviewed Studies for Building A Unified Theory.

<table>
<thead>
<tr>
<th>Domain/Context</th>
<th>Unit of Analysis*</th>
<th>Dependent Variable*</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Publishing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marketing</td>
<td>Journals</td>
<td>Prices</td>
<td>Petersen (1992)</td>
</tr>
<tr>
<td>Marketing</td>
<td>Journals</td>
<td>Prices</td>
<td>Chressanthis &amp; Chres. (1994)</td>
</tr>
<tr>
<td>National Production</td>
<td>Country</td>
<td>No. monographs published</td>
<td>Kishida and Matsui (1997)</td>
</tr>
<tr>
<td>Pricing of Subscriptions</td>
<td>Journals</td>
<td>No. subscriptions</td>
<td>Quandt (1996)</td>
</tr>
<tr>
<td>Acquisitions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Selection</td>
<td>Library</td>
<td>Subscribe or not</td>
<td>Quandt (1996)</td>
</tr>
<tr>
<td>Selection/Deselection</td>
<td>Econ. Journals</td>
<td>No. of libraries</td>
<td>McCain (1992)</td>
</tr>
<tr>
<td>Selection</td>
<td>Books</td>
<td>No. of libraries</td>
<td>Shaw (1991)</td>
</tr>
<tr>
<td>Selection</td>
<td>Titles</td>
<td>No. libraries holding them</td>
<td>Serebnick (1992)</td>
</tr>
<tr>
<td>Selection</td>
<td>Reviewed Books</td>
<td>No. books purchased</td>
<td>Calhoun (1998)</td>
</tr>
<tr>
<td>Evaluation</td>
<td>Journals</td>
<td>Citation frequency</td>
<td>Kreider (1999)</td>
</tr>
<tr>
<td>Selection/Deselection</td>
<td>Journals</td>
<td>Citat. frequency or use</td>
<td>Tsay (1998)</td>
</tr>
<tr>
<td>Budget Allocation</td>
<td>Subject Areas</td>
<td>Circulation</td>
<td>Crotts (1999)</td>
</tr>
<tr>
<td>Classification</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Catalog</td>
<td>Bibliographic Families</td>
<td>[?]</td>
<td>Leazer &amp; Smiraglia (1999)</td>
</tr>
<tr>
<td>Classification/Browsing</td>
<td>Patron</td>
<td>Avg. no. of books</td>
<td>Losee (1993)</td>
</tr>
<tr>
<td>Searching the Catalog</td>
<td>Search Session</td>
<td>Number of hits</td>
<td>Rodman (2000)</td>
</tr>
<tr>
<td>Domain/Context</td>
<td>Unit of Analysis*</td>
<td>Dependent Variable*</td>
<td>Authors</td>
</tr>
<tr>
<td>---------------</td>
<td>------------------</td>
<td>---------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Storage and Preservation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage</td>
<td>Titles</td>
<td>Times circulated</td>
<td>Silverstein &amp; Shieber (1996)</td>
</tr>
<tr>
<td>Storage</td>
<td>Books</td>
<td>Times circ'ed, in-house use</td>
<td>Hayes (1992)</td>
</tr>
<tr>
<td>Hypothetical Collection</td>
<td>Materials</td>
<td>Demand for materials</td>
<td>Lee (1993)</td>
</tr>
<tr>
<td>Preservation</td>
<td>Book Paper</td>
<td>{Brittleness, acidity}</td>
<td>Bennett (1992)</td>
</tr>
<tr>
<td>Circulation</td>
<td>Use</td>
<td>Journals</td>
<td>In-house/circulation/cites</td>
</tr>
<tr>
<td>Circulation</td>
<td>Use</td>
<td>Weeks</td>
<td>Door counts or ref. queries</td>
</tr>
<tr>
<td>Circulation</td>
<td>Catalog Access</td>
<td>Search Session</td>
<td>Prints-mails/downloads</td>
</tr>
<tr>
<td>Circulation</td>
<td>Use</td>
<td>Community, Time</td>
<td>Per capita circulation</td>
</tr>
<tr>
<td>Circulation</td>
<td>Pickup</td>
<td>Week</td>
<td>[No. of books &amp; journals]</td>
</tr>
<tr>
<td>Circulation</td>
<td>Pickup</td>
<td>Day</td>
<td>[No. of books &amp; journals]</td>
</tr>
<tr>
<td>Circulation</td>
<td>Use</td>
<td>Community</td>
<td>Per capita circulation</td>
</tr>
</tbody>
</table>

* Dependent variables and units of analysis were not always specified as such by their authors.
each study reviewed in each broad domain. Not shown, for lack of space, are independent variables, which, when significant, explain the dependent variable in terms of percentage of variance accounted for using a coefficient, such as R-square or some other statistic. Two important properties of the literature are apparent. First, the table clearly shows the dominant role of circulation or its surrogates at nearly every level, with the possible exception of classification, for which there appears to be a gap in recent explanatory literature. Second, it is clear that a variable at one level can be a unit of analysis at another. Under COLLECTIONS, for example, LIBRARIES (Exon & Punch, 1997) are a unit of analysis whereas under ACQUISITIONS, number of libraries is a variable (McCain, 1992; Shaw, 1991). Under STORAGE AND PRESERVATION, BOOKS are the unit of analysis (Bennett, 1992; O’Neill & Boomgaarten, 1995) whereas under CIRCULATION number of books checked out is a variable (Yilmaz, 1998). Otherwise, the distinction between variables and units of analysis at the various levels is not always clear or straightforward. If these two important properties are indeed essential to explanatory theory, as this author believes they are, then theorists have much work to do to sort them out.

**SUMMARY**

The achievements of Copernicus, Kepler, Galileo, Newton, Faraday, Maxwell, Einstein, and others in the reconciliation of natural forces and development of grand unified theory are cited as inspiration for attempting to build a grand unified theory in a humbler sphere, librarianship. Though some may say the vision is naïve or grandiose, the effort to describe the interrelationships of traditional functions of librarianship (i.e., selection, acquisitions, storage and retrieval, classification, collections, and circulation) as integrated and interdependent is an important and worthwhile effort.

Quantitative methods, which can relate the variability of outputs to the variability of inputs, can be used to test the variables of publishing and selection to the variables of acquisitions. The variables of acquisitions, in turn, are important input to storage and preservation which, in combination with the classification scheme, defines the dynamic and static nature of the collection, a necessary condition for its circulation and use. All functions would be tied together in a grand integrated, coherent, and logical scheme in which one functional level explains one level and is explained by another.

To illustrate the potential contribution of recent research to a unified theory, literature for the period 1990 to 2001 was reviewed. Included were studies that used explanatory and predictive statistical methods to explore relationships between variables within and between the broad areas outlined above. These studies do not in themselves constitute broad theory, although, individually, they can be said to posit theory at the narrow level, because when one tests a hypothesis (i.e., computes a correlation) one is also test-
ing theory. One need only connect these hypotheses, these mini-theories, from one level to another.

The review uncovered explanatory studies in nearly every level, with the possible exception of classification, while studies in circulation and use of the library were clearly dominant. A recapitulation showed that a variable at one level may be a unit of analysis at another, a property of explanatory research crucial to the development of theory, which has been either ignored or unrecognized in LIS literature.

It remains for researchers to tie the various levels together more formally—or to find an empirical basis for alternative levels. In a carefully designed study, a theorist might construct a broad scheme in which variables and units of analysis at each level are inevitably and necessarily embraced and follow from the highest level. To a very limited extent, the review suggests that explanatory and predictive relationships do exist and that they can be useful in constructing a comprehensive unified theory of librarianship.

NOTES
* The first half of this paper is based in part on material extracted, shortened, and revised from a paper originally published in Poland in a collection of essays on libraries and democracy (McGrath, 1995b).


2. “Publishing” refers to the production of books, journals, and printed or stored knowledge.

3. We can also define “publications” to mean any collectible information format.

4. “Circulation” is broadly defined to include not only borrowing, but also use inside the library and interlibrary loans, as well as any other type of use.

5. This author failed to recognize that simple fact in a study thirty years ago (McGrath, 1971).

6. It can be shown that any uniformly cyclic data, such as library circulation, can be graphed either as waves or as closed, elliptical orbits—curves intrinsic to celestial mechanics and a dramatic analogue to the Copernicus-Kepler-Newton context discussed at the beginning of this paper.

7. “Community” (u.a.) appears to be defined as town or city.

REFERENCES


Kreider, J. (1999). The correlation of local citation data with citation data from *Journal Citation Reports. Library Resources and Technical Services, 43*(2), 67-77.


McGrath, W. E. (1995b). In the tradition of Copernicus—Building a scientific theory of librarianship; The freedom to research. In M. Kocayowa & G. S. Bobinski (Eds.), *The role of li-


Zwadlo, J. (1997). We don’t need a philosophy of library and information science; We’re confused enough already. Library Quarterly, 67(2), 103–121.
Informetric Theories and Methods for Exploring the Internet: An Analytical Survey of Recent Research Literature

JUDIT BAR-ILAN AND BLUMA C. PERITZ

ABSTRACT

The Internet, and more specifically the World Wide Web, is quickly becoming one of our main information sources. Systematic evaluation and analysis can help us understand how this medium works, grows, and changes, and how it influences our lives and research. New approaches in informetrics can provide an appropriate means towards achieving the above goals, and towards establishing a sound theory. This paper presents a selective review of research based on the Internet, using bibliometric and informetric methods and tools. Some of these studies clearly show the applicability of bibliometric laws to the Internet, while others establish new definitions and methods based on the respective definitions for printed sources. Both informetrics and Internet research can gain from these additional methods.

INTRODUCTION

Tague-Sutcliffe (1992) defined Informetrics as “the study of the quantitative aspects of information in any form . . . and in any social group,” and Brookes (1990) characterized it as “a generic term that embraces both biblio- and scientometrics.” Along the lines of Tague-Sutcliffe, informetrics investigates: Characteristics and measurements of persons, groups, institutions, countries; publications and information sources; disciplines and fields; and information retrieval processes.

When the above definitions were offered, the World Wide Web was still non-existent, but today it is quickly becoming a major information source. Informetric methods can be and are applied to the Web, and new methods are being developed for this medium. This paper presents a selective
review of research based on the Internet, using bibliometric and informetric methods and tools. The review is organized according to the following methods:

- Data collection methods
- Informetric analysis
- Citation analysis
- Cocitation and co-word analysis
- Content analysis
- Evaluation using existing/new measures
- Identifying and calculating indicators
- Models
- Fitting existing models and bibliometric laws

**Data Collection Methods**

Data collection from the Web is far from trivial, due to its size and its extremely dynamic nature. There are no methods to enumerate the “whole Web” (the total population under study) or to enable us to get a truly random sample of Web pages. When studying Web documents, sites, or the structure of parts of the Web, data collection is often carried out using the currently existing information retrieval tools, mainly the search engines, which are far from perfect. Bar-Ilan (2000a) discusses problems related to this type of data collection. Use studies rely mainly on surveys, interviews, and log analysis.

**Surveys**

Surveys on the Internet are employed mainly to receive information on the use of technology. Savolainen (1998) analyzes use studies of electronic networks. A considerable number of the reviewed studies collect data through quantitative surveys. Questionnaires can be sent out by regular mail or e-mail, can be filled out on Web pages, or can use a combination of these methods.

Lazinger, Bar-Ilan, & Peritz (1997) carried out an extensive survey on Internet use of the faculty members of Hebrew University of Jerusalem. The questionnaire was sent out by regular mail, in order to reach also faculty members who did not use e-mail. A follow up was sent to non-respondents. The overall response rate was 59.4 percent. More than 80 percent of the respondents used some Internet services, with e-mail being the most popular one (the questionnaires were sent in spring 1995, when the graphic browsers to the Web were just being introduced [Life on the Internet, n. d.]). Significant differences were found in the use patterns between the Humanities and Social Sciences faculty and the Science and Agriculture faculty.

Kovacs, Robinson, & Dixon (1995) investigated the use of discussion lists by library and information science professionals. The questionnaire was sent out to the participants of fifty-seven library and information science
related discussion groups—approximately 10,000 participants. Filled out questionnaires were returned by e-mail. Only 576 responses were received. The majority of these respondents stated that discussion groups enhanced other sources of professional information. However, the majority also stated that discussion groups did not replace other sources of information.

The purpose of the survey conducted by Zhang (2000) was to enhance understanding of the scholarly use of Internet based e-sources among LIS researchers and to evaluate the potential of Web-based surveys. The population of the survey was 201 researchers with in-press publications in eight LIS journals. An e-mail was sent to these researchers requesting they participate in the survey. The respondents could either fill out a Web-based questionnaire or request a printed copy and return it by mail or fax. Only 10 percent of the researchers requested printed copies, and 20 percent of the researchers returned the questionnaires by regular mail or fax (some of them printed out the Web-based questionnaires by themselves). Three follow-ups were sent out, and the total response rate was 89.1 percent.

Spink, Bateman, & Jansen (1999) demonstrated a different use of Web-based surveys. The survey was made available from the Excite home page (a Web portal—http://www.excite.com) for a five-day period in 1998. About 7.7 percent of the users who visited the survey page (approximately 3,700 visitors) filled out the survey and submitted it (p. 119).

Conducting surveys on the Web or through e-mail is becoming popular. Piper (1998) raises an important question: "Can experiments conducted on the Web avoid the many threats to internal validity, construct validity and external validity?" Her main concerns were "nonrepresentative, volunteer subjects and deception by subjects" (p. 10). Zhang (2000) also addresses the problems of biased sample, biased return, and low response rates. The above examples indicate that the key to achieving a reasonable response rate is to send the questionnaire to a population that enables researchers to also send personalized follow-ups to non-respondents (as in Lazinger, Bar-Ilan, & Peritz, 1997 and Zhang, 2000).

**Monitoring/Logging**

Another method of data collection—again, mainly concerned with the use of different Internet services—is by monitoring and analyzing log files of scientists’ Internet use. Kaminer & Braunstein (1998) analyzed the log files of the sixty-three faculty members of Berkeley’s College of Natural Resources in order to assess the impact of Internet use on scholarly production. They measured the number of distinct processes, the length of the sessions, and the types of services used. A questionnaire was also sent out to these faculty members. The main finding was that “adding measures of Internet use improves the explanatory power of the traditional model of scholarly productivity” (p. 729).

Lawrence & Giles (1999) monitored the queries to different search
engines presented by scientists at the NEC Research Institute. This set of queries constituted a sample of real-life queries. The analysis assumes that this is a truly random sample of user queries, although it is rather doubtful that the queries of NEC scientists at work are representative of the queries of the “typical” user. Based on this set, they calculated the coverage of the different search engines of the Web. At the time of the study (February 1999), the then largest search engine, Northern Light, covered only about 16 percent of the Web pages reachable and indexable by search engines.

Two studies on end-user searching on the Internet were based on huge logs from the search engine Excite (Jansen, Spink, & Saracevic, 2000; Ross & Wolfram, 2000). The first study analyzed 51,473 queries of more than 18,000 users and provided data on changes during the query sessions—on the number of search terms, on the usage of Boolean operators and query modifiers, and on the most highly used search terms. They also identified trends among user mistakes. The second study analyzed term cooccurrence in more than a million queries that “represent a subset of queries submitted to the Excite search engine on a single day” (p. 950).

Crawling

Today the Web is far too large and complex to even attempt to cover it all. Recently, Moore & Murray (2000) estimated that there were at least 2,100 million indexable pages on the Web in July 2000, with an estimated daily growth rate of seven million Web pages. A few years ago the Web was much smaller, and very large crawls of the Web probably depicted a reasonable picture on the structure of the “average Web page.” In November 1995, Woodruff et al. (1996) analyzed 2.6 million documents collected by the search engine Inktomi, developed at the time at Berkeley. The characteristics examined included: Document size, number and types of tags, number of links, and ratio of document size to number of tags. They also listed the “most linked-to URLs.”

At about the same time Bray (1996) analyzed the results of a 1.5 million sample collected by the search engine Open Text (does not exist anymore), and described the “average Web page” in terms of size, number of embedded images, and incoming and outgoing URLs. He also tabulated the biggest and most visible sites (defined according to the number of links pointing to them).

Retrieval by Sampling

Bharat & Broder (1998) attempted to create “random URLs” in order to compare the coverage of different search engines. Their objectives were similar to those of Lawrence & Giles (1998 and 1999), however their methodology was different: They sampled a weighted dictionary of Web words based on pages indexed by the human-edited directory service Yahoo (http://www.yahoo.com). Two term AND and OR queries were presented to the search engines and random URLs were selected from the result sets.
These URLs were assumed to be "random URLs." In spite of the different techniques, the results of Bharat & Broder's experiments are comparable to those of Lawrence & Giles (1998). Both experiments took place in November 1997.

Exhaustive Retrieval from Databases

Retrieving all documents from the Web on a given topic or from a given domain or country allows the researchers to create random samples from the set. Almind & Ingwersen (1997) utilized this method. The initial set of Danish pages on the Web was retrieved from the Nordic Web Index (not operational anymore). To supplement this set, searches were also carried out on other search engines. These additional searches added only 200 new pages to the list of 47,000 Danish URLs retrieved from the Nordic Web Index. The very large overlap between the different sources points to the exhaustiveness of the set of pages indexed by the Nordic Web Index as of December 1995. The Danish Web pages were compared to those of other Scandinavian countries.

Bharat et al. (1998) built a huge snapshot of the link structure of the Web, based on a crawl of 100 million pages of AltaVista (http://www.altavista.com). The so-called "Connectivity Server" does not have data on the content of the different pages, but gives information on the incoming and outgoing links of sets of nodes. The Connectivity Server enables the researchers to carry out experiments in a relatively stable environment.

Search Engines and Other Retrieval Tools

The large general search engines are natural choices for collecting specific data from the Web. There are several ways to utilize the search engines: A single service can be used, or the results of several search tools can be compared or combined. The following three studies are examples of each of these uses.

Rousseau (1997) retrieved all the occurrences of the search terms "informetrics OR bibliometrics OR scientometrics" using AltaVista. AltaVista is one of the most popular search tools among Internet researchers, because it has a wide variety of useful options. However, it has been noted in several studies that its reliability is questionable (e.g., Ingwersen, 1998; Rousseau, 1999; Thelwall, 2000; Bar-Ilan, 2001).

Cronin et al. (1998) searched the Web using five search tools: Excite, Infoseek (currently the service can be found at http://www.go.com), Lycos (today this is an altogether different service, powered by Fast, but can still be found at http://www.lycos.com), WebCrawler (http://www.webcrawler.com), and Yahoo for pages mentioning five prominent professors in library and information science. The results retrieved from these engines were compared, and the combined results were also analyzed.

Bar-Ilan (1998) searched seven of the then largest search tools for pages mentioning the mathematician "Erdos." The results of the seven tools (Al-
taVista, Excite, Infoseek, Lycos, Magellan, Opentext, and Yahoo) were combined in order to get a picture of the way Erdos was depicted on the Web around the end of 1996.


**Additional Data Collection Methods**

Watson (1998) interviewed high school students in order to get a "close look at students' perceptions of using technology" (p. 1024), mainly the Internet. This method of open-ended interviews can only be used for very small populations—nine students in this case.

Rosenbaum (1998) analyzed the content of the Web sites of twenty-four Web-based community networks in Indiana. He did not have to search for these sites, since he already had knowledge of their existence. The same data collection method of retrieving data from known sites was applied by Koehler et al. (2000) when different "demographic aspects" of three e-journals (Cybermetrics, Information Research, and Libres), a print journal (Journal of Internet Cataloging) and a hybrid journal (JASIS) were analyzed. Results included data on the productivity of these journals, characteristics of papers, authors, and funding.

Haas & Grams (2000) used AltaVista's Surprise link (not existent anymore) to collect a set of pages and to characterize them and the types of links emanating from them. The Surprise link was supposed to link to "random" pages from the AltaVista database.

Bucy, Lang, Potter, & Grabe (1999) obtained data on page views from the 100hot's Insite Pro service (http://www.100hot.com). The InSite service does not seem to be operational anymore, but 100hot.com publishes the list of 100 most visited sites based on the usage patterns of over 100,000 Web users from all over the world (100hot methodology, n.d.).

**Informetric Analysis**

Irrespective of the data collection method, the collected data have to undergo some analysis in order to arrive at meaningful conclusions. Sometimes simple processing and standard statistical and mathematical analysis are sufficient, but at other times specific informetric methods, models, or laws are utilized. In the following sections we review the use of these methods, models, and laws for analyzing data from and about the Internet.

**Citation Analysis**

Harter (1996 and 1998) carried out one of the earliest attempts to assess the scholarly impact of electronic journals. He measured the number of citations of thirty-nine e-journals received by February 1996. The citations were extracted from ISI's Citation Indexes. Fifteen journals were not cited
at all, and only seven were cited eleven times or more. Except for one or two exceptions the impact of these journals (in early 1996) was minimal.

Zhang (1998) investigated the citations to e-sources in library and information science journals during the period 1994 and 1996. E-sources were defined as: E-mail messages, messages posted to newsgroups and discussion lists, publications of any kind (not necessarily refereed), commercial sources, and other e-sources available from the Internet. Harter counted citations the specific e-journals received from journals indexed by ISI. Zhang, on the other hand, examined all types of references to e-sources appearing in the ten most highly cited library and information science journals and in four library and information science oriented e-journals. Except for the e-references appearing in the four e-journals, the impact of the e-sources was negligible.

At the very beginning, researchers noticed that incoming links to a Web page measure its visibility (see, e.g., Bray, 1996 or Woodruff et al., 1996). Links can be seen as analogues of citations in the academic world. General search engines, like AltaVista and Hotbot (http://www.hotbot.lycos.com), retrieve lists of URLs in their database linking to a given URL or site. Recently Google (www.google.com) also added this option. Because of the limited coverage of the Web by these search tools, the link information is also limited. For example, consider the homepage of Library Trends (http://www.lis.uiuc.edu/puboff/catalog/trends/). AltaVista found 14 pages linking to it, Hotbot found 6 links, while Google found 129 pages linking to this URL. A similar search for the homepage of JASIS (http://www.asis.org/Publications/JASIS/jasis/html) resulted in 226 links reported by AltaVista, 160 links reported by Hotbot, and 245 links reported by Google. Even this small example illustrates that we cannot rely on search engines to produce reliable visibility data. All searches were carried out on November 18, 2000. The accuracy of the results was not examined.

Chakrabarti, Gibson, & McCurley (1999) advocate the provision of backlinks (pages that link to a given page) by the sites themselves and not through the search engines. Even though the implementation is not difficult, they are aware of privacy concerns and of other barriers of acceptance. For instance, commercial sites most likely will not be interested in linking to bad reviews about their products or to pages that also mention their competitors. In fact, it is hard to imagine that any site would be willing to include in the lists of pages that link to it those pages that have a negative attitude towards the site.

Cui (1999) used citation analysis to rank health Web sites. Again, the hypertext links were viewed as citations. The study analyzed the links appearing on the homepages of the libraries of the top U.S. medical schools, as compiled and published by U.S. News and World Report.

Lawrence, Giles, & Bollacker (1999) took a completely different ap-
approach to citation analysis on the Web. Instead of studying hypertext links as analogues of citations in the academic world, they looked for citations in the classical sense, and their "Autonomous Citation Indexing" (ACI) system can automatically create a citation index from literature in electronic format. The rationale behind this project is that an increasing number of authors, journals, institutions, and archives make research articles available on the Web, mainly in PDF or Postscript formats. ACI is implemented for computer science literature at the "ResearchIndex" site (http://www.researchindex.com/). The system allows one to search articles and citations. When searching for citations, it provides citation context (in the citing article), citation statistics, and links to the citing articles. For full-text articles the system also displays the exact bibliographic reference, the list of citations and the list of references, similar documents (textual similarity), and related documents (based on cocitations). The user interface needs some improvement.

Garfield (1999) related to this project in an address delivered at a symposium in honor of Manfred Kochen: "... without a posteriori human intelligence, the Internet will remain at best a mixed blessing. Artificial intelligence will help but not suffice... The Internet has made it practical for future citation index databases to generate annotated bibliographies and reviews containing contextual quotations based on autonomous citation indexing. To see how this works in the field of computer science just go to www.researchindex.com."

A recent paper (Goodrum, McCain, Lawrence, & Giles, 2001) compares the ISI SCISEARCH Citation Index to ACI in the area of computer science. A major difference between the two systems is that ACI indexes PDF and Postscript formatted publication on the Web, while SCISEARCH indexes only a selected list of journals in the area.

Cocitation and Coword Analysis

The objective of the study carried out by Larson (1996) was to explore the applicability of classical cocitations on the Web, when citations are substituted with hyperlinks. He carried out a cocitation analysis of a set of Earth Science related Web sites. The starting point were two authoritative sites on the topic. The list of pages pointing to these two sites was retrieved using AltaVista, and the links appearing in the relevant pages were extracted. This set underwent a second round of relevance judgment by Larson, and a set of thirty-four "core" pages was created. Again, AltaVista's link option was utilized to retrieve the number of URLs linking to each of the 544 cocitation pairs. The data were converted to a correlation matrix and multidimensional scaling (MDS) was used to create the cocitation map. Larson concluded, "the mappings... seem to produce quite clear, reasonable and interpretable results."

Dean & Henzinger (1999) applied cocitation techniques in order to
find “related pages” on the Web. A related page is one that addresses the same topic as the original page. One of their algorithms, the cocitation algorithm, looks for pages that link to the given page, and assumes that the nearby links point to pages with similar topics. These pages were collected, their cocitation degree computed, and those with the highest degrees were returned as the most related pages.

Kumar, Raghavan, Rajagopalan, & Tomkins (1999) used cocitation techniques in order to identify specific communities on the Web—groups of content creators sharing a common interest. The study exploits “cocitation in the Web graph to extract all communities that have taken shape on the Web, even before the participants have realized that they have formed a community” (p. 1483).

Ross & Wolfram (2000) used coword analysis to analyze term pair topics submitted to the search engine Excite. Their data were based on more than a million queries submitted to Excite on a single day. The most frequent term pairs were coded into thirty categories based on the semantic and pragmatic intent of the term pair; a term pair could belong to more than one category. Cluster analysis and MDS were used for the data analysis. A high proportion of the term pairs were for adult-oriented material.

Leydesdorff & Curran (2000) studied the cooccurrence of the terms “university,” “industry,” and “government” in Web pages in three different domains. The domains were: Brazil, the Netherlands, and the so-called top level domains (.com, .edu, .gov, .org, .net, .mil). They studied the growth over time of these cooccurrences, using AltaVista’s option to limit searches to given dates. The queries were presented both in English and in the local language. Similar trends were detected in all three domains.

Content Analysis

Content analyses of Web and Internet sources serve as exploratory tools for getting a better understanding of the Internet’s content.

Bar-Ilan & Assouline (1997) analyzed the content of messages distributed by the PUBYAC (a discussion list for Children and Young Adult services) for a period of one month in spring 1997. Six content categories were defined (reference, library administration and policy, collection management, extension programs, announcements, and other). The most popular category was reference. The lifespan of topics, the number of active participants, and the productivity of the participants were also examined. From the answers received to a specific question sent to the participants of the discussion list, it seems that the librarians find the list very useful: “It helps them find answers to specific questions and assists in collection management and planning extension programs” (p. 170). Several other studies analyzed the content of discussion lists. Sometimes several groups were analyzed in parallel and their characteristics compared (e.g., Aires-de-Sousa, 1999; Schoch & White, 1997; Berman, 1996).
Not only discussion lists were analyzed, but also Web pages and Web sites. Cronin et al. (1998) searched the Web using five search tools for pages mentioning five prominent professors in library and information science. The retrieved Web pages were characterized according to the "forms of mention." Eleven categories of invocation were defined: Abstract, article, conference proceedings, current awareness, external home page, listerv, personal/parent organization home page, resource guide, book review, syllabus, and table of contents. The data were collected over a period of two months, though the dates are not given. The authors concluded: The Web "engenders new modes of scholarly interaction and signaling. Scholars do not merely post, or publish, their works on the Web: They seed ideas, discuss issues, and debate positions, in ways which, occasionally, deviate from, and challenge, established norms" (p. 1326).

A different kind of content analysis, examining not the form of invocation, but the different contexts in which the mathematician Paul Erdos was mentioned, appears in Bar-Ilan (1998). The paper analyzes the content of 2,685 Web documents collected between the end of 1996 and the beginning of 1997 (Paul Erdos passed away in September, 1996). Six main content categories were defined: Mathematical work, Erdos number, in honor/memory of Erdos, jokes/quotations, math education, and other. Almost 40 percent of the pages were classified as "mathematical work," but a rather surprising 13 percent of the pages belonged to the jokes/quotations category. (The most popular quotations/jokes were: “A mathematician is a machine for turning coffee into theorems” and "Why did the chicken cross the road? It was forced to do so by the chicken-hole principle"). The concept of Erdos number intrigues the authors of the Web pages; the concept was explained on ninety-one (3 percent) different pages (almost always exactly the same explanation), and 9 percent of the collected pages point to the home page of the “Erdos Number Project” (http://www.oakland.edu/~grossman/erdoshp.html). In 40 percent of the pages belonging to “mathematical work,” Erdos’s name was mentioned in bibliographical references.

Formal bibliographical references also appeared in Bar-Ilan (2000c), in a large portion of the pages (in 40.3 percent out of the 807 pages) containing the search terms “informetrics OR informetric.” The searches were carried out in June 1998 using the six largest search engines at that time (AltaVista, Excite, Hotbot, Infoseek, Lycos, and Northern Light). The references extracted from these pages (called the “Web database”) were compared with comparable data retrieved from commercial bibliographical databases. In all except one comparison, the Web database did at least as well as the commercial database, indicating that valuable, freely available data exist in the Web, but cannot be located easily.

Lawrence, Bollacker, & Giles (1999) were able to find large quantities of full-text papers in the area of computer science. They were looking for
different formats, including PDF and PostScript. Bar-Ilan's findings were rather different; she located only a negligible number (4) of full text publications. This may be due to the fact that she collected information about a different subject area or to the fact that general search engines ignore formats like PDF and PostScript. The most productive and the most cited authors and sources, and the most cited papers (papers which are referred to in the largest number of collected Web pages) were also calculated.

Rosenbaum (1998) analyzed the content of the Web sites of twenty-four Web-based community networks in Indiana. The purpose of the study was to learn about the content and the structure of these sites.

Bar-Ilan (2000b) analyzed the content of Web pages containing the phrase “S&T indicators.” Several facets were introduced, including the context in which the search phrase appeared, the type of document, the server, the domain, the geographical area, and the time period for which the indicators were computed. A rather interesting finding was the existence of a large number of Web pages with data from Malaysia. Since 1992, the Malaysian government has consistently published its Science and Technology reports on the Web.

**Evaluation Using Existing/New Measures**

Gordon & Pathak (1999) measured the retrieval effectiveness of Web search engines. Thirty-three members of the faculty at the University of Michigan Business School described to experienced searchers their information needs. The searchers presented appropriately phrased queries to eight search tools. The first twenty hits from each tool were retrieved and the 160 documents in some random order were presented to the faculty members, who judged the relevance of these documents. The absolute retrieval effectiveness was fairly low, and there were statistical differences in precision effectiveness.

A different approach was taken by Bar-Ilan (1999), who, instead of the subjective human relevance judgments, measured the technical precision of the retrieved documents. A document is technically relevant if it satisfies the query (i.e., all the search terms that are supposed to appear are actually present in the document, and all the terms that are not supposed to appear are missing). This is an objective measure, which can be computed simply, but it does not judge the quality of the document.

Oppenheim, Morris, McKnight, & Lowley (2000) gave an extensive review of the evaluation of Internet search engines. Precision was measured in most studies, but recall measuring is extremely difficult. Some suggested alternative methods were reviewed, and the authors recommended developing a standardized set of tools for search engine evaluation.

Page & Brin (1998) introduced a new method of measuring the quality of Web documents, called the PageRank. The method is based on the ideas of classical citation analysis, but instead of simply counting the num-
number of links pointing to a document the quality of the page from which the link emanates is also taken into account. Similar ideas of weighing citations for classical citation analysis were introduced already in Pinski & Narin (1976). Egghe (2000) slightly disagrees with the analogy drawn between classical citations and hypertext links: Paper B citing paper A was necessarily written after paper A; however, this is not the case with Web pages, quite often there are reciprocal links between pages.

Henzinger, Heydon, Mitzenmacher, & Najork (1999) defined a new measure for search engines: “Search engine quality.” The quality of a Web page is based on the links pointing to it. Some portion of the Web is crawled in order to estimate the “quality” of pages, and then the search engines are queried with a sample of the visited high quality pages to check if they index them.

One way to measure page popularity is through the number of links pointing to it (as in Page & Brin, 1998). Another possibility is to count the number of visitors to a site by an objective body (not self-adjustable counters on a Web page). Such a method is utilized by the Direct Hit service (http://www.directhit.com). The service monitors “which web sites Internet searchers select from the search results list, how much time the searchers spend at these sites and a number of other metrics, such as the position of a site relative to other sites. The sites that are selected by searchers are boosted in their ranking, while the sites that are consistently ignored by searchers are penalized in their rankings” (Direct Hit Technology, n.d.).

There are several works which examine formal features of Web pages and sites; for example, size and type of files and images, number of forms and other methods of interaction, applets, number and types of links. Bauer & Scharl (2000) used such data for “quantitative evaluation of Web site content and structure.” Even though the data can be collected automatically, it is difficult to see how it evaluates the site, since evaluation is associated with quality. The authors suggested manual classification as one of the methods to analyze the raw data. Bucy, Lang, Potter, & Grabe (1999) used the data to deduce relationships between Web page complexity (banners, length, colors, graphical, dynamic, and interactive elements) and site traffic. They found significant relationships between site traffic and graphical elements for commercial pages, and between site traffic and asynchronous interactive elements for noncommercial documents. The page usage data were obtained from the 100hot’s Insite Pro service, which tracks the usage patterns of over 100,000 Web users from all over the world.

**Identifying and Calculating Indicators**

Ingwersen (1998) was the first to define specific indicators for the Web. He defined the Web impact factor (WIF) as follows:

\[
\frac{\text{# of pages with a link to the site or country}}{\text{# of pages in the site or country}}
\]
He compared the WIF of different European countries, using AltaVista’s link feature. WIFs of specific sites (like the site of Science Magazine) were also calculated. Just like the classical impact factor of journals, the WIF of a given country or site indicates its relative visibility on the Web.

Smith (1999) examined some methodological issues related to the WIF, and claimed that the external WIF (counting only links emanating from outside the site) is probably the best indicator. Internal WIFs do not really reflect on the visibility of a site, because a large portion of the links may simply be navigational links (back to the home page, etc.) or can be self-inflated, just like self-citations in classical citation analysis. His experiments show that WIFs for countries are not very reliable, but for large organizations the indicator seems useful.

Both Ingwersen and Smith used the link and domain options of AltaVista to calculate WIFs, since currently AltaVista is the only large search engine having both options. Thelwall (2000) warns that the uneven coverage of the Web by the search engines results in misleading calculations of the WIF.

Aguillo (1997) introduced a new procedure to obtain quantitative indicators of science and technology. The indicators are derived from the presence of research and development institutions on the Internet. Hypertext links between these institutions are treated the same way as citations in the ISI databases. The different types of multimedia objects are also subject to quantitative analysis. The planned database (Internet World of Research and Development—IWR&D) will include information on 20,000–25,000 sites. The suggested indicators include: Self-citations, density of links, visibility, WIF, and diversity. In Aguillo & Pareja (2000) some of these indicators were calculated for four Western European countries. The results showed that visualization measures based on WIFs are rather consistent and can be used to supplement scientometric data.

Models

Page & Brin (1998) were the first to rely on the structure of the Web in order to improve information retrieval. They modeled the Web as a directed graph with weights (called PageRank) on the nodes (the Web pages). These weights are a function of the number of incoming links and the weight of the pages they emanate from. This is the model behind the search engine Google.

At about the same time Kleinberg (1998) introduced the model of hubs and authorities. Authorities are pages with quality information, and hubs are pages with lists of links. Kleinberg developed an algorithm for identifying hubs and authorities. An initial set of Web pages on the topic is retrieved by a general search engine. This initial set is augmented with pages pointing to the set and to pages pointed to from the set (corresponding to the notions of cocitation and bibliographic coupling). An iterative weighing process results in a set of authorities and a set of hubs. The algorithm utilizes the link structure of the hypertext system; it does not rely on any lin-
guistic characteristics. The process works even if the initial query has multiple meanings (e.g., jaguar). Kleinberg’s ideas were implemented and extended in the IBM CLEVER Project (Chakrabarti et al., 1999).

Egghe (1997) studied the fractal features of hypertext systems and was able to find a link between the fractal theory of hypertext systems and informetrics. By his definition the fractal dimension is a function of the total number of Web pages and the average number of hyperlinks per page.

**Fitting Existing Models/Bibliometric Laws**

**Growth and core.** Bar-Ilan (1997) examined how newsgroups reacted to a crisis. The specific crisis was the outbreak of “mad cow disease” in Britain in the spring of 1996. Data were collected for a period of 100 days between April and July 1996, using AltaVista, which at the time indexed 14,000 newsgroups. The searches were carried out across the newsgroups using both popular (mad cow disease) and scientific terms (BSE, prion OR prions, bovine spongiform) related to the disease. The growth curve of the messages on the subject resembled the logistic growth function. It was possible to identify an initial period of extremely fast growth, then a second period of moderate growth. By the beginning of July 1996 interest in the disease went down considerably. A similar trend was detected in the number of relevant articles published in the *Times* and the *Sunday Times*. Rather interestingly the graph for BSE, unlike the other graphs, showed a linear growth throughout the whole period. This was due to the fact that B.S.E. is also an abbreviation in electrical engineering.

Data were retrieved from more than a thousand different newsgroups, Bradford’s law was shown to be applicable, and it was possible to identify “core newgroups” that deal with the subject. Other characteristics of the messages were also examined (domains, most productive authors, most popular subjects, etc.).

Two informetric papers studied the growth of differenter topics. Rousseau (1999) carried out three daily single word searches (trumpet*, pope, and saxophone*) in AltaVista and in Northern Light for a period of twenty-one weeks between July and December 1999. The results for Northern Light show slow monotonic growth in the number of results, while large fluctuations were observed for AltaVista. Curves were fitted to the Northern Light data, from which predictions were made as to the growth of the Northern Light database. Leydesdorff & Curran (2000) studied the growth of the number of Web pages containing the term “university,” “industry,” and “government” (and combinations of these terms) for Brazil, the Netherlands, and the top level domain. AltaVista was queried with dates limited to calendar years between 1993 and 1998. When taking this approach, one must be aware that the date of a Web page is at best the last time the page was updated, and if data are unavailable or unreasonable (e.g., dated in the future), the date is the last time the crawler of the search engine visited that page.
Power laws and Zipf-type laws. Rousseau (1997) in an early paper illustrated that bibliometric laws are applicable to the Internet. In May 1997, AltaVista was searched for “bibliometrics OR informetrics OR scientometrics.” The results set, consisting of 343 documents, was retrieved. The number of pages citing each of the pages in the results set was determined using AltaVista’s link option. Rousseau was able to fit appropriate Lotka functions to the data both for the number of retrieved pages per site, and for the number of citations to a site.

It turns out that Rousseau’s results can be generalized to several characteristics of the Web. Huberman, Pirolli, Pitkow, & Luskose (1998) showed that the surfing behavior of Web users follows Zipf-like distributions. The authors proposed a model of Web surfing that explains the empirical findings on distributions of page hits observed at Web sites. Albert, Jeong, & Barabasi (1999), based on a subset of the Web of about 325,000 pages, showed that both incoming and outgoing links obey appropriate power laws. Huberman & Adamic (1999) explained the distribution of the number of pages per site again by a power law. The largest test to date was run by Broder et al. (2000), based on a Web crawl of approximately 200 million pages. This experiment validates the power law distributions both for incoming and outgoing links. The authors noted that Zipf-like distributions (based on rank instead of magnitude) for incoming links give a better fit than the power law distribution. The Web is a complex system, characterized by growth and preferential attachment, as explained by Barabasi & Albert (1999).

Obsolescence. Obsolescence, or more precisely, the characterization of the changes occurring to Web documents, has been studied both in the informetric and the practical setting.

The content and the format of printed literature do not change after publication. This is obviously not the case for Web documents. On the one hand, new documents are continuously being published on the Web. On the other hand, existing documents are removed from the Web, have their location changed, or undergo changes in content or in format. Documents may be removed from the Web for several reasons; for example, the page may become outdated, the server on which it resides ceases to exist or malfunctions, the author of the page is not allowed to use the server anymore, or the author simply loses interest in the topic. The change in the location of a document is usually due to technical reasons. Sometimes there is a forwarding note or an automatic redirect to the new location. Internal changes to a document indicate that the page was updated. Some documents are never removed from the Web, even if they contain totally outdated information. Unfortunately, most of Web documents are not dated. Thus, it is sometimes almost impossible to decide whether the information is current (e.g., opening times of events, entrance fees, or sizes—demographic or Web data).
Bar-Ilan & Peritz (1999) studied changes that occur to Web documents over time regarding a given scientific topic. Documents containing the terms “informetrics OR informetric” were retrieved from the six largest engines at the same time once a month for a period of five months (spring-summer 1998). The set of documents on informetrics seems to be much more stable than documents on general, popular topics. Most of the documents that were retrieved more than once were stable. Among the pages that did change during the observation period, the majority underwent frequent, major changes. Thus, pages are either completely static or are changed often and considerably.

Koehler (1999) analyzed Web page and Web site constancy and permanence. The sample of the URLs was identified by using the random URL generator feature of WebCrawler. There was thus no apriori characterization of the observed Web pages. The pages were retrieved once a week between January 1997 and January 1998. The permanence of these pages was investigated. Three categories were defined: Always present, intermittent, and comatose. At the end of the period about 30 percent of the pages failed to respond. The changes that the pages underwent were also categorized. Nearly all Web pages changed during the year. The influence of the type of URL, and quantitative aspects of the pages (sizes, multimedia, e-mail links, etc.) on constancy and permanence were also studied.

It is important to mention here two other works that studied changes to Web pages for practical reasons. Dough, Feldmann, Krishnamurthy, & Mogul (1997) observed the rate of change of Web pages in order to assess the benefits of caching (the less changes to the pages, the more useful it is). They found that content type and rate of access have a strong influence, while domain and size have little effect. The purpose of Brewington & Cybenko’s study (2000) was to estimate the rate at which Web search engines must re-index the Web in order to remain current. Both studies based their findings on large data sets.

**CONCLUSION**

This review was based on the different methods of classical informetric analysis. A tabulated summary of the review is presented by way of the topics informetrics investigates. Some of the reviewed studies clearly showed the applicability of bibliometric laws to the Internet, while others developed new definitions and methods based on the respective definitions for printed sources. In some cases the Web research community introduced or re-introduced (as in the case with weighted links) models and methods that may also be applied to printed sources. Both informetric and Internet research can gain from these new developments.
Table 1. Characteristics and Measurements of Countries, Groups, Persons (Authors).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Author(s)</th>
<th>Country/Group/Persons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity</td>
<td>Almind &amp; Ingwersen (1997)</td>
<td>Country: Denmark</td>
</tr>
<tr>
<td>Growth</td>
<td>Almind &amp; Ingwersen (1997)</td>
<td>Country: Denmark</td>
</tr>
<tr>
<td>Interaction</td>
<td>Bar-Ilan &amp; Assouline (1997)</td>
<td>Group: Participants of the discussion list</td>
</tr>
<tr>
<td>Topics/Subjects</td>
<td>Bar-Ilan &amp; Assouline (1997)</td>
<td>Group: Participants of the discussion list</td>
</tr>
<tr>
<td>Use</td>
<td>Lazinger, Bar-Ilan &amp; Peritz (1997)</td>
<td>Group: Faculty members of the Hebrew University</td>
</tr>
<tr>
<td>Visibility</td>
<td>Cronin et al. (1998)</td>
<td>Persons: Prominent library and information scientists</td>
</tr>
</tbody>
</table>

Table 2. Characteristics and Measurements of Publications and Publication Sources.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Author(s)</th>
<th>Measurement/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity</td>
<td>Koehler et al. (2000)</td>
<td>Productivity of e-journals in information science</td>
</tr>
<tr>
<td>Growth</td>
<td>Bar-Ilan (1997)</td>
<td>News-group postings viewed as publications</td>
</tr>
<tr>
<td>Obsolescence</td>
<td>Bar-Ilan &amp; Peritz (1999)</td>
<td>For a specific topic</td>
</tr>
<tr>
<td></td>
<td>Koehler (1999)</td>
<td>For a set of pages</td>
</tr>
<tr>
<td>Core</td>
<td>Bar-Ilan (1997)</td>
<td>News groups viewed as publication sources</td>
</tr>
<tr>
<td>Ranking/Visibility</td>
<td>Direct Hit Technology (n.d.)</td>
<td>Measures the number of visits to a page</td>
</tr>
<tr>
<td></td>
<td>Page &amp; Brin (1998)—PageRank</td>
<td>Measures the link popularity</td>
</tr>
<tr>
<td>Topics</td>
<td>Bar-Ilan (2000a)</td>
<td>Characterization of the topics of pages retrieved for the query “informetrics” and for “S&amp;T indicators”</td>
</tr>
<tr>
<td></td>
<td>Bar-Ilan (2000b)</td>
<td></td>
</tr>
<tr>
<td>Structure</td>
<td>Aguillo &amp; Pareja (2000)</td>
<td>Structure of R&amp;D sites of four western European countries</td>
</tr>
<tr>
<td>Linguistic</td>
<td>Leydesdorff &amp; Curran (2000)</td>
<td>Comparing occurrences of words in English vs. the local language</td>
</tr>
<tr>
<td>Characteristics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Citation Patterns</td>
<td>Lawrence, Bollacker, &amp; Giles (1999)</td>
<td>Classical citations</td>
</tr>
<tr>
<td></td>
<td>Chakrabarti, Gibson, &amp; McCurley (1999)</td>
<td>Hypertext links as citations</td>
</tr>
<tr>
<td>Use</td>
<td>100hot Methodology, n.d.</td>
<td>Displays list of 100 top viewed sites based on surfing patterns of over 100,000 users. Data is updated weekly</td>
</tr>
</tbody>
</table>

Web pages and e-mail messages are viewed as publications, and sites, discussion lists, and news-groups as publication sources.
### Table 3. Characteristics and Measurements of Disciplines, Fields, Subfields, and Topics.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Measurement</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growth</td>
<td>Bar-Ilan &amp; Peritz (1999)</td>
<td>Informetrics</td>
</tr>
<tr>
<td>Interdisciplinarity/Interaction</td>
<td>Ingwersen (1998)</td>
<td>Between fields of research</td>
</tr>
<tr>
<td>Indicators</td>
<td>Aguillo (1997)</td>
<td>WIF</td>
</tr>
<tr>
<td></td>
<td>Rousseau (1999)</td>
<td>Predictions on the growth rate of Northern Light</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Measurement</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use</td>
<td>Spink, Bateman, &amp; Jansen (1999)</td>
<td>Survey of Excite users</td>
</tr>
</tbody>
</table>

### Note
1. The URL of a service or a site is given only the first time the service or site appears in the text.

### References


Watson, J. S. (1998) "If you don’t have it, you can’t find it." A close look at students’ perceptions of using technology. *Journal of the American Society for Information Science, 49*(11), 1024–1036.


Solving Problems in Library and Information Science Using Fuzzy Set Theory

**William W. Hood and Concepción S. Wilson**

**ABSTRACT**

Various mathematical tools and theories have found application in Library and Information Science (LIS). One of these is Fuzzy Set Theory (FST). FST is a generalization of classical Set Theory, designed to better model situations where membership of a set is not discrete but is "fuzzy." The theory dates from 1965, when Lotfi Zadeh published his seminal paper on the topic. As well as mathematical developments and extensions of the theory itself, there have been many applications of FST to such diverse areas as medical diagnoses and washing machines. The theory has also found application in a number of aspects of LIS. Information Retrieval (IR) is one area where FST can prove useful; this paper reviews IR applications of FST. Another major area of Information Science in which FST has found application is Informetrics; these studies are also reviewed. A few examples of the use of this theory in non-LIS domains are also examined.

**BACKGROUND**

When an information professional is confronted with a problem, there may be many different ways to tackle it. In the armoury of the profession, there are a number of tools and techniques that can be drawn upon to address the situation. A good problem solver needs to be aware of a wide range of tools that can be used in that particular situation. Tools developed for one specific situation may be applicable to others, though they be quite different. One class of tools that can be applied to library problems are mathematical tools. Mathematical tools are indispensable for solving a
whole range of different types of problems. These tools include statistics, probability theory, operations research (including, for example, queuing theory), and cluster analysis.

Mathematical tools that are used to solve real-world problems fall into the category of applied mathematics. The essence of applied mathematics is abstraction and modeling. Some aspect of the real world may be modeled by a mathematical theory, which is an approximation of the reality. Development can take place in the mathematical theory, independent of any applications, and the results can then be applied back to the real world. How useful this is depends on how well the mathematical model captures the essence of the reality, and also how well the model has been formulated and developed. A good model will be able to provide useful insights into the real life situation, and will be a good tool for problem solving.

Set Theory is one theory or model that has proved enormously useful in a wide range of situations. Any collection of objects can be regarded as a set. Operations, such as union, intersection, and complementation, can be carried out on these sets. In fact, most of mathematics has Set Theory as its theoretical underpinning. The classical formulation of Set Theory applies to situations where membership of a set is discrete. The “set of red balls” or the “set of white cars” are situations where membership (or not) of the set from a universe of objects is definite. The “set of documents in a filing cabinet” or “the set of books on the library shelf” are also discrete and clear-cut sets. Set Theory has been applied in many situations that can be modeled by discrete membership, and has proven to be a useful tool.

However, there are many situations where classical Set Theory does not provide a good model. If there is some vagueness or fuzziness about the membership of a set, then classical Set Theory may not be useful. The “set of tall people” has the problem of defining exactly what constitutes a tall person: Where do you make the boundary of “tallness” and what happens if someone is marginally shorter than this boundary? The “set of relevant documents” also suffers from this problem. In Library and Information Science, “relevance” is sometimes regarded as dichotomous, but in reality, relevance is a graded concept with documents ranging from highly relevant for a particular purpose, to highly irrelevant, and every degree of relevance in between.

In a seminal paper on what he defined as Fuzzy Sets, Zadeh (1965) attempted to provide a mathematical model that would be better suited to these vague situations. Fuzzy Set Theory (FST) has become a branch of mathematics that generalizes the concept of a set to provide better tools for dealing with the sorts of situations described in the previous paragraph. Though designed to model fuzziness, the theory itself is not fuzzily defined. This essay will give an introduction to what FST is, as well as provide some of the applications for which it has been used. The material for this article has been developed from the first author’s Ph.D. thesis (Hood, 1998).
Basic Idea Behind Fuzzy Set Theory

The basic idea behind FST is to generalize the concept of membership of a set. In classical (or crisp) sets, membership of a set can be regarded as a function with only two possible values. That is, an item either belongs to the set or does not. The generalization that is made to produce Fuzzy Sets is to allow the membership function to be multivalued. This allows an item to have a degree of membership in a set. An item can belong to a Fuzzy Set with any degree of membership from none to full. Let us consider the example of a "Fuzzy Set of Relevant Documents" for a particular query. In this case, a highly relevant document may belong to this set with high degree of membership; whereas a marginally relevant document will still belong to the set, but with only a small degree of membership. A totally nonrelevant document will not belong to this set at all.

The concept of a Fuzzy Set can be formally defined mathematically, and interested readers may care to consult Zimmerman (1991), which is one of the current standard texts on FST and its applications. As well as the definition of a Fuzzy Set itself, various classical set operations such as union, intersection, and complementation can be generalized to Fuzzy Sets.

From these basic definitions, many extensions and developments are possible. Zimmerman (1991, p. 6) summarizes the developments that have taken place in FST, along two different lines:

1. As a formal theory which, when maturing, became more sophisticated and specified and was enlarged by original ideas and concepts as well as by "embracing" classical mathematical areas such as algebra, graph theory, topology, and so on by generalising (fuzzifying) them.
2. As a very powerful modeling language, that can cope with a large fraction of uncertainties of real-life situations. Because of its generality, it can be well adapted to different circumstances and contexts.

Other Measures of Vagueness or Uncertainty

There are other tools and measures of uncertainty and vagueness apart from FST. One such tool that would be quite familiar to most readers is Probability Theory. Probability concerns a set of events which, taken together, are certain, but each separate event only has a degree of certainty. Thus, when tossing a coin, there are only two possible outcomes, as it is certain that the coin will land on either heads or tails. However, Probability Theory tells us that for a nonbiased coin, each of the two events are equally likely, so each has a probability of one half. FST has no such universe of certainty, and therefore is applied in different types of situations. A third tool that can also be used to measure vagueness is Possibility Theory. For a discussion of the distinction between some of the different measures of uncertainty, see Zimmerman (1991, Chap. 8).
FUZZY SET THEORY IN LIBRARY AND INFORMATION SCIENCE

One of the characteristics of mathematical theories is that they are often applied in a wide range of different situations, beyond the wildest imaginations of the original developers. This is certainly true of FST. The applications of particular interest here are, of course, in the area of Library and Information Science (LIS). Within LIS, FST has been applied to traditional librarianship, as well as to problems in Information Retrieval (IR). Applications have also been made in Bibliometrics and Informetrics, which are closely allied to LIS. Some of these applications will be discussed below.

Library Applications of Fuzzy Set Theory

Following are two examples of FST applications to library decision-making. The first is taken from Egghe & Rousseau (1990) and is based on Turner & O'Brien (1984) and Robinson & Turner (1981).

Many libraries have to make decisions about when and if to bind their periodicals. The decisions may be based on a number of criteria including the number of missing issues, the future expected use of the periodical, etc. Each of these criteria is vague, and can be modeled with a Fuzzy Set. In addition, the decision may be based on the opinions of more than one decision maker. A possible formalization of the methodology is as follows:

A small committee of experts is formed. For reasons of simplicity, we shall consider a team of two experts. Three criteria will be used:
- number of citations obtained by the journal, as measured by ISI's (Institute for Scientific Information) citation files;
- percentage of missing issues;
- number of circulations (local use) per issue.

Each committee member must decide on his/her membership function for each of these variables. So, although each of these criteria can be measured in an objective way, the interpretation of the measurements with respect to the ultimate binding decision is subjective and requires an application of concepts borrowed from fuzzy set theory.

When experts have decided on membership functions, every journal set can be judged on all criteria. This can now be done in a straightforward way and no longer requires a specific intellectual input.

Finally, each expert must also have decided, beforehand, on the relative importance of each of the three criteria, and the library committee must have decided on the relative importance of each expert (before the data were collected!). This leads to a ranking of journals according to their suitability for binding. (Egghe & Rousseau 1990, pp. 200-201)

A similar approach can be used to making tattletaping decisions of periodicals (Turner, 1981). The methodology outlined above may help the library produce a list of journals that are the most likely candidates for tattletaping.
Information Retrieval Applications of Fuzzy Set Theory

The main application for Fuzzy Sets in LIS to date has been in the area of IR. As mentioned earlier, the concept of "relevance" is essentially a fuzzy concept; for any search, there will be documents that are more relevant or less relevant than others. IR is concerned with retrieving documents that meet some particular user need, or are relevant for some particular situation. The earliest attempts to apply Fuzzy Sets in this area appear to be those of Tahani (1976) and Radecki (1976). An ARIST review of this area is provided by Bookstein (1985) and a survey of the use of FST in IR and databases is given by Kerre, Zenner, & De Caluwe (1986). A theoretical background to the application of Fuzzy Sets to IR is given in Radecki (1983).

Traditionally, the main mathematical tool in IR has been Boolean algebra. Nearly everyone who has done any searching using bibliographic databases (such as those available through the DIALOG information systems), or searched library catalogs or the World Wide Web has used Boolean operators to construct sophisticated searches. In turn, Boolean algebra is based on Set Theory: Each search or index term results in a set of retrieved documents, which can then be combined using the Boolean operators (AND, OR, NOT). An IR system can be regarded as consisting of a set of "documents" and a set of "index terms." Each index term corresponds to a set of documents, which will be a subset of the universe of all documents in the system. This subset will consist of all those documents related to the index term. Traditional Boolean searches correspond to set operations on these index-term subsets.

As has been mentioned earlier, "relevance" is a concept that is not really dichotomous, and can readily be modeled by Fuzzy Set models instead. So Fuzzy IR systems work as follows: When documents are added to the system, index terms are assigned to the document, and each term is assigned a weight, indicating the degree to which that index term is associated with the document. The indexer is then free to indicate that a term applies only partially to a document, without having to make an absolute yes/no decision. Retrieval in a Fuzzy IR system is then based on Fuzzy Set algebra rather than Set algebra. The same Boolean operators are used (AND, OR and NOT), but the operators now rely on fuzzy union, fuzzy intersection, and fuzzy negation, rather than their classic (exact) equivalents.

This approach to IR has a lot of theoretical appeal, as it appears to be a much better model of the underlying process of selection (by users) of "relevant" documents. It is also a (relatively minor) modification of the traditional Boolean retrieval mechanism, so much of the existing infrastructure and mechanisms of IR are still valid. In addition, Fuzzy IR is more flexible in the assignment of index terms, with the use of partially relevant terms as well as fully relevant ones. The output can also be ranked according to relevance. Despite these advantages, there has not been much use
made of Fuzzy IR in commercial systems. Reasons for this include: The cost of indexing continues to increase; many of the problems inherent in Boolean retrieval are still problems in Fuzzy IR; the capacity for ranking is not sensitive to all terms in the request; and traditional Boolean systems have done an adequate job in many situations (Bookstein, 1985, p. 124ff.).

Despite a lack of Fuzzy IR usage in most commercial IR systems, research has continued into the development of such systems, and there have been many applications in areas related to IR. Some of these will be listed below.

**Expert systems and artificial intelligence.** Gaines & Shaw (1985) discuss the history and development of expert systems, and the introduction of concepts from FST into this area. Graham (1991) also describes the use of fuzzy logic in commercial expert systems. FST has also been applied more generally in the area of artificial intelligence (Hofstadter, 1980; Winston, 1984). Nauck & Kruse (1999) use medical data to create fuzzy classification rules.

**Knowledge-assisted document retrieval.** A number of papers discuss the implementation of a knowledge-assisted document retrieval system (Subramanian, Biswas, & Bezdek, 1986; Biswas et al., 1987a, 1987b).

**Relational databases with vague queries.** Motro (1988) describes a database system that provides a user interface that permits vague queries based on FST. Some theoretical work done by Hashimoto (1985) can also be applied to Fuzzy databases.

**Fuzzy clustering.** The use of Fuzzy clustering algorithms in IR is also an area that has received a lot of attention. The excellent monograph by Miyamoto (1990a) provides a good description of the theory behind and the many uses of Fuzzy clustering. Fuzzy clustering can be applied in any situation where normal clustering is useful. Applications of Fuzzy clustering are described in Miyamoto, Miyake, & Nakayama (1983); Nomoto et al. (1987); Miyamoto, Midorikawa & Nakayama (1989); and Nomoto et al. (1990).

**Fuzzy thesauri-based retrieval.** Particular attention has been paid to the Fuzzy clustering of citations. These clusters can be used to form a thesaurus-like structure. Some work has been done on constructing Fuzzy thesauri to assist in creating queries and searching IR systems. Work in this area is reported in Miyamoto (1989, 1990b).

**OPACs.** Meikle (1995), in a literature review, includes the application of FST to searching on OPACs. Meikle notes that, despite some research effort, there have not been any commercial applications of Fuzzy Sets to OPAC searching to date.

**Other.** Ahrens (1994) describes tests on a retrieval system (Knowledge Finder) to compare user opinions of the effectiveness of this system versus a traditional Boolean IR system. The results were favourable. Kall & Srinivasan (1990) compare Fuzzy and probabilistic models for user relevance judgements. Klir (1991) also uses Fuzzy Sets in developing a generalized information theory.
Bookstein (1997) describes the rationale behind the application of FST to informetrics:

Informetrics shares with the other social sciences the ubiquity of uncertainty. Key concepts are vague. All mathematical relationships are approximate. Yet we are able to make measurements and learn from them. Clearly, we must have developed adaptations to uncertainty, sometimes explicitly, sometimes intuitively, often inadvertently. (p. 10)

Some examples of the types of uses that FST has found in informetrics are given below in roughly chronological order:

- Zunde & Dexter (1969a, 1969b) apply Fuzzy Set concepts to the measurement of indexing consistency and quality.
- Brusilovsky (1978) characterizes science itself as a “Fuzzy system.” As such, forecasting and scientometric studies in general can benefit from the application of FST. Jones (1976) describes a Fuzzy Set characterization of interaction in scientific research that provides a better formalization of the notion of citation than nonfuzzy methods.
- Windsor (1979) uses Fuzzy Sets to create a method to predict the clinical fate of a drug based on an informetric analysis of the patent and nonpatent literature about it.
- Price (1981) uses a Fuzzy Set approach to analyze interactions between various entities such as papers, journals, countries, etc.
- Dobrov & Skofenko (1989) discuss the improvements to the review procedure in making Research and Development (R & D) decisions based on a Fuzzy Set model. They regard FST as a good method of modeling the uncertainty inherent to the process of expert reviews of R & D proposals.
- A Fuzzy Set approach has been used to model a network of research institutions (Korennoi, 1989). Korennoi uses a Fuzzy Cluster Analysis to model the relationship between different research institutions, the similarity measure between institutions being inherently fuzzy.
- The uses Japanese researchers have made of FST in informetric research (and other topics) has been described in two similar articles by Miymoto, Midorikawa, & Nakayama (1989) and Midorikawa, Miyamoto, & Nakayama (1990).
- Egghe & Rousseau (1990) give the basic concepts behind Fuzzy Sets, and then offer some examples of how Fuzzy Sets may be used in informetric (and bibliometric) analysis.
- The influence of the information scientist Manfred Kochen who, amongst other things, studied Fuzzy Sets, has been examined using citation analysis by Lancaster, Bushur, & Low (1993)—though they did not use FST in their analysis.
Egghe & Rousseau (2001) provide an exact definition of a bibliography using FST, Lorenz curves, and concentration measures. If a strict delineation is preferred, the fuzzy core can be “defuzzified.” They claim that the proposed method does not depend on the subjective notion of “importance” and that the method is completely reproducible.

**Other Applications of Fuzzy Set Theory**

To provide the reader with a broad idea of where FST is used, this section will offer just a few of the non-LIS examples of Fuzzy Sets applications. Zadeh et al. (1975) cover a number of the applications of FST. Zimmerman (1991), in the second half of his book, outlines a wide range of different applications. He provides a classification of four different types of application (p. 129):

1. Applications to mathematics (i.e., generalizations of traditional mathematics such as topology, graph theory, algebra, logic, etc.). The largest and most important of this type of application is undoubtedly fuzzy logic.
2. Applications to algorithms (e.g., clustering methods, control algorithms, mathematical programming, etc.)
3. Applications to standard models (e.g., “the transportation model,” “inventory control models,” etc.)
4. Applications to real-world problems of different kinds. The most important of these would include fuzzy expert systems and fuzzy control. Others would include applications to psychology (Kochen, 1975).

To get some idea of the broad applicability of Fuzzy Set methods, a list of just a few of the applications in various disciplines or research areas is now provided:

- Fuzzy computer programs (Giles, 1980).
- Fuzzy Set models in inventory control (Kacprzyk & Staniewski, 1982).
- Fuzzy Set models in production control and scheduling (Aliev, 1987).
- Fuzzy Set models in logistics (Klingman, Mote, & Phillips, 1988).
- Fuzzy Sets in psychology (Zetenyi, 1988).
- Support logic programming (Graham, 1989).
- Approximate reasoning (Kienitz, 1990).
- Fuzzy logic (Godo, Jacas, & Valverde, 1991).
- Fuzzy control (Moore & Harris, 1992).
- Fuzzy decisions (Lapiga & Polyakov, 1992).
- Fuzzy languages (Gerla, 1992).
- Fuzzy linear programming (Tomsovic, 1992).
- Fuzzy Sets in engineering (Dubois & Prade, 1993).

**LITERATURE OF FUZZY SET THEORY**

*Seminal Paper*

In 1965, Lotfi A. Zadeh published the seminal paper on FST (Zadeh, 1965). As demonstrated in the previous section, this theoretical work has found applications in a vast array of different disciplines, including medicine, engineering, and information retrieval. As well as applications of this theory, much development to the theory itself has taken place, and this is recorded in the pure mathematical literature.

*Main Information Sources: Journals and Books*


*Historical Information Sources*

Quite a few papers give some insight into the history of the development of FST. A number of these were written around 1991, to commemorate the twenty-fifth anniversary of Zadeh’s (1965) paper. They include Gupta (1991), Turksen et al. (1991), Hohle (1991), and Hohle & Stout (1991). Other items with some historical content include Krarup (1984); Gaines & Shaw (1985); El-Kafrawy, El-Ramly, & Mahmoud (1986); Gaines (1976); and Shostak (1989). Ostasiewicz (1992) provides a discussion of some of the early work that predates and provides the setting for Zadeh’s (1965) seminal paper.

**CONCLUSIONS**

What has been presented here is a mathematical theory, FST, which can be used to model a whole variety of situations in which there is some degree of vagueness or uncertainty. The LIS domain is one area in which this theory has found application. It has been used to assist in decision-making (such as when to bind a periodical), and also in the area of IR. Use has also been made in bibliometrics and informetrics, where some of the quantities being measured have a degree of fuzziness about them.

However, despite the considerable research effort to try to apply FST
to solve particular types of LIS problems, and despite the considerable theoretical appeal that this theory has over some of the alternatives, there has been little application in large-scale or commercial systems. More work is needed to take this (and many other) theories from the research papers into practical applications. The benefits that can be gained by using theories such as FST need to be tested and explored, and if found positive, need to be incorporated into the systems in use. Other domains have taken up FST (such as manufacturing and process control) and found it an enormously useful tool. It is time for LIS to do the same.

NOTES
1. For recent reviews of the literature of relevance, see Schamber (1994), Saracevic (1996), and Mizzaro (1997).
2. Sets in the original sense of the term are sometimes called “classical” or “crisp” sets to distinguish them from Fuzzy Sets.
3. Some other articles mentioning IR and FST include: Buell (1982); Buell (1985); McCune et al. (1985); Rada (1985); Rousseau (1985); Gauch & Smith (1991); Turtle & Croft (1991); Hassebrock & Prietula (1992); Savoy (1992).

REFERENCES
Egghé, L., & Rousseau, R. (2001). The core of a scientific subject: An exact definition using concentration and fuzzy sets. In M. Davis & C. S. Wilson (Eds.), 8th International Confer-


Surveying the Use of Theory in Library and Information Science Research: A Disciplinary Perspective

LYNNE (E. F.) McKECHNIE AND KAREN E. PETTIGREW

ABSTRACT
A content analysis of 1,160 Library and Information Science (LIS) articles published in six LIS journals between 1993 and 1998 was conducted to examine the use of theory in LIS research. Overall, 34.2 percent of articles incorporated theory in either the title, abstract, or text for a total of 1,083 theory incidents or an average of .93 incidents per article. Articles dealing with topics from the humanities (e.g., information policy, history) had the highest rate of theory use with 1.81 incidents per article, followed by social science papers (e.g., information behavior, management) with .98 incidents per article and science articles (e.g., bibliometrics, information retrieval) with .75 theory incidents per article. These findings imply that differences exist in the use of theory in LIS that are associated with the broad disciplinary content of the research. These differences may arise from variant conceptions of and approaches to the use of theory in the research traditions of the humanities, social sciences, and sciences. It is suggested that the multidisciplinary background of LIS researchers provides a rich but still under-utilized opportunity for the use and development of theory within LIS.

BACKGROUND
Scholars have been concerned with theory and written about it in diverse ways for many years. Basic definitions found within the literature include: “A set of explanatory concepts” (Silverman, 1993, p. 1); “a statement or group of statements about how some part of the world works—frequently
explaining relationships among phenomena" (Vogt, 1993, p. 232); "a systematic explanation for the observed facts and laws that relate to a particular aspect of life" (Babbie, 1992, p. 55); "generalizations which seek to explain relationships among phenomena" (Grover & Glazier, 1986, p. 228); and, in reference to LIS theory, an "explanation of information systems efficiency, of user behavior, of the function of different search agents such as descriptors, citation, titles, and so on" (Hjørland, 1998, p. 607).

Preoccupation with the use and development of theory is common within academic disciplines, including LIS. According to the philosophy of science, the use of theory in scholarly research is a distinguishing characteristic of a discipline's academic maturity (Hauser, 1988). LIS literature is replete with calls for making the field more theoretical, including those by Grover & Glazier (1986), Templeton (1994), and Hjørland (1998). While the development of theory unique to LIS is essential to the growth of the discipline, it must also be remembered, as is so aptly stated by LIS scholar Elfreda Chatman (1996), that "[w]orking with conceptual frameworks and empirical research has never been an easy task" (p. 205).

Little research has actually examined the use of theory in LIS. The few existing studies concluded that most LIS research is atheoretical, reporting rates of theory use ranging from 10 to 21 percent (Feehan et al., 1987; Jarvelin & Vakkari, 1990; Julien, 1996; Julien & Duggan, 2000; Nour, 1985; Peritz, 1980). This paper arises from a larger study of the use of theory in LIS, funded by a research award from the Association for Library and Information Science Education (ALISE). The results have been reported previously in McKechnie & Pettigrew (1998), Pettigrew & McKechnie (2001), and McKechnie, Pettigrew, & Joyce (2001). The findings of this larger study indicate that theory was discussed in 34.2 percent of 1,160 articles published in six prominent LIS journals from 1993 to 1998 which, when compared to the results of earlier studies, suggests an increase in the use of theory within LIS. However, theory was not used consistently across the articles. For example, some researchers simply mentioned a theory while others explicitly used a theory to frame the study, develop research questions, and analyze results. A particular "theory" might be referred to as a model, conceptual construct, or a grand theory by different scholars in different papers and, on occasion, by a single scholar within the same paper. Theory citation practices also varied widely: While most scholars identified and discussed theories within the text of their papers and provided bibliographic references for the theories used, only a few mentioned theories in article abstracts and many of the references provided referred to secondary rather than primary resources for the theory. Thus, a major finding of this study was that LIS scholars do not share a single perspective about what theory comprises and how it should be used within research. Chatman (1996) is indeed correct when she claims that using and developing theory is hard work.
The current article explores a possible explanation for this phenomenon of inconsistent use. Are the different approaches to theory, as evident in the LIS literature, related to the multidisciplinary backgrounds of LIS researchers and the multidisciplinary nature of the content of the field? More specifically, do the different research approaches and traditions associated with work in the broad disciplines of the humanities, social sciences, and sciences have an impact on the use of theory in LIS research? And is this evident in the published reports of LIS research?

**Method**

To answer these research questions, a content analysis was conducted of 1,160 articles that appeared from 1993 to 1998 in six journals:

1. *Information Processing and Management* (*IP&M*; six issues per year)
3. *Journal of Documentation* (*JDOC*; quarterly)
5. *Library and Information Science Research* (*LISR*; quarterly)
6. *The Library Quarterly* (*LQ*; quarterly)

These journals were chosen because they are prominent and contain peer reviewed articles covering most areas of research in LIS. All articles except for columns, book reviews, and news items, such as conference announcements and obituaries, were coded for the authors’ use of theory.

Each article was coded for the first author’s affiliation as listed in the article (e.g., private sector, government, academic department), subject area (e.g., information retrieval, human information behavior, history), and type of article (e.g., report of empirical research, literature review, method paper). Subjects were further grouped under the broad disciplinary categories of humanities (e.g., information policy), social sciences (e.g., management), and sciences (e.g., bibliometrics). The code book is appended. Theories cited in the articles were counted and coded as to whether they originated within LIS, the sciences, social sciences, or humanities, and where they were used in the article (i.e., title, abstract, or main text). No matter how many times a theory was mentioned in a particular article, it was only counted once. To test for inter-coder reliability, thirty articles (five randomly chosen from each of the six journals) were independently coded by three individuals. The final rate of agreement for all coding decisions was 94.7 percent suggesting that the coding scheme was reliable and valid.

**Findings**

The findings from the analysis of the 1,160 articles in terms of their subject content by the broad disciplinary categories of humanities, social sci-
rences, and sciences are presented in terms of the basic characteristics of the articles (i.e., journal of publication, subject content, author affiliation, and type of article) and the description of theory deployment (i.e., frequency of theory use, originating broad discipline, and use within the article).

Basic Characteristics
Of the 1,160 articles analyzed (see Table 1), the majority were published in *JASIST* (40.9 percent) and *IP&M* (27.0 percent).

Articles dealing with topics associated with the sciences comprised 59.5 percent ($n = 690$) of the sample and accounted for 84.7 percent of the content of *IP&M*, 66.6 percent of the content of *JDOC*, and 66.0 percent of *JASIST*. Articles from the broad discipline of the social sciences represented 30.0 percent ($n = 348$) of the sample. Social science articles were most prominent in *JELIS* (89.6 percent of the content), *LISR* (57.9 percent), and *LQ* (48.7 percent). Humanities articles constituted 10.5 percent ($n = 122$) of the sample and were most frequently found in *LQ* (36.8 percent of the content). All six journals published articles from all three disciplines during the six-year period studied. Therefore, while science may have been the most frequently found content in *IP&M*, the journal also published articles dealing with the social sciences (8.6 percent) and humanities (6.7 percent), and while *LQ* devoted substantial space to humanities work, it also included articles from the social sciences (48.7 percent) and sciences (14.5 percent). Nonetheless, definite trends are apparent in disciplinary publishing patterns for these six journals with humanities, social science, and science materials more likely to be found in some journals than in others. The prominence of science articles is clearly related to the large proportion of articles in the sample from *IP&M* and *JASIST*, which are published more frequently (bimonthly and monthly) than journals like *LQ* and *JELIS*, which include more from the humanities and social sciences but are only issued quarterly.

The primary affiliation (see Table 2) for the first author of over half

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Journal</th>
<th>IP&amp;M</th>
<th>JASIST</th>
<th>JDOC</th>
<th>JELIS</th>
<th>LISR</th>
<th>LQ</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humanities</td>
<td></td>
<td>21</td>
<td>46</td>
<td>7</td>
<td>8</td>
<td>12</td>
<td>28</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(6.7%)</td>
<td>(9.7%)</td>
<td>(6.7%)</td>
<td>(8.3%)</td>
<td>(12.6%)</td>
<td>(36.8%)</td>
<td>(10.5%)</td>
</tr>
<tr>
<td>Social Sciences</td>
<td></td>
<td>27</td>
<td>115</td>
<td>28</td>
<td>86</td>
<td>55</td>
<td>37</td>
<td>348</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(8.6%)</td>
<td>(24.3%)</td>
<td>(26.7%)</td>
<td>(89.6%)</td>
<td>(57.9%)</td>
<td>(48.7%)</td>
<td>(30%)</td>
</tr>
<tr>
<td>Sciences</td>
<td></td>
<td>266</td>
<td>313</td>
<td>70</td>
<td>2</td>
<td>28</td>
<td>11</td>
<td>690</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(84.7%)</td>
<td>(66%)</td>
<td>(66.6%)</td>
<td>(2.1%)</td>
<td>(29.5%)</td>
<td>(14.5%)</td>
<td>(59.5%)</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>314</td>
<td>474</td>
<td>105</td>
<td>96</td>
<td>95</td>
<td>76</td>
<td>1160</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(27%)</td>
<td>(40.9%)</td>
<td>(9%)</td>
<td>(8.3%)</td>
<td>(8.2%)</td>
<td>(6.6%)</td>
<td>(100%)</td>
</tr>
</tbody>
</table>
Table 2. Affiliation of First Author by Broad Disciplinary Content (n = Number of Articles).

<table>
<thead>
<tr>
<th>Affiliation of First Author</th>
<th>Humanities</th>
<th>Social Sciences</th>
<th>Sciences</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private Sector</td>
<td>4 (3.3%)</td>
<td>15 (4.3%)</td>
<td>43 (6.2%)</td>
<td>62 (5.4%)</td>
</tr>
<tr>
<td>Government</td>
<td>4 (3.3%)</td>
<td>4 (1.2%)</td>
<td>23 (3.3%)</td>
<td>31 (2.7%)</td>
</tr>
<tr>
<td>LIS</td>
<td>85 (69.7%)</td>
<td>242 (69.5%)</td>
<td>307 (44.5%)</td>
<td>634 (54.7%)</td>
</tr>
<tr>
<td>Humanities</td>
<td>3 (2.4%)</td>
<td>3 (0.9%)</td>
<td>8 (1.2%)</td>
<td>14 (1.2%)</td>
</tr>
<tr>
<td>Social Sciences</td>
<td>14 (11.5%)</td>
<td>38 (10.9%)</td>
<td>68 (9.9%)</td>
<td>120 (10.3%)</td>
</tr>
<tr>
<td>Sciences</td>
<td>5 (4.1%)</td>
<td>31 (8.9%)</td>
<td>208 (30.1%)</td>
<td>244 (21.0%)</td>
</tr>
<tr>
<td>Don't Know</td>
<td>7 (5.7%)</td>
<td>15 (4.3%)</td>
<td>33 (4.8%)</td>
<td>55 (4.7%)</td>
</tr>
<tr>
<td>Total</td>
<td>122 (100%)</td>
<td>348 (100%)</td>
<td>690 (100%)</td>
<td>1160 (100%)</td>
</tr>
</tbody>
</table>

(54.7 percent) of the articles was associated with either a university LIS program or LIS practice, a trend that was consistent for authors writing in all three major discipline areas.

Science scholars made up 21 percent of the sample, social science scholars 10.3 percent, and humanities scholars 1.2 percent. Interestingly, while scientists were more likely to write about topics related to science (85.2 percent or 208 of the 244 articles by individuals associated with science programs in universities), humanists authored more articles about science (56.7 percent or 8 of 14 articles) and just as many about social science topics (21.4 percent or 3 of 14 articles) as they did about the humanities (21.4 percent or 3 of 14 articles). Social scientists wrote more about science (56.7 percent or 68 of 120 articles by first authors affiliated with the social sciences) and less about the humanities (11.6 percent or 14 of 120 articles) compared to the social sciences (31.7 percent or 38 of 120 articles). Clearly, scholars affiliated with non-LIS workplaces, but publishing in LIS venues, do not hesitate to cross broad disciplinary boundaries in their research. Finally, authors associated with private sector and government organizations were also evident in the sample, producing work associated with all three broad disciplines.

Reports of empirical research were the most frequently occurring type of article (see Table 3), accounting for 59.3 percent of the total, followed by descriptive papers (14.3 percent) and papers using verbal argumentation (7.3 percent).

While this pattern held for articles dealing with the social sciences and sciences, it was somewhat different for those falling within the humanities. Historical treatises were the most frequent type of article for the humanities (27.0 percent), followed by reports of empirical research (23.0 percent) and papers using verbal argumentation (22.1 percent). Each of the three disciplinary areas had other article types that were relatively more represented within their subset of articles: Method (9.0 percent) and theory (9.8...
Table 3. Type of Article by Broad Disciplinary Content (n = Number of Articles).

<table>
<thead>
<tr>
<th>Type of Article</th>
<th>Humanities (n =)</th>
<th>Social Sciences (n =)</th>
<th>Sciences (n =)</th>
<th>Total (n =)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Descriptive</td>
<td>6 (4.9%)</td>
<td>56 (16.1%)</td>
<td>104 (15.1%)</td>
<td>166 (14.3%)</td>
</tr>
<tr>
<td>Discourse Analysis</td>
<td>1 (0.8%)</td>
<td>3 (0.9%)</td>
<td>0 (0%)</td>
<td>4 (0.3%)</td>
</tr>
<tr>
<td>Empirical Research</td>
<td>28 (23%)</td>
<td>216 (62%)</td>
<td>444 (64.3%)</td>
<td>688 (59.3%)</td>
</tr>
<tr>
<td>Historical</td>
<td>33 (27%)</td>
<td>9 (2.6%)</td>
<td>10 (1.5%)</td>
<td>52 (4.5%)</td>
</tr>
<tr>
<td>Math Modeling</td>
<td>2 (1.7%)</td>
<td>0 (0%)</td>
<td>51 (7.4%)</td>
<td>53 (4.6%)</td>
</tr>
<tr>
<td>Verbal Argument</td>
<td>27 (22.1%)</td>
<td>31 (8.9%)</td>
<td>27 (3.9%)</td>
<td>85 (7.3%)</td>
</tr>
<tr>
<td>Literature Review</td>
<td>2 (1.7%)</td>
<td>8 (2.3%)</td>
<td>27 (3.9%)</td>
<td>37 (3.2%)</td>
</tr>
<tr>
<td>Method</td>
<td>11 (9.0%)</td>
<td>10 (2.9%)</td>
<td>13 (1.9%)</td>
<td>34 (2.9%)</td>
</tr>
<tr>
<td>Theory</td>
<td>12 (9.8%)</td>
<td>14 (4%)</td>
<td>12 (1.7%)</td>
<td>38 (3.3%)</td>
</tr>
<tr>
<td>Other</td>
<td>0 (0%)</td>
<td>1 (0.3%)</td>
<td>2 (0.3%)</td>
<td>3 (0.3%)</td>
</tr>
<tr>
<td>Total</td>
<td>122 (10.5%)</td>
<td>348 (30%)</td>
<td>690 (59.5%)</td>
<td>1160 (100%)</td>
</tr>
</tbody>
</table>

percent) papers in the humanities; theory papers in the social sciences; and mathematical modeling/algorithm development papers in the sciences. This suggests that different approaches to research are, to some extent, associated with the broad disciplinary subdivisions of LIS research.

Theory Deployment

Overall, 34.2 percent (n = 397) of articles incorporated theory (Table 4) in the title, abstract, and/or text, resulting in a total of 1,083 incidents of theory use or an average of .93 theory incidents per article. When one considers only the articles including theory, the average number of theory incidents per article increases to 2.73.

Distinct disciplinary differences in theory use are evident in the data. Humanities articles had the highest levels of theory use with 1.81 incidents per article and 4.09 incidents per article with theory. Theory use in social science articles approximated the averages for the entire sample, using .98

Table 4. Theory Use by Broad Disciplinary Content (n = Number of Articles).

<table>
<thead>
<tr>
<th>Theory Use</th>
<th>Humanities (n =)</th>
<th>Social Sciences (n =)</th>
<th>Sciences (n =)</th>
<th>Total (n =)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Articles</td>
<td>122 (10.5%)</td>
<td>348 (30%)</td>
<td>690 (59.5%)</td>
<td>1160 (100%)</td>
</tr>
<tr>
<td>Number of Theories</td>
<td>221 (20.4%)</td>
<td>342 (31.6%)</td>
<td>520 (48%)</td>
<td>1083 (100%)</td>
</tr>
<tr>
<td>Number of Theories per Article</td>
<td>1.81</td>
<td>.98</td>
<td>.75</td>
<td>.93</td>
</tr>
<tr>
<td>Number of Articles with Theory</td>
<td>54 (44.3%)</td>
<td>119 (34.2%)</td>
<td>224 (32.5%)</td>
<td>397 (34.2%)</td>
</tr>
<tr>
<td>Number of Theories per Article with Theory</td>
<td>4.09</td>
<td>2.87</td>
<td>2.32</td>
<td>2.73</td>
</tr>
</tbody>
</table>
incidents of theory per article for all social science articles and 2.87 incidents per social science article using theory. The incidence of theory use was lower than average for science articles at .75 incidents per article for all science articles and 2.32 incidents for those containing theory.

Theories used (Table 5) were drawn first from the social sciences (45.4 percent), followed by LIS (29.9 percent), the sciences (19.3 percent), and the humanities (5.4 percent).

Articles dealing with the social sciences relied most heavily on theories drawn from the social sciences (69.9 percent) and LIS (22.5 percent) but less so on those from the sciences (6.4 percent) and humanities (1.2 percent). Science papers turned first to theories from LIS (41.4 percent) and then almost equally to theories from the sciences (29.6 percent) and social sciences (24.8 percent). Papers dealing with the humanities relied more on theories drawn from the social sciences (56.1 percent) and just as much on science (14.9 percent) and LIS theories (14.5 percent) as they did on theories from the humanities (14.5 percent). While only articles with content from one of the three broad disciplines—social sciences—relied most heavily on theories from the same broad discipline, when one examines the data from the perspective of the discipline of the theory used, a positive relationship exists between the discipline of the theory and the disciplinary content of the article. For example, humanistic theories are most often found in papers dealing with the humanities and science theories in articles dealing with the sciences. Authors proposed eighty-six new theories, distributed proportionately according to the total number of articles in each discipline between articles about the humanities (n = 8; 9.3 percent), the social sciences (n = 26; 30.0 percent), and the sciences (n = 52; 60.1 percent). Overall, the findings suggest that there are some discipline dependent differences associated with the use of theory in LIS research.

As shown in Tables 6 and 7, citation practices did not differ substantially among articles in the three disciplines.

Theories were mentioned in article titles about 10 percent of the time, in abstracts about 20 percent of the time, and almost always in the text of articles. Authors provided bibliographic references for approximately 85

| Table 5. Sources of Theory by Broad Disciplinary Subject (n = Number of Theories Cited). |
|-----------------------------------------------|-----------------------------------|---------------------------------|-----------------|-----------------|
| Sources of Theory                            | Humanities                      | Social Sciences                 | Sciences        | Overall         |
| LIS                                           | 32 (14.5%)                      | 77 (22.5%)                      | 215 (41.4%)     | 324 (29.9%)     |
| Humanities                                    | 32 (14.5%)                      | 4 (1.2%)                        | 22 (4.2%)       | 58 (5.4%)       |
| Social Sciences                               | 124 (56.1%)                     | 239 (69.9%)                     | 129 (24.8%)     | 492 (45.4%)     |
| Sciences                                      | 33 (14.9%)                      | 22 (6.4%)                       | 154 (29.6%)     | 209 (19.3%)     |
| Total                                         | 221 (100%)                      | 342 (100%)                      | 520 (100%)      | 1083 (100%)     |
percent of theories mentioned. Surprisingly, a few authors only included a theory in either the title or abstract without mentioning it in the text. While it is encouraging that references were provided for the majority of the theories, often these were citations to secondary sources rather than primary works associated with a theory. Differences in theory citation practices appear to be associated with individual authors rather than the disciplinary content of the work.

DISCUSSION AND CONCLUSION

The findings suggest that differences exist in the use of theory in LIS that are associated with the broad disciplinary content of the research. Scholars publishing humanistic research within the six LIS journals analyzed for this study used theory in their articles almost twice as frequently as those working in the social sciences, and almost two and one half times more often than those publishing in the sciences. It is hypothesized that these findings arise from differing conceptions of and approaches to the use of theory associated with the traditions of humanities, social science, and science research. It may be, for example, that the lower rate of theory use in articles dealing with science-related topics reflects a disciplinary reliance on theories that are assumed to be commonly understood by the scholarly community active in the research area and, therefore, not in need of identification and explanation. More research is needed to explore this idea
further. For example, interviews with authors working in the three broad areas could uncover “hidden” aspects of theory use in research that may not always be evident in the articles arising from that research.

Reports of earlier stages of this project (McKechnie & Pettigrew, 1998; McKechnie, Pettigrew, & Joyce, 2001; Pettigrew & McKechnie, 2001) found that, with the exception of articles written by LIS scholars publishing outside of LIS, LIS theories are not being cited in non-LIS journals. A surprising finding of this analysis is that many non-LIS scholars are publishing within the LIS journals examined, especially scholars associated with academic science departments, such as computer science, engineering, and mathematics. Although it was disappointing to see that LIS theories had not made substantial inroads in other disciplines, it is interesting to think of the opportunities afforded by exposure to non-LIS theories brought into LIS publishing by scholars working outside of the discipline.

LIS, with its broad cognitive domain and faculty recruited from diverse backgrounds, is often regarded as an inter-disciplinary orthogonal field (Bates, 1999). Some, such as Patrick Wilson in “Interdisciplinary Research and Information Overload” (1996), identify the challenges implicit in the need to master more than one area in order to conduct valid interdisciplinary work. Many others, including Machlup & Mansfield (1983), Harmon (1987), and Grover & Greer (1991) have advocated more interdisciplinary work as a potentially rich venue for answering the field’s complex research questions. Tom Wilson (1997), in a review of non-LIS literature dealing with information behaviour, states that “the ideas presented throughout this review demonstrate to the information science researcher that exploration of other disciplines can be productive of research ideas . . . [including] analytical concepts, models and theories” (pp. 569-570). The large number of distinct theories from widely diverse disciplines discovered in this project, and the large number of new theories proposed in the articles, suggest that interdisciplinary work may indeed be enriching LIS in terms of the use and development of theory. However, if interdisciplinarity continues to be important within LIS, special attention must be paid to the problems it poses for theory deployment and development within the field.

One simple solution suggested by the findings of this study would be to encourage scholars publishing within LIS to adopt better citation practices when writing about theory. Theories should be clearly identified and authors should list one or more primary sources for a theory. Theory names should be included in article abstracts so that individuals interested in learning about a theory and how it has been used can easily retrieve relevant research articles by searching LIS databases like Library and Information Science Abstracts. Authors could also provide brief explanations of theories and how they have been used within the text of the article itself. These practices would be helpful for LIS scholars with little or no knowledge of a particular theory. The widely diverse disciplinary affiliations of first authors
publishing within LIS, evident in this study, indicates that the multidisciplinary expertise needed to increase and improve the use of theory from other disciplines and to aid in the development of new theory unique to LIS is already available in the community of scholars, a rich and underutilized treasure.

APPENDIX: CONTENT ANALYSIS CODE BOOK

Note: “Affiliation of the first author” was coded using information provided within the article itself or in another part of the journal issue, such as an “About Our Contributors” section. “Type of Article” codes were developed to answer the question “What kind of article is this? Or “What approach to writing is used in this article?” Subject codes describe the main content areas of LIS. When an article covered two or more subject areas, the principal subject (i.e., that receiving the most coverage) was coded. Articles that dealt with LIS in general or LIS research were included in the “General LIS” category. Subjects were further grouped under the broad disciplinary headings of humanities, social sciences, and sciences.

Affiliation of first author
- Private sector
- Government
- LIS university/practice
- Humanities university
- Sciences university
- Social sciences university
- Unknown

Type of article
- Report of empirical research
- Descriptive paper
- Verbal argumentation
- Mathematical modeling/algorithm development
- Discourse analysis
- Historical paper
- Literature review
- Theory paper
- Method paper
- Other

Primary subject of article
- Humanities
- General LIS
- History
- Information policy
- Social sciences
- LIS education and pedagogy
Human information behavior
Library services (design and delivery of services and programs)
Management (human resources, fiscal, planning)
Scholarly communication and publishing
Sciences
Bibliometrics
HCI/interface design
Indexing/abstracting/cataloguing and classification
Information retrieval
Information technology (including www., cd-rom, .gis, systems)

References


Journal Evaluation: 
Technical and Practical Issues

RONALD ROUSSEAU

ABSTRACT

This essay provides an overview of journal evaluation indicators. It highlights the strengths and weaknesses of different indicators, together with their range of applicability. The definition of a "quality journal," different notions of impact factors, the meaning of ranking journals, and possible biases in citation databases are also discussed. Attention is given to using the journal impact in evaluation studies.

The quality of a journal is a multifaceted notion. Journals can be evaluated for different purposes, and hence the results of such evaluation exercises can be quite different depending on the indicator(s) used. The impact factor, in one of its versions, is probably the most used indicator when it comes to gauging the visibility of a journal on the research front. Generalized impact factors, over periods longer than the traditional two years, are better indicators for the long-term value of a journal. As with all evaluation studies, care must be exercised when considering journal impact factors as a quality indicator. It seems best to use a whole battery of indicators (including several impact factors) and to change this group of indicators depending on the purpose of the evaluation study. Nowadays it goes without saying that special attention is paid to e-journals and specific indicators for this type of journal.

INTRODUCTION

Few model-based approaches to journal evaluation can be found in the literature. A descriptive, but not explanatory model is the one used by the Leiden-based Centre for Science and Technology Studies (Tijssen & van Raan, 1990). Perhaps this overview will inspire fellow scientists to construct...
an overall model explaining observed journal citation scores, and hence lead to a better understanding of their role in institutional and national evaluations. Theoretical issues dealt with in this article are restricted to giving precise formulations of indicators, in particular of the journal impact factor. No input-output model or explanation of dependent variables, such as journal citation counts, as a function of one or more independent variables (e.g., number of journals in the field or number of active scientists) is provided.

The study of the use and relative impact of scientific journals is an important application of citation analysis. Yet citations are only one aspect of a journal evaluation exercise. Indeed, journal evaluation can be performed with many purposes in mind. Impact factors measure only the (international) use of journals on the research front. Hence, they are of little direct use to a (special) librarian, because, as Line (1977) notes: Users of journals read, but many actually publish little or nothing at all. In this context, it is important to investigate the relation between in-house use and citation use. This has been done, for example, by Ming-yueh Tsay (1998, 1999) in a medical library. Numerous studies have shown that older volumes of scientific journals are less frequently used (read as well as cited) than more recent volumes. This phenomenon is generally described by the term “obsolescence” (Brookes, 1970; Line, 1993). A mathematical model describing the relation between the growth of the literature and obsolescence can be found in Egghe & Rousseau (2000).

It should also be pointed out that scientists read not only as a step in their scientific investigations, but also to keep informed of the latest findings in their field, or simply out of general interest. Further, the importance of scientific journals is not restricted to use (local or international). Geographic penetration in the sense of geographical distribution patterns of subscribers, authors, and citers, as well as the correlations between them, is still another indicator. Irene Wormell (1998) performed such an investigation of geographical distributions for the following journals: College & Research Libraries, Computer Journal, Information Processing & Management, Journal of Documentation, Journal of the American Society for Information Science, Libri, and Scientometrics. Studies like this one tell us whether international journals are really international in scope and impact. Among the journals considered by Wormell, Libri turned out to be the most international one, while College & Research Libraries is a very nationally oriented (i.e., U.S.) journal.

Many people are interested in journal evaluations: Librarians, scientists, science evaluators, publishers, etc. Librarians are interested in journal evaluations and local circulation data for selection and deselection purposes, and in the relation between impact and price (Van Hooydonk et al., 1994; Van Hooydonk, 1995; Abbott, 1999). Scientists want to find the most appropriate journal in which to publish their results. Funding agencies and governments want their grantees to publish in the most
prestigious journals (Pao & Goffman, 1990; Lewison & Dawson, 1997). Editors and publishers may relate high citation scores to a successful editorial practice and policy. Commercial publishers are interested in subscription data and sales. Information brokers are interested in finding those sources that have the most potential of satisfying their clients' needs. University research councils use journal impact and prestige scores as elements in local research evaluation studies in view of enlarging the visibility of the university's research.

Because economic indicators such as subscription data are essential for commercial publishers, an investigation, such as Peritz's (1995), of the relation between these and citation data is of great value. Let us just mention that, in most instances, Peritz found correlations between 0.25 and 0.5.

Besides serving as an archive for research findings, scholarly printed journals also provide professional, institutional, and disciplinary visibility, as well as recognition and prestige, to scientific authors. This, in turn, provides prestige to the journals themselves. Complex systems of "pecking orders" are based on the ranking of journals and a journal's position in them. The quality of the editorial board counts for much, of course, but the typography, quality of the paper used, quality of the illustrations, etc. all play their role. A truly excellent journal regularly garners papers from well-established authors and secures a larger number of institutional and individual subscriptions, thus making for a solid financial (economic) base.

The next sections cover the following topics: The definition of a quality journal, different definitions of impact factors, a general model for the citation distribution, electronic journals, the meaning of ranking journals, possible biases in citation databases, and how to use the journal impact in evaluation studies.

QUALITY JOURNALS

How has a quality journal been defined, what are the elements in such a definition, and how have they been used in practice? As early as 1970, Zweemer published the following list of characteristics of a "good journal":

1. High standards for acceptance of manuscripts (results must be based on new scientific information, reliable methods, adequate controls, and statistical treatment of data);
2. Having a broadly representative editorial board with appropriate representation of subdisciplines;
3. The editor uses a critical refereeing system;
4. Promptness of publication;
5. Being covered by major abstracting and indexing services;
6. Scientists using the articles published in the journal have a high confidence level in its contents;
7. Having a high frequency of citation by other journals.
These seven criteria are also among those used by the Philadelphia-based Institute of Scientific Information (ISI) to determine inclusion (or exclusion) of journals in their database (Garfield, 1990; Testa, 1998). The ISI management further mentions the following requirements:

8. Including abstracts or summaries in English;
9. Including authors' addresses;
10. Providing complete bibliographic information.

For new journals the reputation of the publisher and of the main editor is a good indicator of the possible importance or quality of the journal. If, for example, Elsevier, the American Chemical Society, or the IEEE launches a new journal, this will probably be a more important one than the newly established "Research Reviews of the Department of . . . of the . . . University."

Panels of (subject) experts have acted as judges to determine the value of journals and to draw formal ranked lists (Van Fleet, McWilliams, & Siegel, 2000). This approach is especially useful in the social sciences and humanities where the Science Citation Index (SCI) and Journal Citation Reports (JCR) cannot be used, and where local journals are often important. This is due to the local character of the investigations, as is the case in (national) law, or the literature or linguistics of small languages (Luwel et al., 1999).

Depending on the purpose and the type of journal, different journal indicators may be determined. Popular science journals, such as Scientific American, Dr. Dobb's Journal, and the New Scientist, are only marginally interested in impact factors. Besides practicing good (science) journalism, the number of subscriptions and corresponding revenues is what really counts for such journals.

The number of interlibrary lending (ILL) requests is still another local "use" indicator. Indeed, if a library does not subscribe to a journal, the librarian cannot directly determine its local use. In that case the number of local ILL requests for that journal can act as an indicator of its importance for the community served by the library.

Finally, a quality journal is indexed by many databases. Hence, the number of databases indexing this journal can be used as an indicator of its importance. However, as sheer numbers are not very important here, it is probably more relevant to investigate whether a scientific journal is covered by the most important database(s) in the field.

Citation Impact

Investigations related to journal citations and impact received a considerable impetus since the annual publication (since 1976) of Journal Citation Reports (JCR) by the Institute of Scientific Information (then under the direction of Eugene Garfield). Generally speaking, the JCR is a statistical data set providing information on how often journals are cited,
how many items have been published, and how often, on the average, each item is cited. It also reports those source journals responsible for the references of each journal, the number of references each journal has published, and the distribution of those references in time (Egghe & Rousseau, 1990).

As early as 1960, Raisig suggested the use of a journal impact factor. He called it the "index of research potential realized" (p. 1418). Nowadays different "impact factors" are used. Defining exactly what is meant by the notion of an impact factor is not easy. Indeed, different impact factors exist, and a precise notation and some mathematical terminology is necessary in order to show their differences. First, it is stressed that citations, and hence impact, is always calculated with respect to a certain pool of journals. In practice these are usually all journals covered by ISI. For the moment, it is assumed that the journal of which the impact is calculated belongs to that pool. Impact factors are always quotients of the form: Number of citations received, divided by number of items published. They differ by the periods considered.

**How to Calculate Impact Factors**

The standard ISI (or Garfield) impact factor (Garfield & Sher, 1963) of a journal J in the year 2002 is obtained as follows:

- Collect the number of citations received in the year 2002 by journal J. Not all citations are used, however; only those related to articles published in the two previous years: 2001 and 2000. These numbers are denoted as CIT\(_J(2002, 2001)\) and CIT\(_J(2002, 2000)\).
- Find the number of articles published in journal J in the years 2001 and 2000. These numbers are denoted as PUB\(_J(2001)\) and PUB\(_J(2000)\).

Written as a mathematical formula this is:

\[
\frac{\text{CIT}(2002, 2001) + \text{CIT}(2002, 2000)}{\text{PUB}(2001) + \text{PUB}(2000)}
\]

If now the symbol CIT\(_J(Y, X)\) denotes the number of citations received (by a fixed journal J, from all members of the pool) in the year Y, by articles published in the year X, and the symbol PUB\(_J(Z)\) stands for the number of articles published by this same journal in the year Z, then one can similarly define a Garfield impact factor for any year (not just the year 2002). The algorithm described above needs only little modifications. It becomes:

- Collect the number of citations received in the year Y by journal J. Use only citations pertaining to articles published in the two previous years: \(Y - 2\) and \(Y - 1\). These numbers are denoted as CIT\(_J(Y, Y - 1)\) and CIT\(_J(Y, Y - 2)\).
• Find the number of articles published in journal J in the years Y - 1 and Y - 2. These numbers are denoted as PUB_{j}(Y - 1) and PUB_{j}(Y - 2).

• Form the quotient of the sum of CIT_{j}(Y, Y - 1) and CIT_{j}(Y, Y - 2), by the sum of PUB_{j}(Y - 1) and PUB_{j}(Y - 2). This is the ISI or Garfield impact factor of the journal J for the year Y.

As a mathematical formula this is:

\[
2. \frac{CIT(Y, Y - 1) + CIT(Y, Y - 2)}{PUB(Y - 1) + PUB(Y - 2)}
\]

ISI defines the so-called immediacy index in the year Y as the number of citations obtained during the year of publication, divided by the number of publications. This is:

\[
3. \frac{CIT(Y)}{PUB(Y)}
\]

Actually, formulae 2 and 3 are biased in favor of “immediate” (i.e., short-term) citations. It is clear that 2 can easily be generalized to include more than two years. This leads to a generalized (n year) synchronous impact factor, denoted as IF(Y, n) (Rousseau, 1988), where now citations and publications over n years are taken into account (the exact formula, equation 4, is presented in the Appendix).

If it is clear from the context which year is meant, or if the exact year does not matter, one simply writes IF(n). Hence, ISI’s or Garfield’s impact factor is IF(2). ISI’s five-year impact factors are denoted as IF(5). All synchronous impact factors, however, suffer from the same problem: They mix different publication years. This practice, however, should not be followed in research evaluation studies. Indeed, the more aspects (in this case the publication year) are kept constant the better. Consequently, a diachronous impact factor, denoted as IMP, keeping the year of publication fixed (see Appendix for a precise formulation) is the preferred index for evaluation studies by the Centre for Science and Technology studies (Moed, Frankfort, & van Raan, 1985; de Bruin et al., 1993; van Raan, 2000). In my LUC evaluation studies (Rousseau, 1995, 1998a, 1998b), I used IMP with a four-year citation window. For a description of the difference between synchronous and diachronous impact factors and their use in research evaluation, the reader is referred to Ingwersen et al. (2001).

Obviously, for a librarian, the long-term impact (perhaps ten years) is of considerable more importance than the short-term (two-year) impact of a journal. Using different generalized impact factors, or different windows, allows one to compare the long-term versus the short-term journal impact. Garfield (1998) performed such an investigation. He found that some journals, such as Cell, The New England Journal of Medicine, Proceedings of the National Academy of Sciences, Nature, and Science, always had a high impact,
whatever the period (two, seven, or fifteen years). Other journals moved up or down significantly. Letters journals in particular suffered considerable downward changes in ranking.

Until now the journal for which the impact was calculated has been assumed to be a member of the pool. This leads one to question how to measure the impact of a journal that is not in the pool (e.g., a non-ISI journal). This will be explained for the ISI impact factor, equation 2; then, comments will be given on the diachronous impact factor (equation 5, see Appendix).

In order to calculate an analogue of the ISI impact factor for a non-ISI journal, one simply adds this journal to the pool of ISI source journals. One determines how often this particular journal is cited by ISI journals (during the period under investigation) and adds the number of times the journal cites itself. Then one simply divides by the number of articles published by the non-ISI journal (Spaventi et al., 1979; Sen, Karanjai, & Munshi, 1989; Stegmann, 1997, 1999). Although this is a simple procedure, there are two caveats. First, ISI always includes journal self-citations, but for these "constructed impact factors" this is not done. For journal evaluation purposes, it may indeed be more appropriate to remove journal self-citations for ISI-covered journals as well (Stegmann, 1997). Second, if this new impact factor is used to compare the non-ISI journal with ISI-journals, the ISI-journals' impact factor must also be recomputed, because the pool of journals has changed.

In the case of the diachronous impact factor, the method (and the caveats) are the same. There is, however, one important benefit here. It becomes possible now to calculate the (diachronous) impact of a book containing conference proceedings or contributions written by different authors. This has been done for *Informetrics* 87/88 (Rousseau, 1997a). Besides the obvious benefits for research evaluation, this fact is also interesting from a theoretical point of view. Indeed, one can even determine a volume, issue, or section diachronous impact factor, leading to a possibly finer grained statistical study of the visibility and impact of a journal.

Although the impact factor is a size-independent measure (or at least a size-limited one), since it is defined as a ratio, with the number of publications in the denominator, it suffers from other limitations. According to Pinski & Narin (1976), the most important drawback of the "traditional" impact factor(s) is the fact that citations are not weighted. All citations are counted as equally important, regardless of the citing journal. To remedy this limitation (and related ones) Pinski & Narin (1976) proposed a new weighted measure for journals. Unfortunately, this measure is seldom used for journal evaluations. Most evaluators stick to some form of the traditional impact factor. Yet, the Pinski-Narin measure inspired the makers of the Internet search engine Google to take the strength of hyperlinks into account for their search output-ranking algorithm (Brin & Page, 1998; Kleinberg, 1999).
Meaning of Self-cited and Self-citing Rates

The self-citing rate of a journal relates a journal's self-citations to the total number of references it gives. The self-cited rate relates a journal's self-citations to the number of times it is cited by all journals in the database. A high self-cited rate is an indicator of a journal's low visibility. A high self-citing rate is an indicator of the isolation of the field covered by the journal (Egghe & Rousseau, 1990). The self-cited (SCD) and self-citing (SCG) rates of a journal over a fixed period are calculated as follows:

If A denotes the number of references in journal J to journal J; B denotes the total number of citations received by journal J; and C denotes the total number of references in journal J, then

\[ SCD = \frac{A}{B} \quad SCG = \frac{A}{C} \]

An interesting (and little known) indicator is the so-called popularity factor of journal J (Yanovsky, 1981): This is the ratio of the number of journals citing (in a particular period) journal J, over the number of journals cited by J. It tells us something about whether the journal exports knowledge (ratio larger than one) or rather imports knowledge (ratio smaller than one). For those willing to evaluate journals by a whole battery of indicators, this is certainly one that deserves inclusion.

The Basic Citation Model and Its Consequences

Recall that a citation curve is a curve showing the number of citations received by a source (usually a journal, but it can also be an author, institute, or country) over a certain period. It is generally agreed that citation curves can be modeled as unimodal graphs, having a mode at the year two (i.e., two years later than the publication of the journal) or later. This is in accordance with Price’s theory on the immediacy effect (Price, 1970): The number of references to literature of a specific age rises until the cited literature is two or three years older than the citing literature, and then falls off gradually. At the mode the curve levels off, so that the number of citations obtained three years after the publication of the article—CIT(Y, Y - 3)—is larger than the average of the number of citations received one and two years after the publication of the article. Wouters (1999, p. 176) offers a nice real-world example of this phenomenon. Of course, it is well known that there are exceptions to this model. This often happens in very dynamic fields, such as biomedicine. Another well-known exception is the self-citation curve of a journal (Rousseau, 1999).

For this basic model it is further assumed that the number of publications does not decrease in time. This means that PUB(Y - 3) = PUB(Y - 2) = PUB(Y - 1), because, for example, PUB(Y - 2) denotes the number of items published two years before year Y, while PUB(Y - 3) denotes the number of articles published three years before year Y. The assumption that sources
(e.g., journals) do not decrease their production over time is a very natural one. Indeed journals, and certainly successful ones, generally increase the number of articles they publish (Rousseau & Van Hooydonk, 1996).

Rousseau et al. (2001) shows that IF(3), the synchronous impact factor calculated over a three-year period, is, in the basic model, always larger than IF(2), the "standard" impact factor.

From the literature, it is known that the basic model can be described by certain statistical distributions, such as the lognormal or the Weibull distribution. Using realistic parameters for these distributions, one can show that it follows from the shape of these curves that the three-year synchronous impact factor is always larger than the two-year one—IF(3) > IF(2). This has been done in Rousseau (1993). The basic model, and, in particular, its consequences concerning the synchronous impact factor, were confirmed by Rousseau (1988) for mathematics journals, and for a random sample of journals in ISI's database by Dierick & Rousseau (1988). Other studies related to the basic model were published by Rao (1973) and Nakamoto (1988). A recent investigation by Rousseau et al. (2001) using the Chinese Science Citation Database did not confirm the basic model.

**Electronic Journals**

The calculation of impact factors for printed journals or for online journals (i.e., e-journals) is exactly the same. Of course, besides impact, both kinds of journals have specific indicators. Subscription data are not meaningful for free e-journals, while counting links from Web sites or other e-journals to a particular e-journal is a typical aspect of e-journal evaluation.

One of the many criticisms of citation counts as an indicator for use (or visibility) is the fact that they only measure a special kind of use. They offer no information on reading, browsing, or other forms of use. For e-journals, though, it is possible to collect use data on a finer scale. One can not only count how many persons visit a journal's site, but one can collect viewers' data per article. This corresponds roughly to measuring the number of times a printed article is examined in a library (maybe several times by the same person). If this electronic article does not only exist in HTML format, but also in a complete downloadable PDF or PostScript format (as is often the case), then one can also count the number of download operations. This distinguishes "browsers" or occasional visitors from persons who are genuinely interested in the article. Finally, one can count the number of links made to this article. This corresponds to an electronic citation (sometimes called, with a pun, a sitation (Rousseau, 1997b)). Note that some e-journals, such as *Conservation Ecology* (Holling, 1999), already collect some of these data. Hence, this yields three visibility indicators for articles in e-journals: The number of visits to the article's page, the number of downloads, and the number of links (sitations). This leads to an appreciable increase of usage information with respect to citation counts that,
however, would continue to play their role as another kind of visibility or use indicator. Admittedly, there are, at the moment, some problems with this approach. Some people download (via the "save as" option in popular browsers) or directly print the HTML version. However, downloading a complete article in this way requires that one saves different objects (text, graphs, pictures) separately, which is not handy. Further, printing the HTML file usually leads to a poorer quality copy than that obtained by printing the PDF or PS version. Hence, for these reasons, download counts would miss only a small percentage of all interested scientists.

The announcement of the publication of a paper on the Web, by a news-group or another alerting service, may lead to an enormous increase in the hit rate for this paper. This effect has been termed the Slashdot effect (Adler, 1999). Similarly, a catchy phrase in the title of a Web-based article or a site is probably even more effective in generating traffic to that paper or site. Hence, a "catchy phrase effect" is predicted for Web sites and articles.

Yet, notwithstanding a "slashdot or catchy phrase effect" for separate articles or sites, e-journals themselves have, until now, not been able to generate high impact factors (Harter, 1998).

RANKING JOURNALS: THE MEANING OF A RANK

Impact factors, such as those published in the JCR, lead to a global ranking of journals. It is, however, clear at a glance that the top of this general list is dominated by certain types and fields: Multidisciplinary and review journals and journals in biomedicine are obviously at an advantage with respect to journals in engineering or the library and information sciences. Indeed, such general rankings exhibit an inherent bias against journals from small fields. Even within fields, rankings are often heavily influenced by the uneven impact of subfields on the broader field.

Consequently, ISI has devised a field classification scheme and journal rankings can also be viewed per subfield (subject category listings). The idea to devise a "disciplinary impact factor" dates already from 1978 (Hirst) and is regularly taken up again. Sometimes field rankings use the whole database as citation pool, sometimes only journals in the field are considered to be sources of citations. Both approaches have positive and negative aspects. In the second case, there is a clear discrimination of journals that try to act as a bridge between several subdomains, or between the applied and the basic side of a discipline. In the first case, it is possible that a journal receives more citations from outside the field than from inside, and perhaps that too is not always desirable. Again, trying to use both approaches (if possible) is the appropriate way to proceed.

As mentioned before, there are significant differences in the citation potentials of different scientific fields, that is, in the maximum number of times any given article—and, hence, also any journal—will be cited in its lifetime. It is clear that the number of research workers in the field is an impor-
tant factor here. Yet, Garfield (1979) claims that the major determinant of these citation potentials is the average number of references per article.

**What Is the Meaning of a Rank?**

Lists of ranked journals (ranked according to, for example, impact factor) are said to help users to identify sources with significant contributions (Todorov & Glänzel, 1988). Yet rankings of journals according to the number of citations received or the impact factor are only meaningful as long as fluctuations reflect a real rise or drop in the importance or influence of the journal, and is not only the result of noise or of a purely random process. In order to account for the random effect on citation measures, Schubert & Glänzel (1983) devised a method for estimating the standard error of mean citation rates per publication and applied this method to find confidence intervals for the impact factor. Nieuwenhuysen & Rousseau (1988) devised a “quick and easy” method to find a lower bound on the size of fluctuations of the impact factor. As there are many more journals with a low impact factor than journals with a high one, rankings for the low impact ones are less stable than for the high impact ones. Table 1 (a hypothetical example) illustrates the influence of fluctuations on a journal’s impact ranking.

It suggests that, for high impact journals, noise and fluctuations have only a small influence on the impact, and do not lead to any change in ranking. For low impact journals, on the other hand, noise and random effects may lead to a considerable change in ranking (i.e., it is possible that journal E actually ranks third and not fifth). This example agrees with McGrath’s observation (1993) that rankings of anything are often unreliable, particularly if those ranks are based on data with large variability. Consequently, adjacent values of data, when ranked, are often not significantly different.

Different types of articles lead to different citation potentials. This ef-

<table>
<thead>
<tr>
<th>Journals</th>
<th># Citations</th>
<th># Publications</th>
<th>Rank</th>
<th>High Impact</th>
<th>Lowest Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100</td>
<td>20</td>
<td>1</td>
<td>104/20</td>
<td>96/20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>= 5.20</td>
<td>= 4.80</td>
</tr>
<tr>
<td>B</td>
<td>50</td>
<td>20</td>
<td>2</td>
<td>54/20</td>
<td>46/20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>= 2.70</td>
<td>= 2.30</td>
</tr>
<tr>
<td>C</td>
<td>22</td>
<td>20</td>
<td>3</td>
<td>25/20</td>
<td>19/20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>= 1.25</td>
<td>= 0.95</td>
</tr>
<tr>
<td>D</td>
<td>20</td>
<td>20</td>
<td>4</td>
<td>23/20</td>
<td>17/20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>= 1.15</td>
<td>= 0.85</td>
</tr>
<tr>
<td>E</td>
<td>18</td>
<td>20</td>
<td>5</td>
<td>21/20</td>
<td>15/20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>= 1.05</td>
<td>= 0.75</td>
</tr>
</tbody>
</table>
fect leaks down to the journal level if journals "specialize" in certain types of articles. Besides the possible effect of letters to the editor, due to a wrong methodology (Moed & van Leeuwen, 1996), Peritz (1983) showed that, at least in sociology, methodological papers are more cited than theoretical or empirical ones. Rousseau & Van Hooydonk (1996) clearly showed that the impact factors of review journals are much higher than those of "normal" journals, while the impact factors of translations are much lower. In general, they found that the more articles a (normal) journal publishes the higher its impact factor.

**Bias?**

ISI's database and hence all measures derived from it are often accused of being biased. They are said to be biased in favor of American journals, in favor of English language publications, or in favor of certain fields (mainly basic science), etc. This is probably true to some extent, but until a scientifically valid definition of bias is given (Garfield, 1997), it is impossible to say to what extent this bias is inherent in the scientific community as a whole, or in the way American scientists (the largest community) behave, or is due to commercial decisions of ISI. It is true, though, as stated by Spinak (1995, p. 353), that research processes are not "objective and neutral" but are part of a social milieu, and, as a result, can vary from one society to another. Using ISI's products as the only standard would reduce evaluation studies to the North American standard, which is not necessarily that of other communities (again this problem is more severe in the social sciences and the humanities than in the sciences). Local citation indices, such as the Chinese Science Citation Database (Jin & Wang, 1999) and the Chinese Scientific and Technical Papers and Citations (CSTPC) database, may provide a solution to this problem.

As stated above, an impact factor is always calculated with respect to a pool of journals. So it is a legitimate question to ask what would happen if ISI covered more or other journals? What if ISI or another organization had started with an initial set of French, Chinese, or Spanish language journals? Would this have led to a different pool of international journals (Rousseau & Spinak, 1996)? Nothing can be stated with certainty, of course, but the question is worth investigating. To some extent, this challenge has been taken up by Leo Egghe, who, in two articles, (Egghe, 1998, 1999) studied limiting properties of a stochastic process describing the evolution of core collections, including the quality of the original set of source journals (Egghe, 1999).

It is clear that the fact of whether a journal is included in the ISI database or not may have a profound impact on its visibility, and hence on its standard impact factor. The inclusion of journal self-citations plays an important role here (Gómez et al., 1997), as some journals derive a large part of their impact factor from self-citations.
Although complaints about bias in citation-based measures continue to be heard, using prestige rankings by peers does not offer a solution, as these are certainly biased. Christenson & Sigelman (1985) found that scholarly journals in sociology and political sciences tend to establish reputations that endure in spite of what they merit. Once a journal has been placed on a discipline's prestige ladder, it tends to retain its place because its reputation is accepted at face value. Such journals are not re-evaluated in the light of changing circumstances. Comparing prestige scores with impact scores showed that good and bad reputations tend to be exaggerations of what impact scores suggest are merited. This clearly is a form of the Matthew effect (Merton, 1968): Already famous persons (or journals) receive more credit than they actually deserve, while recognition of less prestigious scientists (or journals) is withheld. The Matthew effect derives its name from the following quote from the Gospel according to St. Matthew:

For unto everyone that hath shall be given, and he shall have abundance; but from him that hath not shall be taken away even that which he hath. (25:29)

Bonitz, Bruckner, & Scharnhorst (1997, 1999) studied the Matthew effect for countries. They found that:

Few countries with high expectations [i.e. expected number of citations, based on journal impact factors] receive more citations than expected while many countries with low expectations receive fewer citations than expected. (1999, p. 362)

This redistribution effect originates in a relatively small number of journals, headed by *Nature, Physical Review B, Science,* and *Physical Review Letters.* Countries such as China, the former Soviet Union, and Nigeria are among the greatest losers.

**USE OF THE JOURNAL IMPACT IN EVALUATION STUDIES**

Quality journals in science generally contain coherent sets of articles, both in contents and in professional standards. This coherence stems from the fact that most journals are nowadays specialized in relatively narrow subdisciplines and their gatekeepers, that is, editors and referees, share views on questions like relevance, validity, and quality with the invisible college to which they belong (Schubert & Braun, 1993). This is the main reason why journals can play a legitimate role in evaluation studies (de Bruin et al., 1993; Spruyt, de Bruin, & Moed, 1996).

When gauging the impact of research groups, comparisons are made with their peers. The two most interesting indicators are the ratio of the average of the group's citations (per article) with the average of the journals in which they have published, and the ratio of the average of the group's citations with the average of the field (or fields) in which they are active (de Bruin et al., 1993; Rousseau, 1998a, 1998b). When calculating
the impact of a field, two approaches are possible: Either one just takes the average of the impact factors of all journals in the field (this is called the average impact of this set of journals), or one calculates a global average (Egghe & Rousseau, 1996). The latter is the better approach. The difference between these two approaches is shown—mathematically—as follows. If $C_j$ denotes the number of citations (over a certain period) of journal $j$, and if $P_j$ denotes the number of publications in journal $j$, then $I_j$ denotes the impact of journal $j$ (citations per publication). The average impact factor is then defined as:

$$5. \text{AIF} = \frac{1}{n} \sum_{j=1}^{n} \frac{C_j}{P_j} = \frac{1}{n} \sum_{j=1}^{n} I_j$$

The global impact, on the other hand, is calculated as:

$$6. \text{GIF} = \frac{1}{n} \sum_{j=1}^{n} \frac{C_j}{P_j} = \frac{\mu_C}{\mu_P}$$

where $\mu_C$ and $\mu_P$ denote the mean number of citations and the mean number of publications. Hence, the first one is an average of quotients, while the second one is a quotient of averages. An example (Table 2), will illustrate the numerical difference between these two approaches.

The global impact of the meta-journal consisting of the four journals A, B, C, and D is 1.96, while the average of these journals' impact is only 1.35. This difference is due to the fact that (here) the journals with the lowest impact publish the lower number of articles.

### Problems with Using Impact as a Quality Measure

It is clear that there are problems with using impact as a quality measure: These two notions clearly cannot be substituted for each other. Some of these problems were discussed in the previous sections. They are briefly recalled here and some other ones are highlighted.

Some fields are very useful for science as a whole, but by their particu-

### Table 2. Artificial Meta-journal and the Calculation of the Average Impact.

<table>
<thead>
<tr>
<th>Journal</th>
<th># of Articles</th>
<th># of Citations</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>20</td>
<td>8</td>
<td>0.40</td>
</tr>
<tr>
<td>B</td>
<td>20</td>
<td>10</td>
<td>0.50</td>
</tr>
<tr>
<td>C</td>
<td>100</td>
<td>250</td>
<td>2.50</td>
</tr>
<tr>
<td>D</td>
<td>200</td>
<td>400</td>
<td>2.00</td>
</tr>
<tr>
<td>Meta-journal</td>
<td>340</td>
<td>668</td>
<td>1.96 Global Impact</td>
</tr>
</tbody>
</table>

1.35 Average Impact
lar nature, cannot be cited much. If the impact factor (or similar measures) would become the main determinant to judge journal quality this could eliminate whole subfields, and undermine the health of many others. A case in point is basic taxonomy (Valdecasas, Castroviejo, & Marcus, 2000). Doing high-quality work in taxonomy is expensive and time consuming. Good taxonomy articles have continued to be cited for more than a century after their publication. Moreover, taxonomy lies at the basis of all biodiversity studies. Yet, during the short period used to calculate impact factors they will attract few or no citations. This, however, tells us nothing about the quality of taxonomy journals. Similar cases can be made for other fields of science: An enormous gap lies between popular research areas (with many thousands of authors, papers, and citations) and less popular ones (Schoonbaert & Roelants, 1998). Neglecting these less popular fields because of citation counts would lead to an impoverishment of science.

There is also the following technical problem: How should multidisciplinary journals be evaluated? Specifically, how are articles published in these journals treated? It would be best if individual articles were assigned to the proper category and its citations compared with the citation results of that category. This means that one needs a (preferably automatic) method to assign articles to categories, and to delineate categories. This assignment problem of individual articles has been studied, for example, in de Bruin & Moed (1993) and Glanzel, Schubert, & Czerwon (1999).

Finally, with an eye to future developments, I would like to make the following remark concerning the future of journal impact factors. Although journals will always consist of articles, and journal impact will always be a kind of "average" measure of its articles' impact, it is clear that for electronic journals the emphasis will be much more on the individual article, and less on the journal. This trend will probably erode the value given to journal impact factors.

A review of the use of bibliometric techniques for research and institutional evaluation can be found in Russell & Rousseau (in print).

**Conclusion**

The quality of a journal is a multifaceted notion. Journals may be evaluated for different purposes, and the results of such evaluation exercises can be quite different, depending on the used indicator(s). The impact factor, in one of its versions, is probably the most used indicator when it comes to gauging the visibility of a journal on the research front. Generalized impact factors, over longer periods than the traditional two-year period, are better indicators for the long-term value of a journal. The diachronous approach is strongly favored.

As with all evaluation studies, care must be exercised when considering journal impact factors as an indicator of quality. It seems best to use a
whole battery of indicators (including several impact factors) and to change
this group of indicators depending on the purpose of the evaluation study.
Moreover, in the case of journal evaluation, it should be pointed out that
calculating impact factors for one particular year is not very instructive.
Trend analyses of impact factors over several years have much more value
for the evaluation of journals (in the same field, of the same type!).

Journal impact and scores of research groups with respect to the im-
pact of the journals used as publication outlets are just two elements in
evaluation studies. Ranking projects, institutes, or research groups on the
basis of impact factors only makes sense for scientists working in the same
field. Indeed, evaluation, whether of journals, scientists, or institutes, is only
a means to an end, not a goal in itself.

We hope that more people with a library and information sciences
degree will be involved in journal evaluation studies, not only with the aim
of finding an optimal set of journals for local use, but also when it comes
to institutional evaluation exercises. Consequences are too heavy to leave
the job to computer scientists or alumni of a management school. A librar-
ian's daily task involves handling, buying, canceling, copying, binding, and
discussing journals. They have the expertise to be part of an evaluation
team, at least when it comes to having a well-founded opinion on the quali-
ty of journals. The author hopes this article helps them in better under-
standing the mathematical technicalities.

Finally, the subject of journal evaluation and the use of journals in re-
search evaluation exercises have attracted scores of empirical articles. Yet,
relatively few model-based approaches can be found in the literature. Perhaps
the time is ripe to make a "grant model" that can be used to explain observed
journal citation scores, and hence their role in institutional evaluations.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the support of issue editor, Bill McGrath,
and of my colleague M. Dekeyser.

APPENDIX: MATHEMATICAL FORMULATIONS OF THE
SYNCHRONOUS AND DIACHRONOUS IMPACT FACTORS

The n-year synchronous impact factor is defined as:

\[ IF(Y, n) = \frac{\sum_{i=1}^{n} CIT(Y, Y - i)}{\sum_{j=1}^{n} PUB(Y - j)} \]

Taking \( n = 2 \) yields the standard, or Garfield, impact factor. The n-year di-
achronous impact factor for the year \( Y \) is defined as:
8. \[ IMP(n) = \frac{\sum_{i=k}^{n} CIT(Y + i, Y)}{PUB(Y)} \]

with \( k = 0 \) or 1. Sometimes one includes the publication year \( (k = 0) \), sometimes one does not \( (k = 1) \).

**GLOSSARY OF TERMS**

*average impact factor*
The average impact factor of a group of journals (or meta-journal), as opposed to the global impact factor. See text for a mathematical formulation.

*basic citation model*
A citation model. The number of citations to a fixed journal issue is assumed to reach a top quickly (after two or three years) and then start a slow decline. During the first period, when the journal becomes “better” with time, the Burgundy effect (getting better with age) prevails. The basic citation model also assumes that the number of publications in a journal does not decline over time.

*catchy phrase effect*
Term to denote that articles with a special or trendy phrase in the title attract more attention than other ones, especially on the Internet.

*Chinese Science Citation Database (CSCD)*
Database compiled by the Documentation and Information Center of the Chinese Academy of Sciences (DICCAS). It has a similar purpose as the Science Citation Index, but uses only Chinese sources. Source of the Chinese Scientometric Indicators.

*Chinese Scientific and Technical Papers and Citations (CSTPC)*
Database compiled by the Institute of Scientific and Technical Information of China (ISTIC). It has a similar purpose to the Science Citation Index, but uses only Chinese sources. It is the source of the Chinese S&T Journal Citation Reports.

*citation pool*
The set of documents whose references are used in counting citations.

*diachronous impact factors (IMP)*
A group of impact factors using citations received in different years, but referring to one specific publication year. See Appendix for an exact mathematical formulation.

*Garfield impact factor*
Popular name for the synchronous impact factor referring to a two-year citation window.
**global impact factor**
The impact factor calculated for a group of journals considered as one whole (meta-journal). See text for a mathematical formulation.

**HTML format**
HyperText Markup Language (HTML) is a high-level programming language used to write hypertext documents with corresponding text and hyperlinks. It allows nonprogrammers to design Web pages by specifying their structure and content, but leaves the detailed presentation and extraction of information to the client's Web browser.

**immediacy index**
An indicator used by ISI to determine the impact of a journal’s publications during the year of publication.

**indicator**
Statistic used to determine the state of an activity. This is usually an economic activity, but the term is used in bibliometric studies to study science or information-related entities, such as journals, research output of institutes, Web-activity, and so on.

**Institute of Scientific Information (ISI)**
ISI, the company founded by Eugene Garfield, is now a Thomson Scientific Company, and part of The Thomson Corporation. The company, through its Science Citation Index, the Web of Science, and related products, indexes the most influential scientific and technical journals from 1945 onwards. ISI captures all bibliographic information including the citations or references that are part of a peer-reviewed article or item. ISI’s databases may be used for information retrieval and for science evaluation purposes.

**ISI impact factor**
See Garfield impact factor.

**Journal Citation Reports (JCR)**
The Journal Citation Reports, a product of ISI, provides quantitative measures for ranking, evaluating, categorizing, and comparing journals. The impact factor is one of these.

**journal impact factor**
This is a measure giving the relative number of citations received by a journal. There exist several different versions (see synchronous and diachronous impact factor) which are all useful in clarifying the significance of absolute citation frequencies.

**journal self-cited rate (SCD-rate)**
The self-cited rate relates a journal’s self-citations to the number of times it is cited by all journals in the citation pool. See text for a mathematical description of the SCD rate.
journal self-citing rate (SCG-rate)
The self-citing rate of a journal relates a journal's self-citations to the total number of references it gives. See text for a mathematical description of the SCG rate.

Matthew effect
The term refers to the observation that already famous people (or journals) receive more credit than they actually deserve, while recognition of less prestigious scientists (or journals) is withheld. The term derives its name from the Gospel according to St. Matthew.

meta-journal
A group of journals considered for evaluation (or other) purposes as one large journal.

PDF format
Adobe® Portable Document Format (PDF) is a universal file format that preserves all of the fonts, formatting, colors, and graphics of any source document, regardless of the application and platform used to create it. PDF files are compact and can be shared, viewed, navigated, and easily printed.

popularity factor
The ratio of the number of journals citing a journal (during a particular period) over the number of journals cited by this journal.

PostScript (PS) format
PostScript is a device-independent high-level programming language for describing the appearance of text and graphics on a printed page.

Science Citation index (SCI)
The ISI Science Citation Index provides access to current and retrospective bibliographic information, author abstracts, and cited references found in 3,500 leading scientific and technical journals covering more than 150 disciplines. The Science Citation Index Expanded format available through the Web of Science and the online version, SciSearch, covers more than 5,700 journals.

standard impact factor
See Garfield impact factor.

synchronous impact factors (IF)
A group of impact factors using citations received in the same year, but referring to different publication years. See Appendix for an exact mathematical formulation.

REFERENCES


Garfield, E. (1997). A statistically valid definition of bias is needed to determine whether the Science Citation Index discriminates against third world journals. *Current Science*, 73(8), 639-641.


ABSTRACT

The Matthew Effect for Countries (MEC) consists of the systematic deviation in the number of actual (observed) citations from the number of expected citations: A few countries, expecting a high impact (i.e., a high number of cites per paper) receive a surplus of citations, while the majority of countries, expecting a lower impact, lose citations.

The MEC is characterized by numerous facets, but two are the most impressive. The first is the possibility of ranking the science nations by their overall efficiency of scientific performance, thus making the MEC attractive for science policy. The second is the concentration of the MEC in a small number of scientific journals which happen to be the most competitive markets for scientific papers and, therefore, are of interest to librarians as well as scientists.

First, by using an appropriate measure for the above-mentioned deviation of the observed from the expected citation rate one can bring the countries under investigation into a rank order, which is almost stable over time and independent of the main scientific fields and the size (i.e., publication output) of the participating countries. Metaphorically speaking, this country rank distribution shows the extent to which a country is using its scientific talents. This is the first facet of the MEC.

The second facet appears when one studies the mechanism (i.e., microstructure) of the MEC. Every journal contributes to the MEC. The "atoms" of the MEC are redistributed citations, whose number turns out to be a new and sensitive indicator for any scientific journal. Bringing the journals into a rank order according to this indicator, one finds that only 144 journals out of 2,712 contain half of all redistributed citations, and thus...
account for half of the MEC. We give a list of these "Matthew core journals" (MCJ) together with a new typology relating the new indicator to the well-known ones, such as publication or citation numbers. It is our hypothesis that the MCJ are forums of the fiercest competition in science—the "Olympic games in science" proceed in this highest class of scientific journals.

INTRODUCTION

The Discovery of the Matthew Effect for Countries

It is often regretted that research papers, especially in the natural sciences, follow the stereotyped approach "introduction-method-results-conclusions," while the circumstances under which the authors achieved their results remain hidden. In contrast, this paper starts with a historical survey of the research lines we have followed since 1990. Impatient readers may skip this introductory section.

The effect was detected in 1994. A eureka moment of the kind known from discoveries in the natural sciences encouraged us to call what we could see on the computer screen "Matthew effect"—later, more precisely, "Matthew effect for countries" (MEC) (Bonitz, Bruckner, & Scharnhorst, 1995a). This event was no accident, it was preceded by long years of investigations into the structure of national science systems (Bonitz, Bruckner, & Scharnhorst, 1991, 1992, 1993). For instance, a hypothesis of the existence of two worlds in science—a "Right World" and a "Left World"—was a forerunner of the MEC (Bonitz, Bruckner, & Scharnhorst, 1995a, 1995b, 1996a, 1996b). Furthermore, if we hadn't had in the backs of our minds that there was a "Matthew effect in science," as introduced by the eminent scholar R. K. Merton into the sociology of science (Merton, 1968), we never would have dared name our phenomenon "Matthew effect."

In the first phase of our investigations, we studied the effect's time-stability, field-dependency, and its order of magnitude. The effect turned out to be stable over time, independent of scientific fields, and to have a small order of magnitude (Bonitz, Bruckner, & Scharnhorst, 1997). It is not an artifact. At this time, any speculations concerning the practical impact of our findings were beyond the scope of our considerations. Then, a measure for the effect was developed—"Matthew-Index"—the value of which must be computed for each country (Bonitz, Bruckner, & Scharnhorst, 1999a). Countries can be ranked according to this measure, and one can easily see how a certain country is affected by the MEC. We found our country ranking method more expressive than a relational charts representation developed by other researchers (Braun, Glänzel, & Schubert, 1989).

At the beginning, we were taking for granted the public understanding of the Gospel parable described in St. Matthew 25:14–30, and of Merton's Matthew effect in science. We declared, that the Right World (citation rich) countries were "taking away" citations from the Left World
(citation poor) countries (Bonitz, Bruckner, & Scharnhorst, 1995a). It was some time before we grasped the very essence of the famous Biblical parable and then found it surprisingly compatible with our findings (Bonitz, 1997). This fact helped us in treating the "meaning" of the country rank distribution. It enabled us to understand whether it reflects a "discrimination against certain countries," the "quality of national science systems," the "usage of scientific talents," or the "efficiency of competition in science."

Next, we looked for the mechanisms underlying the country rank distribution for the "microstructure of the MEC." It became clear that we had to shift from the "country side" of the MEC to its "journal side." All of the nearly 3,000 journals in the database were expected to (more or less) contribute to the MEC. It seemed evident that the journals are like molecules—molecules that combine to produce the entity we call the MEC. We could not, however, presuppose that these molecules themselves are composed of different sorts of "atoms" (i.e., citations given to the journals), and that only one of these sorts is responsible for producing the MEC. This special sort, which had never before been described in journal investigations, we called "redistributed citations" or "Matthew citations." Our investigations into the behaviour and the properties of the Matthew citations yielded surprising results. The Matthew citations have a very skewed distribution over all journals: Most of the Matthew citations are concentrated in few journals, with 144 journals containing half of the Matthew citations.

These lucky journals also play a highly distinguished role in scientific communication. We proved this hypothesis by trying to falsify it. However, journal ranking by number of publications, by number of citations, by number of participating countries, and by impact factor, failed to yield journal rank distributions highly correlated with the distribution by Matthew citations. Thus, a special role of the "Matthew core journals" (MCJ), as we called them, seemed to be established.

How should this new type of scientific journal be characterized? The journals with the highest reputation? The most important journals in science? The journals with the highest quality articles? If we would choose one of these features we could easily run into boundary problems by having to distinguish between journals of high and low reputation, between those of high and low importance, between high and low quality papers. The appearance of the Matthew citations offered a new possibility: Our proposal is that the number of Matthew citations in a journal reflects the degree of scientific competition going on within its pages. Those competing are scientists, scientific institutions, and countries in science. MCJ are thus the most competitive markets in science. They mirror the experience of other competitive areas, such as the economy or sports, which supports our metaphor that "the Olympic games in science" proceed in the highest class of scientific journals—in the MCJ. Another metaphorical filiation appears, reaching from the MEC to the treatment of the Parable of Talents in St. Matthew:
Not “the rich are becoming richer and the poor poorer,” but those who are most effectively competing, irrespective of the amount of talent entrusted to them, will reach the kingdom of heaven (i.e., science).

The Parable of Talents

The knowledge of the parable’s full text helped us to understand the nature of our findings. St. Matthew 25:14–30:

For the kingdom of heaven is as a man travelling into a far country, who called his own servants, and delivered unto them his goods. And unto one he gave five talents, to another two, and to another one; to every man according to his several ability; and straight way took his journey. Then he that had received the five talents went and traded with the same, and made them other five talents. And likewise he that had received two, he also gained other two. But he that had received one went and digged in the earth, and hid his lord’s money. After a long time the lord of those servants cometh, and reckoneth with them. And so he that had received five talents came and brought other five talents, saying, Lord, thou deliveredst unto me five talents; behold, I have gained beside them five talents more. His lord said unto him, Well done, thou good and faithful servant: thou hast been faithful over a few things, I will make thee ruler over many things; enter thou into the joy of thy lord. He also that had received two talents came and said, Lord, thou deliveredst unto me two talents; behold, I have gained two other talents beside them. His lord said unto him, Well done, good and faithful servant; thou hast been faithful over a few things, I will make thee ruler over many things; enter thou into the joy of thy lord. Then he which had received the one talent came and said, Lord, I knew thee that thou art an hard man, reaping where thou hast not sown, and gathering where thou hast not strawed: And I was afraid, and went and hid thy talent in the earth: lo, there thou hast that is thine. His lord answered and said unto him, Thou wicked and slothful servant, thou knewest that I reap where I sowed not, and gather where I have not strawed: Thou oughtest therefore to have put my money to the exchangers, and then at my coming I should have received mine own with usury. Take therefore the talent from him, and give it unto him which hath ten talents. For unto every one that hath shall be given, and he shall have abundance: but from him that has not shall be taken away even that which he hath. And cast ye the unprofitable servant into outer darkness: there shall be weeping and gnashing of teeth. (The Bible, 1993)

It is an open question, whether R. K. Merton, writing his well-known paper “The Matthew effect in science” (Merton, 1968) (see also the next section), had in mind the whole parable or only the verse “For unto every one that hath shall be given, and he shall have abundance: but from him that has not shall be taken away even that which he hath” (Merton, 1999). In actual fact, Merton quoted only this one verse. Thus, the bulk of subsequent papers citing him fully and exclusively relied on it. Everybody was convinced that Merton’s experimental data or observations, and so this verse, reflected the “Matthew effect in science.” Initially, so did we, the only difference being that we called “our” Matthew effect “Matthew effect for
countries” and could exactly measure it, while our forerunners could not. However, in measuring, we ran into many difficulties—difficulties that were only overcome by understanding the whole Parable of Talents, the essence of which is likely not “the rich are becoming richer, and the poor poorer,” but “the employment of your given talents is rewarded, and their neglect punished” (see Figure 1). To better explain, recently and fortunately, we became aware of a “New Living Translation” of the Bible, where Merton’s verse is translated in the following way: “To those who use well what they are given, even more will be given, and they will have an abundance. But from those who are unfaithful, even what little they have will be taken away” (St. Matthew 25:29, Holy Bible, 1997).

Merton’s Matthew Effect in Science
The material discussed in Merton’s insightful paper has so many dimensions, that it could hardly have elaborated its correspondence with a whole Biblical text. Moreover, the story of Merton’s Matthew effect in science was not finished with the publication of the “Science” paper in 1968. Twenty years later Merton “updated” it through another insightful paper (The Matthew effect in science, II), in which he included his thoughts about cumulative advantage and the symbolism of intellectual property (Merton, 1988). Thus, by no means could Merton be accused of treating the Matthew matter too simplistically. While he faced the difficulty that he could not measure the phenomena he observed at the microlevel of science (i.e., of the allocation of credit to scientists or scientific institutions), we were lucky, at the macrolevel, to observe a measurable effect. However, to explain what...

Figure 1. “To those who use well what they are given, even more will be given . . .” (Holy Bible, 1997, St. Matthew 25:16). Reprinted with permission of Sadifa Media Verlags GmbH.
we measure and observe, we nevertheless must go down to the microlevel again, and here we participate in the tremendous experience described in Merton’s work.

Very often an effect is something that happens against a certain expectation or model underlying this expectation. The effect then disappears when the model is improved; the observation is in accord with the expectation. However, the measurability of the effect is the pre-condition for investigating these interactions. The MEC fulfills this condition. The behaviour of the third servant in the parable deviates from the expected behavior, although his smaller abilities compared to the other servants were already taken into account.

COUNTRIES: THE FIRST FACE OF THE MEC

A Measure for the MEC: The Matthew-Index

When we construct for each of our forty-four countries a rank distribution plotting the observed value of its “impact” (or “citations per paper”), we achieve a skewed curve. That, however, has nothing to do with the Matthew effect. When we take our forty-four countries in the same rank order and plot for each the expected value of its “impact” (or “expected citations per paper”), we achieve another skewed curve that has also nothing to do with the Matthew effect. When we superimpose the two curves, they do not coincide. Instead, in the region of high impact, the “observed values” are, in most of the rank positions, systematically greater than the “expected values,” while in the region of low impact the “observed values” are, in nearly all rank positions, systematically smaller than the “expected values.” This effect we call the MEC. We introduce a convenient measure for the deviations—the “Matthew-Index.” This measure is positive in cases where the observed values exceed the expected values; it is negative in the opposite cases, when the expected values exceed the observed ones. (For details of the methodology see Appendix A.) When the countries are re-ranked according to the Matthew-Index, one gets Figure 2. In interpreting Figure 2, one should keep in mind that it does not explicitly show that the countries with a gain in citations (from Switzerland to Finland) have higher expectation values, and that the countries with citation losses (from PR China to Belgium) have lower expectation values. Neither does it show that the absolute values of the gains and/or losses may differ significantly from country to country, because the Matthew-Index gives relative values (in percent). For instance, the relative gain of Switzerland may be 14 percent against 7 percent in the case of Germany FR, but the absolute gain of Switzerland is only 2,000 for Switzerland but 4,000 for Germany FR. Likewise the gain of 4,000 citations for Germany (only 7 percent) has a very different impact from the loss of 4,000 citations for India, where it corresponds to -44 percent! Generally, it should be noted, that the size of a country (in publica-
tions) does not play a role in Figure 2: A small country like Sweden can belong to the “winners,” and large countries like India or Russia can belong to the “losers.”

*The Right World and the Left World in Science*

A rank order, due to its one-dimensionality, provokes immediate judgement: The top ranked are the “best,” all others are not as good. What is the rank number of my own country? Why is it not better? Obviously the method is wrong! Long before seeking explanations for the rank order of Figure 2, we called, for mere convenience, the “winner” countries “Right World countries,” and the “loser” countries “Left World countries.” The bars for the first point to the right, those for the second, to the left side. Figure 2 seems not to be chaotic; it seems to make sense. Obviously, the countries “going to the right” (see Figure 2) are also on the “right” track. But all these considerations are not an explanation of Figure 2. Even if we say that it reflects the MEC, we have to answer the simple question “What is the Matthew effect?”

We can, however, falsify from the beginning the most frequently generated hypotheses. “The rich are becoming richer, the poor poorer.” So Sweden is a rich country in science, and Russia is a poor country? Rich and poor in what respect? Or: “The Left World countries are discriminated against by the Right World countries.” So, Denmark discriminates against PR China? Why not the other way round? Or: “The language barrier puts non-English countries into the category of the Left World countries.” But why does India belong to this category? No doubt, there may be a component of discrimination, there may be a language barrier, but how essential are these and numerous other components we could think of, cultural, historical, geographical, economical, and political ones?

Our method is based on the Science Citation Index (SCI). If we consider the citing authors as experts in their fields, the SCI turns out to be the largest expert system of the world (Bonitz, 1990). This unique property of the SCI guarantees its high reliability when it is used, as in our case, for studies at a high macrolevel of science. Any hypothesis of a systematic discrimination of countries would be, therefore, a hypothesis against the whole community of scientists.

We knew that a well-founded explanation of the MEC could be achieved only when the micromechanisms underlying were investigated and understood. This is the task of the next section. However, we present here, in part, the conclusions of that section. After discovery of the “atoms” of the MEC, and after studying their “meaning” and function, we can conclude: The country rank distribution given in Figure 2 reflects the extent to which a country is using its scientific talents, or better, it reflects the efficiency of competition between the countries participating in the global enterprise “science.” The Right World countries generally compete more efficiently
Figure 2. Matthew Effect for Countries. A few countries are gaining surplus citations on a high level of impact, while the majority of countries are losing citations on a low level of impact. Matthew-Index = (obs - exp) + exp [%].
than the Left World countries. This efficiency is lowest for PR China and highest for Switzerland.

**Impact on Science Policy**

If the rank distribution in Figure 2 actually reflects what we claim it reflects—the national ability for competition in global science—then it should be of interest for science politicians of many countries. A lack of this ability obviously means the waste of national resources (Russia loses a quarter of its expected reward, India more than 40 percent). But improving the ability to compete does not necessarily mean increasing the resources. It can also be achieved by learning from the MEC.

**Journals: The Second Face of the MEC**

*Investigation of the MEC's Microstructure*

We mentioned above that the Matthew-Index, according to which the countries are ranked in Figure 2, can be computed for every country, when the numbers of the observed and of the expected citations are known. While the observed citations just have to be counted, the expected citations must be computed. The observed citations can, in principle, stem from any of the 2,712 journals in our journal sample, while the expected citations have to be derived from the numbers of papers in, and the impact factors of, the journals in which the countries publish. For a given journal, the national number of expected citations is \( \exp = (\text{number of national papers}) \cdot (\text{journal impact factor}) \). A journal impact factor is, roughly speaking, the number of the citations given in a certain time to all papers in the journal divided by the number of papers. An impact factor of 5 says that an “average” paper receives five citations, while an impact factor of 0.2 requires five articles to attract one citation. The journal impact factor tells how many citations an author can “expect” for his paper, provided it is of average quality. Journals with high impact factor seem to have a higher reputation than journals with low impact factor. For an understanding of what we call the microstructure of the MEC, one must be informed about what is going on in every journal. Some of the fundamentals are demonstrated in the next figure.

The upper graph of Figure 3 shows the national impacts for the journal *Nature*. The impact factor of this journal is 29, because the 7,983 papers received 231,749 citations. However, not a single country achieves 29 citations per average paper—a few countries are getting more than 29, most of the countries get less. Finland, for instance, receives only 5 citations, but Japan receives 38 citations per average paper. This behavior is typical for any scientific journal (with exception of the mono-national journals). There are always countries exceeding the journal impact, and other countries the national impact of which is below the journal impact value. It cannot be predicted whether a certain country in a certain journal will be on the “winning” side or on the “losing” side. The knowledge about the national im-
Figure 3. National Impact and Matthew Citations in a Scientific Journal.
impact in a journal could provide useful information for designing a national publication strategy; however, for merely practical reasons the scientific community retains the model of "the same impact factor for all." Comparison of the reality with this model provides new insight. At first, we learn that the MEC has its roots in this model. Second, at the order of magnitude of the deviation, we reach surprising conclusions on the very nature of the journals in science.

The lower graph of Figure 3 represents the countries that publish in *Nature* in the same order, but gives their gain or loss of citations with respect to their national impact factor in absolute numbers. So, the United Kingdom loses about 8,000 citations, while Germany FR gains 5,000. It is important to mention that, by the definition of the journal impact factor, the number of citations lost by the "losing" countries in a journal, is equal to the number of surplus citations gained by the "winning" countries of that journal. It seems to be a consequence of the model of "the same impact factor for all," that this number of citations is redistributed from left to right, from the "loser" to the "gainer" countries. We call these citations "redistributed citations" or "Matthew citations." The journal *Nature* has 33,901 Matthew citations, this number being the difference between the numbers of observed and expected citations on each side. The sign is negative at the left side and positive at the right side. Now we are prepared to understand the "mechanism" leading from the redistribution in the single journals to the MEC at the macrolevel. For every country and for all journals in which this country publishes, one has to sum up the numbers of Matthew citations, taking into account their positive or negative sign.

If the sum is positive, this country will belong to the Right World countries; if the sum is negative, it will belong to the Left World countries. Thus, the MEC is the result of the countrywise summing up of Matthew citations. Whether a country belongs to the "winners" or to the "losers" in a certain journal can by no means be predicted from the country rank distribution in Figure 2. For instance, the USA—a "winner" at the macrolevel—belongs to the "losers" in some journals, while Russia—a "loser" at the macrolevel—is a clear "winner" in certain journals. So one must take into account all journals in order to get the final country ranking of Figure 2.

**Matthew Citations: The Atoms of the MEC**

We find it appropriate to call the Matthew citations the "atoms of the MEC." Just as the atoms in the physical microworld build up our macroworld, the Matthew citations are responsible for the MEC. Only a small percentage of the citations that are received by a journal's papers are Matthew citations. In the case of *Nature* about 15 percent. How can we detect whether a "normal" citation is also a Matthew citation or not? Of course, there is no way, and there is no need. Matthew citations appear, when we apply the model "the same impact factor for all." They signal that something
more is going on than predicted by that too simple model. Their number can only be computed; no institution in science exists that, as the Lord in the parable, could actually redistribute citations. No simple mechanism is conceivable that produces Figure 3, upper graph, in the case of *Nature*, and quite another graph for the journal *Biochemistry*. The Matthew citations help us to refine our simple model. Moreover, they turn out to be a sensitive indicator for essential processes in the whole system of scientific communication.

**Journal Ranking**

Journals can be ranked by numerous parameters and indicators. Well-known is the ranking by journal size (number of papers), by recognition (number of achieved citations), by impact (number of citations per paper), or by “internationality” (number of participating countries). Correlations between the different rank distributions have been studied, power laws have been described for the size-recognition dependency. It seems that we know everything about the scientific journal in its proud 335-year history.

However, nobody has ever ranked scientific journals by their atoms of the MEC, by their number of Matthew citations, because this parameter came into being only when the microstructure of the MEC was investigated (Bonitz, Bruckner, & Scharnhorst, 1999b). When the 2,712 journals of our sample are ranked by their numbers of Matthew citations, the top journal is *Nature* (33,901), and the last ranking are 25 journals with zero Matthew citations, though among these 25 are 4 journals with so many papers that they even possess the status of a “publication core journal” (see definition below). The distribution is not linear but extremely skewed: Half of all Matthew citations are concentrated in the 144 first-ranking journals! We call these journals MCJ. So, when the Matthew citations are responsible for the MEC, then the 144 MCJ—only 5 percent of all journals—produce half of the effect.

**A New Type of Scientific Journal: The Matthew Core Journal**

So many types of scientific journals already exist (based on very different parameters, but also on the different journal functions) that the question is legitimate whether the MCJ can add an essential new feature to the whole picture. When we declare, in accordance with Garfield’s saying “A few account for the most” (Garfield, 1977, 1996), that the publication core journals account for half of the size of all journals, or that the citation core journals account for half of the recognition achieved by all journals, and that the participation core journals account for half of the internationality represented by all journals—then we say, of course, that the MCJ account for half of the MEC. But what is the MEC, not in our phenomenological definition, but in its nature? Everyone looking at the list of the MCJ (given in Appendix C) will admit that they are apparently of high “importance.” Are they all simultaneously publication, citation, and participation core jour-
nals? No, they are not. This can be shown by a new typology of the scientific journals that includes the "newcomers," the MJC (see Appendix B). This highlights something very specific about science, something that characterizes all scientific journals, but that particularly characterizes the MJC.

It is our hypothesis that one of the most essential features of science—competition—is reflected in a scientific journal by the citation redistribution phenomenon or the number of Matthew citations, and that the MJC are, therefore, the most competitive markets in the fields of their scientific papers. When we highlight 5 percent of all journals as the most competitive markets, this cannot mean that the "rest" of 95 percent of the journals should or could be neglected. The editors of these journals and the authors publishing in them must not feel they are being discriminated against or doing a useless job. Every journal has its place and its importance in the system of scientific communication. The many are a necessary condition for the functioning of the few. We think it can be helpful to be reminded of the world of sports. There, competition is one of the essential features, and the success of the best is guaranteed only by the existence of a broad national and international basis for the different teams. The "Olympic games in science" proceed in the highest class of science journals—the MJC.

**Impact on Scientists, Journal Editors, and Librarians**

It is always pleasant when one faces an overwhelming crowd of things and is offered a pre-selected core that makes decisions easy. When the core selection is well-founded, it can help to improve the functioning of the whole system of scientific communication. Scientists who have produced excellent results should know the MJC in their field and try to get published there. In doing so, they create the possibility of garnering many surplus citations, but they also take the risk—due to the high competition—to lose citations, a risk that has its source in an unusually high level of expectation. Journal editors also should be aware of the rank position of their journal. If it lies in the core, they can be proud, but they must not be disappointed if not. Our rank distribution of journals reflects competition, but there are plenty of journals fulfilling other important tasks, though they do not act as forums for competition, for instance, review journals. Librarians, who always have the problem of acquiring the best and least expensive journals at the same time, will surely profit from the list of journals ranked by the number of Matthew citations. At least the MJC should be present in any field represented in the library's journal collection.

**Conclusions**

The consequences of the newly discovered measurable MEC are two-fold. With the help of the Matthew-Index, a country rank distribution can be constructed to reflect how effectively each country is taking part in the competition in science. Half of the atoms of the MEC—the Matthew cita-
tions—produce half of the MEC and are concentrated in forums of the highest competition in science—in the MCJ. Science politicians as well as individual scientists, journal editors, and librarians might find these new results useful for their work.

ACKNOWLEDGEMENTS

First of all, I thank my colleagues and friends Andrea Scharnhorst and Eberhard Bruckner for their continuous and most fruitful collaboration over many years. This is the most important basis of this paper besides the interest expressed by numerous members of our community of scientometricians. I express again my deep admiration for Robert K. Merton, whom I eventually met in 1999, and who warmly encouraged us to continue this type of fundamental research. I am also inspired by Eugene Garfield, especially by his ability to describe essential processes in scientific communication in a simple manner, without using sophisticated formulae. I am indebted to Ingetraut Dahlberg and New Testament scholar Marinus de Jonge. Their knowledge of the Bible helped me to understand that there is more behind the Gospel parable than “The rich are becoming richer and the poor poorer.” Wolfgang Glänzel’s expert support with the raw data indispensable for the investigations is gratefully acknowledged. Alan Gross patiently corrected my English, by helping me to match the draft with what I told him it should express.

APPENDICES

Appendix A: The Data

In accordance with previous papers (Bonitz, Bruckner, & Scharnhorst, 1993, 1997), we study a set of forty-four countries, chosen for being highly productive during a certain period of time. These countries and their abbreviations are: ARG—Argentina; AUS—Australia; AUT—Austria; BEL—Belgium; BGR—Bulgaria; BRA—Brazil; CAN—Canada; CHE—Switzerland; CSR—Czechoslovakia; DEU—Germany FR; DNK—Denmark; EGY—Egypt; ESP—Spain; FIN—Finland; FRA—France; GRE—Greece; HKG—Hong Kong; HUN—Hungary; IND—India; IRL—Ireland; ISR—Israel; ITA—Italy; JPN—Japan; KOR—South Korea; MEX—Mexico; NGA—Nigeria; NDL—Netherlands; NOR—Norway; NZL—New Zealand; POL—Poland; PRC—PR China; PRT—Portugal; ROM—Romania; SAR—Saudi Arabia; SGP—Singapore; SUN—USSR; SWE—Sweden; TUR—Turkey; TWN—Taiwan; UKD—UK; USA—USA; VEN—Venezuela; YUG—Yugoslavia; ZAF—South African R; OTH—Other Countries; WLD—World.

Previous analyses started from 1980. Therefore, for our purposes, we still consider all countries of the former Soviet Union as belonging to a “virtual” common national science system. In this report, the time period from 1990 to 1994 is taken into account. The data were prepared by “Re-
search Association for Science Communication and Information e.V." (RASCI) on the basis of SCI. First author count is used for national allocation.

The analysis includes 2,712 journals in this time span. Two additional conditions have been imposed: (1) For consideration, a journal had to appear during all five years, and journals with less than 100 papers in five years were excluded. (2) For each journal, countries with more than 10 papers were considered explicitly; countries with a lower number of papers were merged into a category called "other countries" (OTH). This category also covers the countries outside our sample.

The journal impact factors are computed from the citations given during the five years to the papers published in the same five years. Due to this procedure, the journal impact factors are higher than the journal impact factors computed by the ISI.

Appendix B. A New Typology of Scientific Journals

A journal can be a core journal or a non-core journal relative to the four parameters: Publications (PU), citations (CI), participations (PA), and Matthew citations (MC). For instance, a journal of the type "PUCIPAMC" belongs to the cores of all four types; a journal of the type "CIMC" is a citation core journal and a Matthew core journal, but not a publication core journal and not a participation core journal. So, the absence of the corresponding letters denotes that a journal does not belong to the cores of this type. In our sample of 2,712 journals there are 1,981 journals not belonging to any of the four cores (type "NOCORE").

In Appendix C we present a list exclusively of the MCJ. This list includes the journal type, the journal title, the number of the journal's Matthew citations, the corresponding journal rank, and the journal's impact factor with the corresponding journal rank. For a given type and field, the journals are ranked by descending number of Matthew citations.

Appendix C. The Matthew Core Journals

<table>
<thead>
<tr>
<th>Journal Type</th>
<th>Journal Title</th>
<th>Matthew Citations</th>
<th>Rank</th>
<th>Impact Factor</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multidisciplinary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>NATURE</td>
<td>33901</td>
<td>1</td>
<td>29.0</td>
<td>13</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>SCIENCE</td>
<td>14271</td>
<td>3</td>
<td>29.2</td>
<td>12</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>ANNALS OF THE NEW YORK ACADEMY OF SCIENCES</td>
<td>1640</td>
<td>79</td>
<td>2.2</td>
<td>992</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Life Sciences</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PUCIPAMC</td>
<td>JOURNAL OF BIOLOGICAL CHEMISTRY</td>
<td>9559</td>
<td>5</td>
<td>13.2</td>
<td>42</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>LANCET</td>
<td>7427</td>
<td>8</td>
<td>5.7</td>
<td>206</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>NEW ENGLAND JOURNAL OF MEDICINE</td>
<td>6502</td>
<td>9</td>
<td>10.8</td>
<td>58</td>
</tr>
<tr>
<td>Journal Type</td>
<td>Journal Title</td>
<td>Matthew Citations</td>
<td>Rank</td>
<td>Impact Factor</td>
<td>Rank</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------</td>
<td>-------------------</td>
<td>------</td>
<td>---------------</td>
<td>------</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE U.S.A.</td>
<td>6372</td>
<td>11</td>
<td>20.8</td>
<td>26</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>BIOCHEMICAL AND BIOPHYSICAL RESEARCH COMMUNICATIONS</td>
<td>5881</td>
<td>13</td>
<td>7.1</td>
<td>125</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>BIOCHIMICA ET BIOPHYSICA ACTA</td>
<td>5443</td>
<td>15</td>
<td>6.6</td>
<td>144</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>FEBS LETTERS</td>
<td>5437</td>
<td>16</td>
<td>6.9</td>
<td>130</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>JOURNAL OF IMMUNOLOGY</td>
<td>4904</td>
<td>20</td>
<td>14.3</td>
<td>38</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>BIOCHEMICAL JOURNAL</td>
<td>4693</td>
<td>21</td>
<td>7.8</td>
<td>101</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>NEUROLOGY</td>
<td>4201</td>
<td>24</td>
<td>4.8</td>
<td>287</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>BLOOD</td>
<td>4116</td>
<td>26</td>
<td>12.1</td>
<td>50</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>NUCLEIC ACIDS RESEARCH</td>
<td>3889</td>
<td>28</td>
<td>8.5</td>
<td>86</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>AMERICAN JOURNAL OF PHYSIOLOGY</td>
<td>3730</td>
<td>29</td>
<td>6.8</td>
<td>140</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>EMBO JOURNAL</td>
<td>3512</td>
<td>31</td>
<td>25.7</td>
<td>18</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>BIOCHEMISTRY</td>
<td>3463</td>
<td>32</td>
<td>10.2</td>
<td>64</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>BRITISH MEDICAL JOURNAL</td>
<td>3210</td>
<td>36</td>
<td>2.2</td>
<td>999</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>BRAIN RESEARCH</td>
<td>2863</td>
<td>38</td>
<td>6.0</td>
<td>180</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>EUROPEAN JOURNAL OF PHARMACOLOGY</td>
<td>2847</td>
<td>39</td>
<td>6.0</td>
<td>179</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>JOURNAL OF CLINICAL INVESTIGATION</td>
<td>2843</td>
<td>40</td>
<td>16.0</td>
<td>36</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>BRITISH JOURNAL OF PHARMACOLOGY</td>
<td>2716</td>
<td>42</td>
<td>8.2</td>
<td>94</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>CIRCULATION</td>
<td>2585</td>
<td>43</td>
<td>11.2</td>
<td>55</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>EUROPEAN JOURNAL OF BIOCHEMISTRY</td>
<td>2452</td>
<td>47</td>
<td>6.8</td>
<td>131</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>NEUROSCIENCE LETTERS</td>
<td>2419</td>
<td>48</td>
<td>4.9</td>
<td>277</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>JOURNAL OF CELL BIOLOGY</td>
<td>2364</td>
<td>50</td>
<td>23.2</td>
<td>24</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>ONCOGENE</td>
<td>2204</td>
<td>53</td>
<td>12.8</td>
<td>43</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>ENDOCRIOLOGY</td>
<td>2172</td>
<td>56</td>
<td>9.8</td>
<td>70</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>JOURNAL OF MOLECULAR BIOLOGY</td>
<td>2067</td>
<td>58</td>
<td>10.5</td>
<td>63</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>AMERICAN JOURNAL OF CARDIOLOGY</td>
<td>2015</td>
<td>61</td>
<td>4.4</td>
<td>331</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>CANCER RESEARCH</td>
<td>1974</td>
<td>62</td>
<td>12.0</td>
<td>51</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>JOURNAL OF VIROLOGY</td>
<td>1968</td>
<td>64</td>
<td>11.9</td>
<td>53</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>NEUROSCIENCE</td>
<td>1955</td>
<td>65</td>
<td>8.0</td>
<td>97</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>AMERICAN REVIEW OF RESPIRATORY DISEASE</td>
<td>1865</td>
<td>69</td>
<td>9.2</td>
<td>76</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>JOURNAL OF PHYSIOLOGY—LONDON</td>
<td>1793</td>
<td>70</td>
<td>9.5</td>
<td>71</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>JOURNAL OF INFECTIONOUS DISEASES</td>
<td>1786</td>
<td>71</td>
<td>7.9</td>
<td>96</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>EUROPEAN JOURNAL OF IMMUNOLOGY</td>
<td>1738</td>
<td>73</td>
<td>10.7</td>
<td>60</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>JOURNAL OF BACTERIOLOGY</td>
<td>1727</td>
<td>75</td>
<td>8.1</td>
<td>96</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>APPLIED AND ENVIRONMENTAL MICROBIOLOGY</td>
<td>1640</td>
<td>80</td>
<td>5.7</td>
<td>293</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>JOURNAL OF CLINICAL MICROBIOLOGY</td>
<td>1632</td>
<td>82</td>
<td>6.3</td>
<td>160</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>JOURNAL OF CLINICAL ENDOCRIOLOGY AND METABOLISM</td>
<td>1629</td>
<td>84</td>
<td>8.3</td>
<td>92</td>
</tr>
<tr>
<td>Journal Type</td>
<td>Journal Title</td>
<td>Matthew Citations</td>
<td>Rank</td>
<td>Impact Factor</td>
<td>Rank</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------------------------------------------------------</td>
<td>-------------------</td>
<td>------</td>
<td>---------------</td>
<td>------</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>TRANSPLANTATION</td>
<td>1567</td>
<td>89</td>
<td>5.6</td>
<td>210</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>MOLECULAR MICROBIOLOGY</td>
<td>1454</td>
<td>95</td>
<td>8.8</td>
<td>80</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>JOURNAL OF THE AMERICAN COLLEGE OF CARDIOLOGY</td>
<td>1413</td>
<td>98</td>
<td>8.5</td>
<td>84</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>JOURNAL OF NEUROCHEMISTRY</td>
<td>1292</td>
<td>107</td>
<td>8.4</td>
<td>88</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>JOURNAL OF PHARMACOLOGY AND EXPERIMENTAL THERAPEUTICS</td>
<td>1237</td>
<td>113</td>
<td>7.2</td>
<td>122</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>PLANT PHYSIOLOGY</td>
<td>1196</td>
<td>115</td>
<td>8.4</td>
<td>156</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>METHODS IN ENZYMOLGY</td>
<td>1177</td>
<td>118</td>
<td>5.7</td>
<td>199</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>INFECTION AND IMMUNITY</td>
<td>1166</td>
<td>120</td>
<td>7.0</td>
<td>129</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>ANTIMICROBIAL AGENTS AND CHEMOTHERAPY</td>
<td>1133</td>
<td>124</td>
<td>6.0</td>
<td>182</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>GENOMICS</td>
<td>1124</td>
<td>126</td>
<td>9.5</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td><strong>Physics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>PHYSICAL REVIEW</td>
<td>15380</td>
<td>2</td>
<td>5.9</td>
<td>183</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>PHYSICAL REVIEW LETTERS</td>
<td>10254</td>
<td>4</td>
<td>12.7</td>
<td>44</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>PHYSICS LETTERS B</td>
<td>7680</td>
<td>6</td>
<td>6.5</td>
<td>148</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>APPLIED PHYSICS LETTERS</td>
<td>7538</td>
<td>7</td>
<td>6.3</td>
<td>157</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>JOURNAL OF CHEMICAL PHYSICS</td>
<td>6417</td>
<td>10</td>
<td>6.8</td>
<td>132</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>PHYSICA C</td>
<td>4978</td>
<td>18</td>
<td>5.2</td>
<td>240</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>PHYSICAL REVIEW D—PARTICLES AND FIELDS</td>
<td>4951</td>
<td>19</td>
<td>5.1</td>
<td>256</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>JOURNAL OF APPLIED PHYSICS</td>
<td>4507</td>
<td>22</td>
<td>3.2</td>
<td>609</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>CHEMICAL PHYSICS LETTERS</td>
<td>4277</td>
<td>23</td>
<td>5.0</td>
<td>264</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>NUCLEAR PHYSICS B</td>
<td>4168</td>
<td>25</td>
<td>7.3</td>
<td>114</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>PHYSICAL REVIEW A</td>
<td>4041</td>
<td>27</td>
<td>4.9</td>
<td>281</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>ASTROPHYSICAL JOURNAL</td>
<td>3262</td>
<td>34</td>
<td>7.2</td>
<td>119</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>ASTRONOMY AND ASTROPHYSICS</td>
<td>2198</td>
<td>55</td>
<td>4.0</td>
<td>407</td>
</tr>
<tr>
<td></td>
<td><strong>Chemistry</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>JOURNAL OF PHYSICAL CHEMISTRY</td>
<td>5679</td>
<td>14</td>
<td>5.7</td>
<td>198</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>JOURNAL OF THE AMERICAN CHEMICAL SOCIETY</td>
<td>5026</td>
<td>17</td>
<td>10.0</td>
<td>68</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>TETRAHEDRON LETTERS</td>
<td>3426</td>
<td>33</td>
<td>4.2</td>
<td>359</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>SURFACE SCIENCE</td>
<td>2925</td>
<td>37</td>
<td>4.3</td>
<td>342</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>JOURNAL OF CHROMATOGRAPHY</td>
<td>2765</td>
<td>41</td>
<td>3.8</td>
<td>434</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>JOURNAL OF ORGANIC CHEMISTRY</td>
<td>1869</td>
<td>65</td>
<td>5.4</td>
<td>228</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>ANALYTICAL CHEMISTRY</td>
<td>1726</td>
<td>76</td>
<td>7.2</td>
<td>118</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>JOURNAL OF THE CHEMICAL SOCIETY—CHEMICAL COMMUNICATIONS</td>
<td>1466</td>
<td>94</td>
<td>4.4</td>
<td>327</td>
</tr>
<tr>
<td>PUCIPAMC</td>
<td>MACROMOLECULES</td>
<td>1353</td>
<td>101</td>
<td>5.0</td>
<td>266</td>
</tr>
<tr>
<td>Journal Type</td>
<td>Journal Title</td>
<td>Matthew</td>
<td>Rank</td>
<td>Impact Factor</td>
<td>Rank</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------------------------------------------</td>
<td>---------</td>
<td>------</td>
<td>---------------</td>
<td>------</td>
</tr>
<tr>
<td>Life Sciences</td>
<td>PUPAMC TRANSPLANTATION PROCEEDINGS</td>
<td>2473</td>
<td>46</td>
<td>2.0</td>
<td>1128</td>
</tr>
<tr>
<td></td>
<td>PUPAMC MUTATION RESEARCH</td>
<td>2026</td>
<td>60</td>
<td>4.5</td>
<td>319</td>
</tr>
<tr>
<td></td>
<td>PUPAMC JOURNAL OF UROLOGY</td>
<td>1661</td>
<td>78</td>
<td>3.6</td>
<td>494</td>
</tr>
<tr>
<td></td>
<td>PUPAMC KIDNEY INTERNATIONAL</td>
<td>1624</td>
<td>85</td>
<td>7.0</td>
<td>128</td>
</tr>
<tr>
<td></td>
<td>PUPAMC NEUROSURGERY</td>
<td>1577</td>
<td>88</td>
<td>1.7</td>
<td>1356</td>
</tr>
<tr>
<td></td>
<td>PUPAMC JOURNAL OF GENERAL VIROLOGY</td>
<td>1372</td>
<td>99</td>
<td>7.1</td>
<td>126</td>
</tr>
<tr>
<td></td>
<td>PUPAMC AIDS</td>
<td>1360</td>
<td>100</td>
<td>6.6</td>
<td>143</td>
</tr>
<tr>
<td></td>
<td>PUPAMC IMMUNOLOGY</td>
<td>1308</td>
<td>105</td>
<td>5.8</td>
<td>188</td>
</tr>
<tr>
<td></td>
<td>PUPAMC INTERNATIONAL JOURNAL OF CANCER</td>
<td>1279</td>
<td>109</td>
<td>5.6</td>
<td>207</td>
</tr>
<tr>
<td></td>
<td>PUPAMC BRITISH JOURNAL OF CANCER</td>
<td>1242</td>
<td>112</td>
<td>5.3</td>
<td>237</td>
</tr>
<tr>
<td></td>
<td>PUPAMC CHEST</td>
<td>1233</td>
<td>114</td>
<td>2.3</td>
<td>958</td>
</tr>
<tr>
<td></td>
<td>PUPAMC JOURNAL OF THORACIC AND CARDIOVASCULAR SURGERY</td>
<td>1123</td>
<td>127</td>
<td>3.3</td>
<td>584</td>
</tr>
<tr>
<td></td>
<td>PUPAMC GENE</td>
<td>1109</td>
<td>128</td>
<td>5.0</td>
<td>270</td>
</tr>
<tr>
<td></td>
<td>PUPAMC HEPATOLOGY</td>
<td>1068</td>
<td>132</td>
<td>7.2</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>PUPAMC BIOCHEMICAL PHARMACOLOGY</td>
<td>1063</td>
<td>135</td>
<td>4.2</td>
<td>353</td>
</tr>
<tr>
<td></td>
<td>PUPAMC FEMS MICROBIOLOGY LETTERS</td>
<td>1026</td>
<td>143</td>
<td>2.6</td>
<td>820</td>
</tr>
<tr>
<td>Physics</td>
<td>PUPAMC JOURNAL OF PHYSICS—CONDENSED MATTER</td>
<td>2509</td>
<td>44</td>
<td>2.8</td>
<td>737</td>
</tr>
<tr>
<td></td>
<td>PUPAMC JOURNAL OF MAGNETISM AND MAGNETIC MATERIALS</td>
<td>2401</td>
<td>49</td>
<td>2.4</td>
<td>895</td>
</tr>
<tr>
<td></td>
<td>PUPAMC SOLID STATE COMMUNICATIONS</td>
<td>2253</td>
<td>52</td>
<td>2.9</td>
<td>696</td>
</tr>
<tr>
<td></td>
<td>PUPAMC PHYSICAL REVIEW C—NUCLEAR PHYSICS</td>
<td>2170</td>
<td>72</td>
<td>3.7</td>
<td>476</td>
</tr>
<tr>
<td></td>
<td>PUPAMC NUCLEAR INSTRUMENTS &amp; METHODS IN PHYSICS</td>
<td>1636</td>
<td>81</td>
<td>2.3</td>
<td>955</td>
</tr>
<tr>
<td></td>
<td>PUPAMC MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY</td>
<td>1632</td>
<td>83</td>
<td>5.5</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>PUPAMC GEOPHYSICAL RESEARCH LETTERS</td>
<td>1618</td>
<td>86</td>
<td>4.2</td>
<td>364</td>
</tr>
<tr>
<td></td>
<td>PUPAMC JOURNAL OF MAGNETIC RESONANCE</td>
<td>1586</td>
<td>90</td>
<td>5.5</td>
<td>215</td>
</tr>
<tr>
<td></td>
<td>PUPAMC OPTICS LETTERS</td>
<td>1511</td>
<td>92</td>
<td>4.5</td>
<td>320</td>
</tr>
<tr>
<td></td>
<td>PUPAMC JOURNAL OF CRYSTAL GROWTH</td>
<td>1475</td>
<td>93</td>
<td>3.2</td>
<td>588</td>
</tr>
<tr>
<td></td>
<td>PUPAMC ZEITSCHRIFT FUR PHYSIK C—PARTICLES AND FIELDS</td>
<td>1349</td>
<td>102</td>
<td>4.5</td>
<td>313</td>
</tr>
<tr>
<td></td>
<td>PUPAMC THIN SOLID FILMS</td>
<td>1315</td>
<td>104</td>
<td>2.3</td>
<td>942</td>
</tr>
<tr>
<td></td>
<td>PUPAMC NUCLEAR INSTRUMENTS &amp; METHODS IN PHYSICS</td>
<td>1300</td>
<td>106</td>
<td>2.1</td>
<td>1060</td>
</tr>
<tr>
<td></td>
<td>PUPAMC EUROPHYSICS LETTERS</td>
<td>1284</td>
<td>108</td>
<td>4.9</td>
<td>264</td>
</tr>
<tr>
<td></td>
<td>PUPAMC JOURNAL OF PHYSICS B—ATOMIC MOLECULAR AND OPTICAL PHYSICS</td>
<td>1184</td>
<td>117</td>
<td>3.5</td>
<td>520</td>
</tr>
<tr>
<td>Journal Type</td>
<td>Journal Title</td>
<td>Matthew Citations</td>
<td>Rank</td>
<td>Impact Factor</td>
<td>Rank</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>-------------------</td>
<td>------</td>
<td>---------------</td>
<td>------</td>
</tr>
<tr>
<td>PUPAMC</td>
<td>JOURNAL OF GEOPHYSICAL RESEARCH—ATMOSPHERES</td>
<td>1175</td>
<td>119</td>
<td>5.7</td>
<td>197</td>
</tr>
<tr>
<td>PUPAMC</td>
<td>PHYSICA B</td>
<td>1188</td>
<td>122</td>
<td>1.5</td>
<td>1463</td>
</tr>
<tr>
<td>PUPAMC</td>
<td>PHYSICS LETTERS A</td>
<td>1095</td>
<td>131</td>
<td>2.3</td>
<td>951</td>
</tr>
<tr>
<td>PUPAMC</td>
<td>JOURNAL OF THE CHEMICAL SOCIETY—FARADAY TRANSACTIONS</td>
<td>1067</td>
<td>133</td>
<td>3.4</td>
<td>535</td>
</tr>
<tr>
<td>PUPAMC</td>
<td>JOURNAL OF VACUUM SCIENCE &amp; TECHNOLOGY B</td>
<td>1066</td>
<td>134</td>
<td>3.9</td>
<td>417</td>
</tr>
<tr>
<td>PUPAMC</td>
<td>NUCLEAR PHYSICS A</td>
<td>1054</td>
<td>137</td>
<td>3.7</td>
<td>454</td>
</tr>
<tr>
<td>PUPAMC</td>
<td>IEEE TRANSACTIONS ON MAGNETICS</td>
<td>1041</td>
<td>139</td>
<td>1.6</td>
<td>1425</td>
</tr>
<tr>
<td>PUPAMC</td>
<td>JOURNAL OF PHYSICS A—MATHEMATICAL AND GENERAL</td>
<td>1040</td>
<td>140</td>
<td>2.6</td>
<td>817</td>
</tr>
<tr>
<td>PUPAMC</td>
<td>PHYSICS OF FLUIDS B—PLASMA PHYSICS</td>
<td>1022</td>
<td>144</td>
<td>3.5</td>
<td>501</td>
</tr>
<tr>
<td></td>
<td>Chemistry</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PUPAMC</td>
<td>TETRAHEDRON</td>
<td>1898</td>
<td>67</td>
<td>3.6</td>
<td>489</td>
</tr>
<tr>
<td>PUPAMC</td>
<td>JOURNAL OF ELECTROANALYTICAL CHEMISTRY AND INTERFACIAL ELECTROCHEMISTRY</td>
<td>1432</td>
<td>97</td>
<td>3.9</td>
<td>419</td>
</tr>
<tr>
<td>PUPAMC</td>
<td>LANGMUIR</td>
<td>1258</td>
<td>111</td>
<td>4.3</td>
<td>350</td>
</tr>
<tr>
<td>PUPAMC</td>
<td>ANALITICA CHIMICA ACTA</td>
<td>1134</td>
<td>123</td>
<td>3.3</td>
<td>562</td>
</tr>
<tr>
<td></td>
<td>Engineering</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PUPAMC</td>
<td>ELECTRONICS LETTERS</td>
<td>2269</td>
<td>51</td>
<td>2.0</td>
<td>1102</td>
</tr>
<tr>
<td>PUPAMC</td>
<td>SCRIPTAMETALLURGICA ET MATERIALIA</td>
<td>1063</td>
<td>136</td>
<td>2.0</td>
<td>1068</td>
</tr>
<tr>
<td>PUPAMC</td>
<td>JOURNAL OF THE AMERICAN CERAMIC SOCIETY</td>
<td>1028</td>
<td>142</td>
<td>3.1</td>
<td>638</td>
</tr>
<tr>
<td></td>
<td>Life Sciences</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PUCIMC</td>
<td>JAMA—JOURNAL OF THE AMERICAN MEDICAL ASSOCIATION</td>
<td>6270</td>
<td>12</td>
<td>4.2</td>
<td>357</td>
</tr>
<tr>
<td>PUCIMC</td>
<td>CELL</td>
<td>3256</td>
<td>35</td>
<td>72.3</td>
<td>3</td>
</tr>
<tr>
<td>PUCIMC</td>
<td>JOURNAL OF EXPERIMENTAL MEDICINE</td>
<td>2203</td>
<td>54</td>
<td>25.6</td>
<td>19</td>
</tr>
<tr>
<td>PUCIMC</td>
<td>MOLECULAR AND CELLULAR BIOLOGY</td>
<td>2098</td>
<td>57</td>
<td>17.9</td>
<td>31</td>
</tr>
<tr>
<td>PUCIMC</td>
<td>DEVELOPMENT</td>
<td>1734</td>
<td>74</td>
<td>15.1</td>
<td>37</td>
</tr>
<tr>
<td>PUCIMC</td>
<td>ANNALS OF INTERNAL MEDICINE</td>
<td>1531</td>
<td>91</td>
<td>7.7</td>
<td>103</td>
</tr>
<tr>
<td>PUCIMC</td>
<td>AMERICAN JOURNAL OF PATHOLOGY</td>
<td>1277</td>
<td>110</td>
<td>11.3</td>
<td>54</td>
</tr>
<tr>
<td>Journal Type</td>
<td>Journal Title</td>
<td>Matthew Citations</td>
<td>Impact Factor</td>
<td>Rank</td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>---------------------------------------------------</td>
<td>-------------------</td>
<td>---------------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>Chemistry</td>
<td>PUCIMC ANGEWANDTE CHEMIE—INTERNATIONAL EDITION IN ENGLISH</td>
<td>1970</td>
<td>7.6</td>
<td>107</td>
<td></td>
</tr>
<tr>
<td>Life Sciences</td>
<td>PUMC AMERICAN JOURNAL OF PSYCHIATRY</td>
<td>3701</td>
<td>3.0</td>
<td>657</td>
<td></td>
</tr>
<tr>
<td>Life Sciences</td>
<td>PUMC ARCHIVES OF INTERNAL MEDICINE</td>
<td>2499</td>
<td>4.4</td>
<td>332</td>
<td></td>
</tr>
<tr>
<td>Life Sciences</td>
<td>PUMC ARCHIVES OF OPHTHALMOLOGY</td>
<td>1442</td>
<td>2.6</td>
<td>842</td>
<td></td>
</tr>
<tr>
<td>Life Sciences</td>
<td>PUMC HYPERTENSION</td>
<td>1185</td>
<td>3.1</td>
<td>644</td>
<td></td>
</tr>
<tr>
<td>Life Sciences</td>
<td>PUMC HYPERTENSION</td>
<td>1105</td>
<td>8.3</td>
<td>91</td>
<td></td>
</tr>
<tr>
<td>Life Sciences</td>
<td>CIMC FASES JOURNAL</td>
<td>1723</td>
<td>20.9</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Life Sciences</td>
<td>CIMC NEURON</td>
<td>1102</td>
<td>31.7</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Life Sciences</td>
<td>PAMC ANNALS OF NEUROLOGY</td>
<td>1140</td>
<td>8.5</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>Life Sciences</td>
<td>PAMC DIABETES CARE</td>
<td>1033</td>
<td>4.7</td>
<td>290</td>
<td></td>
</tr>
<tr>
<td>Life Sciences</td>
<td>MC IMMUNOLOGY TODAY</td>
<td>2054</td>
<td>23.5</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Life Sciences</td>
<td>MC TRENDS IN PHARMACOLOGICAL SCIENCES</td>
<td>1930</td>
<td>24.8</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Life Sciences</td>
<td>MC BIO-TECHNOLOGY</td>
<td>1610</td>
<td>6.1</td>
<td>169</td>
<td></td>
</tr>
<tr>
<td>Life Sciences</td>
<td>MC TRENDS IN BIOCHEMICAL SCIENCES</td>
<td>1318</td>
<td>24.9</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Life Sciences</td>
<td>MC JOURNAL OF CLINICAL PSYCHIATRY</td>
<td>1130</td>
<td>3.4</td>
<td>553</td>
<td></td>
</tr>
<tr>
<td>Life Sciences</td>
<td>MC TRENDS IN GENETICS</td>
<td>1061</td>
<td>17.8</td>
<td>32</td>
<td></td>
</tr>
</tbody>
</table>

**References**


WOLFGANG GLÄNZEL

ABSTRACT

The present study aims at describing both the common and the distinguishing features of coauthorship trends and patterns in selected science fields. The relation between coauthorship schemes and other bibliometric features, such as publication activity and citation impact are analyzed. I show that, while copublication activity has grown considerably, the extent of coauthorship and its relation with productivity and citation impact largely varies among fields. Besides universally valid tendencies, subject specific features can be found.

INTRODUCTION

Authorship is a primary bibliometric descriptor of a scientific publication. Its trends and patterns characterize the social and even the cognitive structure of research fields. The most characteristic tendency of recent times is intensifying scientific collaboration. Collaboration in research is reflected by the corresponding coauthorship of published results, and can thus be analyzed with the help of bibliometric methods.

Kretschmer has conducted profound analyses of coauthorship patterns as a function of the authors' productivity (e.g., Kretschmer, 1994). She concluded that, in invisible colleges, coauthorship between scientists with the same number of publications is more frequent than between authors of different publication activity and that the opposite is valid in institutionalized communities. On the other hand, the reverse question, whether higher "cooperativity" of authors exhibits a greater publication activity, has lit-
tle been dealt with so far. The relation between collaboration and productivity was first studied by Beaver & Rosen (1979). The authors analyzed scientific papers of the French elite in the early eighteenth century, and concluded that collaboration is associated with higher productivity. In a recent paper, Braun, Glänzel, & Schubert (2001) have analyzed the relation between cooperativity and productivity in different author categories in the field of neurosciences. In the following study, I extend some of these results to broader science fields.

Bibliometric meso and macro studies concerned with the analysis of copublication patterns at the institutional (e.g., Hicks, Ishizuka, Keen, & Sweet, 1994; Hicks & Katz, 1997), and the national level (Gómez, Fernández, & Méndez, 1995; REIST-2, 1997; Glänzel, 2001) have shown a growing copublication activity. This applies to both scientific collaboration between industry and universities and research cooperation at the domestic, national, and supra-national level. These studies have also proved that international collaboration is—at least on the average—associated with a higher citation impact.

Besides economic and political factors, intra-scientific factors (e.g., Luukkonen, Persson, & Silvertsen, 1992), especially changing communication patterns and increasing mobility of scientists, are influencing collaboration. These factors motivate cooperation in "less expensive" areas, such as pure mathematics, and theoretical research in social sciences, too. The growing share of copublications in theoretical fields could be substantiated in the named literature.

The question arises whether one can observe the same tendencies also at the lowest level of aggregation, that is, at the level of individual publications and of authors. In the light of the above considerations, the following three questions will be answered:

- Does the development of coauthorship at the micro level, that is, at the level of individual papers, follow the trend of intensifying collaboration found at the meso (institutional) and macro (i.e., national and supra-national) level, particularly in the context of international research collaboration?
- Has the cooperativity any influence upon the authors' productivity?
- Do multiauthored papers exhibit a greater citation impact than publications with single authors?

These issues have to be addressed and answered at each level of aggregation separately since the results by Gómez, Fernández, & Méndez (1995) and Katz (2000) have shown that different types of collaboration may exhibit contradictory effects. For instance, while some types of collaboration exhibit Matthew effect, others exhibit the inverse effect (see Katz, 2000). Therefore, conclusions made for a higher level of aggregation cannot be simply assigned to a lower one and vice versa. Consequently, the results of
the following analysis should not be generalized as being valid for all types of scientific collaboration.

**Data Sources**

All papers recorded in the annual volumes of the Science Citation Index (SCI) of the Institute for Scientific Information (ISI) as *article, letter, note,* or *review* were taken into consideration. For instance, documents of the type *corrections, editorial material, bibliographical items, meeting abstracts, book reviews, news items,* etc. have been omitted. The latter types are from the bibliometric viewpoint not considered conveyers of relevant scientific information related to original research results, and are thus not regarded as citable items. All (co)authors indicated in the corresponding search field have been taken into account. Author names were taken as recorded into the database, no corrections have been made for spelling variants or for adjustment of homonyms.

Subject classification of publications was based on the field assignment of journals (in which the publications in question appeared) according to the major fields of science representing the life sciences, the natural sciences, and mathematics. In particular, the fields of Biomedical Research (BRE), Chemistry (CHE), and Mathematics (MAT) have been selected. The definition of these subject areas is in keeping with the subject scheme used in the 2nd edition of the *European Report on Science and Technology Indicators* (*REIST*-2, 1997). The field Biomedical Research includes the following subfields: (1) Pharmacology and Pharmacy, (2) Pathology, (3) Research Medicine, and (4) Immunology. The subject area Chemistry comprises: (1) Inorganic Chemistry and Engineering, (2) Analytical Chemistry, (3) Physical Chemistry, and (4) Organic Chemistry. The field of Mathematics is not subdivided into any particular subfield.

The study is based on papers published in the years 1980, 1986, 1992, 1996, and 1998. Citation counts have been determined in a three-year period on the basis of an item-by-item procedure using special identification keys. In particular, citations were counted in the year of publication and the two subsequent years, that is, in the period 1996–1998 for papers published in 1996. The applicability of the three-year citation window scheme has been proved in several recent methodological studies (e.g., Glänzel & Schoepflin, 1995 and *REIST*-2, 1997).

**Methods and Results**

*Theoretical Implications*

In a current study by Glänzel & de Lange (2002), the distributions of the number of partner countries over internationally coauthored papers is being analyzed for individual countries in the fields of Biomedical Research, Chemistry, and Mathematics. To date, the analysis has resulted in a
modification of the model assumed in the authors’ earlier paper (de Lange & Glänzel, 1997; Glänzel & de Lange, 1997). Originally, a geometric distribution was assumed. This model described extremely skewed distributions with monotonously decreasing probabilities of the number of partners involved. This situation was typical for earlier decades. However, the shapes of the empirical frequency distributions of various countries have changed—they have become less skewed in the 1990s. For some countries, the peak of the distribution is even around the cooperativity value of one or two partner countries. In their study, Glänzel and de Lange have searched for an approximate solution for a suitable distribution within the extended urn model, considering, among others, the geometric, the binomial, the negative binomial, the Poisson, and the Waring distribution.

A characterization theorem for discrete probability distributions substantiates that the empirical distributions under study can be found in the “neighbourhood” of the Poisson distribution. One of the basic features of this distribution is that it may take the maximum probability at any value.

From the formally logical point-of-view, increasing international collaboration and increasing multinationality are not automatically tantamount to growing copublication activity of individual authors, since increasing international collaboration might theoretically be caused by a mere replacement of domestic cooperation by international collaboration. However, it is known that coauthorship has increased at all levels of aggregation and, of course, the growth took place at the micro level to a greater extent than at the national/supranational level. Therefore, the application of the above approximate Poisson model seems to be justified to the frequency distribution of coauthors over papers. Consequently, any considerable change of copublication activity of individual authors has to be reflected by the corresponding change of the shape of the empirical cooperativity distribution. In the following sections, the changing shape of the distribution of coauthors over papers will be analyzed, a theoretical explanation for possible observed changes over time, however, will not be given.

Results

In order to answer the first question concerning the trend in coauthorship patterns of individual papers, the distribution of coauthors over publications have been determined for the following four years: 1980, 1986, 1992, and 1998. The mean cooperativity (M), that is, the average number of authors contributing to one paper, is used as an indicator of collaboration at the micro level. The indicator values for the three selected fields, BRE, CHE, and MAT are presented in Table 1. There is a sharp increase by 48 percent in Biomedical Research. In Chemistry cooperativity increased by 24 percent, and in Mathematics the growth still amounted to 17 percent. This is interesting because cooperativity in the selected lifescience field is traditionally higher than in chemistry or mathematics, where single author-
ship was always typical of the field. Field-specific characteristics of coauthorship patterns have therefore deepened.

Since bibliometric distributions are discrete rather than continuous and are often skew, the interpretation of mean values requires the application of additional statistical tools besides the use of mean values. In order to visualise field-specific changes in coauthorship patterns, the frequency distributions of coauthors over papers is presented in Figure 1. The tails of the distributions proved to be long, and have therefore been cumulated.

The share of papers with a low number of coauthors in Biomedical Research shrunk steadily between 1980 and 1998. Thus, the share of papers with one or two authors halved (from 16 percent [27 percent] in 1980 to 7 percent [13 percent] in 1998), and the share of papers with three authors decreased from 24 percent in 1980 to 16 percent in 1998. The share of papers with four coauthors did not change during the eighteen years of observation. The share of papers with five or more authors considerably increased, so that multiauthored papers became predominant and characteristic for the field.

There is a similar, yet not quite as pronounced, trend in Chemistry. While a chemistry paper published in 1980 was most likely to have two coauthors (33 percent), the local maximum moved to three authors with a share of 25 percent in 1998. It is worth mentioning that one quarter of all papers published in 1998 had at least five authors.

The intensifying collaboration and the associated increase of the share of multiauthored papers in Chemistry and in Biomedical Research does not really surprise. The trend towards coauthorship in Mathematics is, however, somewhat striking. In 1980, about two thirds of all papers were single authored and only 6 percent of all journal publications had more than two coauthors. Eighteen years later, in 1998, most papers are still single authored, but the share of papers with one and two authors almost coincides. About 25 percent of all mathematical publications have at least three authors. Although the distribution remains very skew in this field, a considerable increase in individual copublication activity can be observed in the last two decades.

Table 1. The Development of Coauthors Patterns in Selected Fields (1980–1998) as Reflected by the Mean Cooperativity (M).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Papers</td>
<td>M</td>
<td>Papers</td>
<td>M</td>
</tr>
<tr>
<td>Biomedical Research</td>
<td>64501</td>
<td>3.47</td>
<td>74630</td>
<td>3.96</td>
</tr>
<tr>
<td>Chemistry</td>
<td>66576</td>
<td>3.07</td>
<td>69703</td>
<td>3.27</td>
</tr>
<tr>
<td>Mathematics</td>
<td>14385</td>
<td>2.22</td>
<td>11892</td>
<td>2.30</td>
</tr>
</tbody>
</table>
Figure 1. Frequency Distribution of Coauthors Over Papers in Biomedical Research (top), Chemistry (center), and Mathematics (bottom).
After having found an answer to the first question, namely, that copublication activity at the micro level follows the trend of intensifying scientific collaboration observed at the meso and macro level, we can consider the interrelationship between cooperativity and the authors' productivity as formulated in the second question. Figure 2 shows the average publication activity vs. mean cooperativity plot of the authors in Biomedical Research, Chemistry, and Mathematics for papers indexed in the 1996 volume of the SCI. For authors in Biomedical Research there is a peak of productivity around the cooperativity value of six coauthors. In Chemistry, this peak of productivity can be found around the mean cooperativity of three to four. Finally, in Mathematics, mean publication activity takes its maximum value in the case of one to two coauthors. Otherwise, no unambiguous "effect" on publication activity can be found for the number of authors involved. Collaboration is thus not associated with higher productivity at the level of individual authors. In Mathematics, productivity is even slightly decreasing with growing copublication activity. Here, authors who are—on the average—publishing alone or with only one coauthor are the most productive ones. Although "team work" exhibits higher productivity than single authorship in the two other fields, beyond a field-characteristic level, productivity distinctly decreases with growing cooperativity.

The third question addressed in the introduction is concerned with the citation impact attracted by multi-authored papers. To answer this question, all article, letters, notes, and reviews indexed in the 1996 volume of the SCI and assigned to the three selected subject areas have been processed. Cita-

---

Figure 2. Plot of Average Productivity vs. Average Cooperativity in 1996.
tions have been counted for the period 1996–1998. Unlike in the Journal Citation Reports, journal impact factors have here been calculated for one source year (1996) and a three-year citation window (1996–1998). The plot of the average coauthorship of journals vs. journal impact factor for the three fields is presented in Figure 3.

All plots reflect almost uncorrelated patterns. The application of the F-test shows that the two variables can practically be considered independent in all selected fields. The corresponding statistics are presented in Table 2. \( F_1 = 1 \) for all three samples. It has to be mentioned that there is a slight decline for Chemistry and a certain increase for Mathematics. In case of Biomedical Research, the correlation coefficient is zero. According to the F-test, the two variables are independent at any reasonable confidence level in Biomedical Research. The critical value for degrees of freedom at a confidence level of 99.5 percent is 7.88; that is, the F-values for Chemistry and Mathematics are below this threshold.

In verbal terms, high-impact journals tend to publish chemistry papers with a somewhat lower number of coauthors on the average. The reverse statement applies to mathematics. However, there is no pronounced relation between the journal impact factor and the average cooperativity of papers published in the journal under study, and the hypothesis that the two variables are independent can be accepted at the above confidence level.

Now the question will be answered whether multiauthored papers exhibit a greater citation impact than publications with single authors. First, I will analyze the share of cited papers as a function of the number of coauthors. Both number and share of cited papers with \( k \) coauthors are presented in Table 3.

The well-known fact that biomedical research attracts, on the average, higher citation rates than chemistry, and that chemistry literature itself is, on the other hand, more frequently cited than mathematics, is reflected by the share of cited papers. Within each subject area, a clear dependence of the citedness variable on the number of coauthors can be observed. In particular, the share of cited papers grows with the increasing number of coauthors. Roughly speaking, about three quarters of all papers with at least four coauthors each are cited in the three-year period beginning with the year of publication.

Figure 4 presents the mean citation rate of papers as a function of cooperativity. In all three fields, there is a pronounced tendency of growing citation impact if the number of coauthors increases. The drop at the “high-end” of cooperativity in the mathematical sample can be explained in terms of statistical reliability. Only twenty-five papers, that is, 0.15 percent of all mathematical papers under study, have more than eight coauthors each. The decrease might therefore be considered statistically not significant. The field average of citation impact is reached at a cooperativity of fifty-six in Biomedical Research, at thirty-four in Chemistry, and at two in Mathematics.
Figure 3. Plot of Average Coauthorship of Journals vs. Journal Impact Factor in 1996. Biomedical Research (top), Chemistry (center), and Mathematics (bottom).
Tuble


<table>
<thead>
<tr>
<th>Statistics</th>
<th>Biomedical Research</th>
<th>Chemistry</th>
<th>Mathematics</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r^2$</td>
<td>0.000</td>
<td>0.019</td>
<td>0.049</td>
</tr>
<tr>
<td>$df(f^2)$</td>
<td>614</td>
<td>348</td>
<td>150</td>
</tr>
<tr>
<td>F-statistics</td>
<td>0.01</td>
<td>6.75</td>
<td>7.79</td>
</tr>
</tbody>
</table>

Table 3. Share of Cited Papers as a Function of the Number of Coauthors in 1996.

<table>
<thead>
<tr>
<th>Number of Coauthors ($k$)</th>
<th>Number of Papers with $k$ Coauthors</th>
<th>Share of Cited Papers with $k$ Coauthors</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRE</td>
<td>CHE</td>
<td>MAT</td>
</tr>
<tr>
<td>1</td>
<td>8151</td>
<td>8241</td>
</tr>
<tr>
<td>2</td>
<td>12927</td>
<td>20893</td>
</tr>
<tr>
<td>3</td>
<td>15201</td>
<td>21884</td>
</tr>
<tr>
<td>&gt;3</td>
<td>55928</td>
<td>34066</td>
</tr>
</tbody>
</table>

Biomedical Research (BRE), Chemistry (CHE), and Mathematics (MAT).

ics. It is worth mentioning that these thresholds roughly coincide with the local maximum values in the productivity vs. cooperativity plot in Figure 2. There is, however, no causal relation conditioning such coincidence. In all, multiauthored papers exhibit a clearly greater citation impact than publications with single authors in the three selected fields.

In this context, the question of (author) self-citation has to be discussed. The above citation patterns have not been checked for self-citations. Self-citation analysis has been omitted for the following two reasons. As mentioned in the Data Sources section, no corrections have been made for spelling variants of author names or for adjustment of homonyms. This may result in considerable errors in self-citation statistics. Moreover, Figure 2 shows that the mean publication activity does not exceed two papers per year. That is, it can be concluded indirectly that the higher citation rates are not a consequence of possible self-citations alone, and growing citation impact has to be explained mainly with other aspects of scientific communication.

CONCLUSIONS AND IMPLICATIONS FOR DATABASE INDEXING AND SEARCH STRATEGIES

In earlier papers concerned with the analysis of international scientific collaboration, the author has found considerable changes in copublication activity and multinationality of publications during a period of ten years (de Lange & Glänzel, 1997; Glänzel & de Lange, 1997; and Glänzel, 2001). Moreover, I observed an increase of citation impact in papers published in
Figure 4. Mean Citation Rate vs. Number of Coauthors in 1996. Biomedical Research (top), Chemistry (center), and Mathematics (bottom).
international cooperation. A similar development could be found at the micro level, although direct parallels must not be drawn because of the different conditions for and different meaning of copublication at the lower level of aggregation.

A theoretical explanation for the considerable change in copublication activity of individual authors is not given. The same applies to the striking trend towards multiauthored publications in biomedical research and chemistry that has been found in the present study. Surprising was the decrease of single-authored papers to a clear minority in mathematics. However, truly multiauthored papers in mathematics, with four authors or more, remain rather the exception than the rule.

The lack of an unambiguous relation between cooperativity and publication activity was somewhat unexpected, although a similar tendency has been shown by Braun, Glänzel, & Schubert (2001) for the field of neurosciences. In particular, a peak of productivity around a field-specific cooperativity value could be found. A question arises as to how much the location of this peak depends on the publication period under study. For longer periods, this local maximum might be taken at somewhat higher cooperativity values; however, these values will remain characteristic for the field.

The theory of a relationship between cooperativity and publication activity was thus not supported by these findings. On the other hand, the theory that multiauthored papers are more likely to be cited, and attract more citations, than single-authored papers was strongly supported and proved to be universal. In particular, the mean citation rate of multiauthored papers in mathematics exceeds the field average by even more than 200 percent. It has, however, to be mentioned that these papers only amount to about 2 percent of all publications in this field. These results are contrasted by the lack of any relation between the impact factor of journals and the mean cooperativity of papers published in them.

From the viewpoint of library and database management, the following implications should be mentioned. Quantitative methods in bibliometrics help to uncover important relations underlying the network of science communication, and to measure their strength. Such relations are established by the thematic linkage that can be measured and described not only with the help of bibliographic coupling and coword and cocitation analysis, but also through the coauthorship or copublication relationship.

In a recent paper, Glänzel & Czerwon (1996) have pointed to classical information retrieval as one possible field of application of bibliographic coupling techniques. In particular, they have shown that these techniques can be used to identify "core documents" representing recent "hot" and other research-front topics. Core documents are thus important nodes in the network of documented science communication. A similar statement holds in the context of scientific collaboration and its citation impact, since citations give a formalized account of the information use and can thus be...
taken as a strong indicator of reception. Multiauthored, and first of all internationally coauthored publications, proved to hold key positions within the framework of scientific communication; their citation impact is assumed to exceed standard reception. Apart from the definition of core documents given by Glanzel and Czerwon in the context of bibliographic coupling, other documents, frequently cited and strongly interrelated in terms of theme, can thus serve as core documents in search strategies.

REFERENCES


Hicks, D., & Katz, J. S. (1997). *The changing shape of British science*. STEEP special report No. 6, SPRU.


ABSTRACT

Based on Gestalt theory, the author assumes the existence of a field-force equilibrium to explain how, according to the conciseness principle, mathematically precise gestalts could exist in coauthorship networks. A simple mathematical function is developed for the description of these gestalts which can encompass complementary tendencies (as in the principle of Yin and Yang) in their dynamic interplay and, thus, can reflect the change in gestalts. For example, "Birds of a feather flock together" and "Opposites attract" are explained as complementary tendencies.

The data are obtained by SCI. In analyzing the coauthorship networks, coauthorship relations \(Z\) between scientists (third dimension) are recorded from the point of view of every scientist with productivity \(X\) (first dimension) to all the other scientists with productivity \(Y\) (second dimension).

According to the conciseness principle, three-dimensional well-ordered gestalts from different science disciplines are presented. The results of the study have confirmed Metzger's conjectures that the conciseness principle also has validity for social systems, and is valid even with the same conciseness as in the psychology of perception.

It is possible that the presented mathematical function has assumed a more general character and, in consequence, is also more likely applicable to the description of citation networks or the spreading of information.

INTRODUCTION

In every science discipline, basic research and applied research are complementary tendencies interacting dynamically with each other. Progress in scientometrics and informetrics is possible only in this manner. Evalua-
tion of research institutions by science indicators can be successful only with thorough basic knowledge. For example, citations and coauthorships are reflections of general social relations in networks of people.

The present study is basic research oriented. It will start with general theoretical considerations, followed by applications to coauthorship networks in science.

In the wake of a tangible change of paradigm in science, by the end of the twentieth century a number of holistic theories have emerged (e.g., Bohm, 1980; Stapp, 1993; Prigogine & Stengers, 1984; Sheldrake, 1988; Laszlo, 1997; just to mention a few) that operate on the idea of holographic interacting entities in the world, with several of them also implying a field concept. According to Pribram (1997, p. 12), field concepts are being used when remote-field effects have to be explained.

In psychology, the specialty "‘Gestalt’-psychology" originated at the end of the nineteenth century, with due consideration of psychological processes and with holistic organizational patterns playing a role that comprised humanity and the environment. These holistic entities are often designated as psychological fields. Their tendency towards a stable state of order is called conciseness tendency, a "tendency towards a good gestalt." The stable final state is, if possible, built up in a simple, well-ordered, harmonic, and uniform manner in line with definite rules.

Metzger's definition of "gestalt" reads as follows (Metzger, 1954, quoted in line with Metzger, 1986):

> The form of an object is called 'gestalt' if it is not attributable to the rigidity of material and not based on fixing each individual point as such, but rather on an equilibrium of forces (tensions, etc.). In addition, the form of a process or its course is also called 'gestalt' if it is not fixed by impenetrable conduits, or confined to one degree of freedom, but if it had emerged from the free play of field forces (in case of a diverse number of freedom degrees) . . . Thus, we generally call such objects as gestalts which, as correctly noted by PIAGET, owe their gestalt to be balancing interactions of forces.

In this context the opposite notion to gestalt would be the mosaic. While in a mosaic the individual parts are arranged within an externally defined array, with the parts 'not knowing of each other' to a certain degree, the parts and points of a gestalt are to be found in a more or less close dynamic state of communication and interaction: every one interacts with every other and, if something like an ordered array is brought about, every part and point carried and keeps every other and is instantly carried and kept by the totality of the others. (pp. 130 f.)

The conciseness principle was discovered while studying the phenomena of perception: No doubt, perception is an active process; that is, the objects perceived represent a more regular entity than the physical objects existing in the environment. Metzger presumed that this conciseness principle could be generalized and applied to other fields of the psyche, and to
socio-psychology as well. Here Metzger had in mind the succinct forms of
group structure.

In 1967 Metzger wrote (quoted according to Metzger, 1986):

If the conciseness principle is validly applicable over the entire psychic
sector, its efficacy could also be extended to those wholes, the natural
parts of which are human beings: to social group formations, especially
to the spontaneously configuring natural small-size groups. I cannot
present here any accepted theses, but only preliminary presumptions.
(p. 142)

Metzger (1986) mentioned:

An order of behaviour that without any constraints builds itself up due
to internal vectors should qualify as an excellent, a succinct, like the
order in the field of perception. (p. 203)

As for the structure of social groups, Metzger (1982, quoted by Metzger
1986, p. 196) suggested that already in the prehistoric times of higher ver-
etbrates—birds and mammals—two succinctly distinguishable conciseness
forms of group structures had apparently existed that are also identifiable
in humans: Step structure and ring structure. The step structure reveals
individual members arranged in an hierarchical sequence (pecking order
of the chicken run), whereas the “ring”-members, with their common con-
cern in the center, are distributed “over equal heights.”

In his deliberations about the formation of a group, Metzger (1986, p.
222) also touched upon the proverb “Birds of a feather flock together,” and
gave it a grain of truth. At the same time, however, he suggested that simi-
larly could only be viewed as one factor among many, irrespective of wheth-
er it may turn out to be an indispensable or just sufficient requirement for
group formation.

This point of view was adopted and, in this study, extended to additional
knowledge from the literature on the characteristics of structures in social
systems. The results of studies, as contained below, indicate that Metzger’s
definition of gestalt, which implies the balancing interaction of forces (ten-
sions, field forces, etc.), can be fully applied to social systems, even while
retaining the validity of the conciseness principle in a still more precise form
than it would have been thought possible by Metzger himself. Hence, there
are structures existing in social systems that are strictly mathematically de-
scribable.

Without assuming the existence of a field-force equilibrium, it would
be difficult to explain how such mathematically precise gestalts—which are
thought to have been established by the free cooperation (self-organization)
of scientists around the world—could exist. (Cf. all three-dimensional
figures of gestalts in the coauthorship networks of this study.)
GENERAL CHARACTERISTICS OF STRUCTURES IN INTERPERSONAL RELATIONS IN SOCIAL NETWORKS

When discussing the structural characteristics of interpersonal relations in social networks, the author references one of Wolf's works (1996), rather than the many studies conducted and contained in the literature. As a result, one can identify a definite structure underlying a great number of social processes of a distributive character, such as the spreading of diseases, the propagation of information, the change of views, or the distribution of innovations. A generalization of this structure reveals three pivotal aspects:

1. Over-coincidental similarity among persons in contact with each other ("Birds of a feather flock together")
2. Decrease of interpersonal relations with declining similarity
3. Emergence of the "edge effect" (see below).

The author illustrates these three aspects on the basis of an empirical example (Wolf, 1996, p. 35). Independently of whether or not socio-demographic features, socio-structural characteristics, or general approaches are taken into account, it has repeatedly been shown that persons with social contacts reveal greater characteristic similarities than could be expected from persons with accidental associations. Relations may qualify as friendships, marriages, professional contacts, or other types of relationship.

Wolf, in one of his empirical examples, studied similarity underlying relations of friendship due to common education. It was unequivocal that those persons preferred to become friends with individuals who had achieved the same level of education. These data can also be used to observe the edge effect. The edge effect designates the more pronounced similarity of friendly couples observable at the edges of status features (referring both to persons at the lowest and the highest levels of education). Using Wolf's data file, it is possible to identify four-times-higher relations between high-school leavers and university graduates than it would be expected at a fortuitous choice of friends. The tendency to choose status-homogeneous friends is less clearly perceptible with persons having medium-level school degrees. As a result, at the same level of education a U-curve of data arose.

Two hypotheses are primarily suggested that should explain the edge effect. On the one hand, it is maintained that the persons of the lowest and the highest group would be visibly exposed due to their social position and, thus, developed a stronger sense of affiliation than people having a medium-level social status. In addition, those people at a medium status display a stronger orientation towards career so that they are reluctant to have frequent contacts with people of the same level. On the other hand, it is suggested that the choices of people who are either at the very bottom or at the top are blocked in one direction.
Quite similar results were obtained in other studies, for example, the distribution of persons within age groups. The persons belonging to the youngest and those to the oldest groups display a much stronger inclination to remain among their groups than is the case for the medium-age groups.

The well-known proverb "Birds of a feather flock together" can be conveniently integrated into this theory, together with the empirical results published. Far less evidence is found, however, for the opposite saying, "Opposites attract"—although several efforts have been put into proving its correctness; for example, Winch, Ksanes, & Ksanes (1954), who considered the complementarity of personality features the decisive factor for partnership relations.

The descriptions available in literature on the crucial specifics of social structures refer to important and special aspects of individual phenomena. In Wolf's empirical example, and in those of many other authors, it became obvious that only one of the two proverbs was used ("Birds of a feather flock together"), leaving out the other, with its opposite meaning. In addition, such examples used the U-curve only in one of its positions (edge effect), and not vice versa. But apart from the U-curve, the assumptions were linear, for instance, Wolf's assumption (1996) on the "Decrease of contacts with declining similarity" (an extension of the proverb "Birds of a feather..."), or monotonously falling (e.g., Marsden's "Unidimensional Social Distance Model" (1981)).

Marsden (1981) operated on the premise that: "... the likelihood of sociable intercourse between persons in groups is an inverse function of the distance between those groups along a single dimension" (p. 21), with distance being distance in similarity. By contrast, this study will suggest that the opposing proverbs should only be perceived as the conspicuously visible state of a holistic process caused by the conditions to which the system under study was subjected at the time of investigation. In addition, the same applies to both opposing views of U-curves—that is, with edge effect on the one side, and the reverse case, on the other side.

**DEVELOPMENT OF A MATHEMATICAL FUNCTION TO DESCRIBE GESTALTS IN SOCIAL NETWORKS**

**Matrix of Interpersonal Relations**

If one started from the assumption that all individual manifestations of social structure, as invariably mentioned in the literature, have come to interact within a system of the equilibrium of forces, an hypothesis might be established on the emerging forms of the adequate three-dimensional gestalts. These forms should be as simple, ordered, harmonic, and uniform as possible, according to the conciseness tendency, and should be structured in line with definite rules.
Their uniformity could be expressed by the visible retention of the balancing interaction of the different and also opposing individual phenomena in social structures, as known from the literature, and could become visible in only one function. Thus, the diversity of patterns or gestalts is then expressed by the variation of the parameters of this function, with the diversity being dependent upon the conditions causing these patterns (e.g., the environment). These many gestalts can be classified into types in line with their similarity.

Both the opposing proverbs and the U-curves in their contrasting situations give rise to reflect on the notion of complementarity. Capra (1996) wrote that the term “complementarity” (e.g., particle/wave), introduced by Niels Bohr, has become a firm integral part of the conceptual framework within which physicists attentively weigh the problems of nature, and that Bohr had repeatedly indicated that this idea could also be beneficial outside of physics. In conformity with the above, Capra also suggested that the modern notion of complementarity had existed already in a clear cut manner in old Chinese thought, in the Yin/Yang teaching. Yin and Yang have to be seen as polar forces, as complementary tendencies interacting dynamically with each other, so that the entire system is kept flexible and open to change. Capra (1996) said:

> It is important and difficult to understand for the people in the western world that these oppositions do not belong to different categories but are opposing poles of only one whole. There is no separate Yin and no separate Yang. All natural phenomena are manifestations of a continuous interplay between both poles, all transitions proceed in a direct and uninterrupted sequence. The natural order manifests itself in a dynamic equilibrium between Yin and Yang. (p. 32; translated from German by the author)

It is consistent with all above considerations to seek a simple mathematical function (the conciseness principle) for the description of gestalt that can encompass the complementary tendencies (Yin and Yang) in their dynamic interplay and, accordingly, also the change of gestalt. The basic requirement for establishing this function is, however, the classification of persons according to a variable of personality characteristics, for example, age or education.

Following the interpersonal relations between these persons (variable $Z$)—for example, friendship or coauthorship—will be recorded from the point of view of every individual person with value $X$ of the variable of personality characteristics to all the other authors with value $Y$ of this variable. If the relations are recorded from the point of view of every individual person (with $X$) to all the other persons (with $Y$), then a symmetrical matrix of $Z_{XY}$ is obtained. For example, there are three friends classified according to education (elementary school: $X,Y = 1$; junior high school: $X,Y = 2$; grammar school: $X,Y = 3$; university: $X,Y = 4$):
- person A with X (or Y resp.) = 1
- person B with X (or Y resp.) = 4
- person C with X (or Y resp.) = 3

From the viewpoint of A with X = 1, there is one relation recorded to B with Y = 4, that is, $Z_{14}$, and one relation to C with Y = 3, that is, $Z_{13}$.

From the viewpoint of B with X = 4, there is one relation recorded to A with Y = 1, that is, $Z_{41}$, and one relation to C with Y = 3, that is, $Z_{43}$.

From the viewpoint of C with X = 3, there is one relation recorded to A with Y = 1, that is, $Z_{31}$, and one relation to B with Y = 4, that is, $Z_{34}$.

See Table 1 for a symmetrical matrix of friendship relations $Z_{XY}$.

<table>
<thead>
<tr>
<th>X/Y</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

In general, according to this principle, matrices of interpersonal relations between persons classified according to a variable of personality characteristics can be obtained.

The mathematical function $Z = f(X,Y)$ to describe three-dimensional gestalts in such social networks should depend on the above named three pivotal aspects of the structure of social networks.

Three coordinated steps of approximation to the description of gestalt will be discussed. Both the first and the second steps are only related to similarity or dissimilarity, but the third one concerns the three aspects of structures in interpersonal relations in social networks in total.

**Similarity and Dissimilarity**

Dissimilarity or contrary similarity between two groups of persons can be measured by the difference between X and Y:

$$X - Y$$

The difference is chosen because of the above mentioned symmetry in its absolute form:

$$|X - Y|$$

There is both a minimum of the difference,

$$|X - Y|_{\text{min}}$$
and a maximum of the difference 

$$|X - Y|_{\text{max}}$$

The similarity is highest at the minimum and lowest at the maximum and vice versa, that is, the dissimilarity is highest at the maximum and lowest at the minimum. Moreover, there is a complementary variation of similarity and dissimilarity: With increasing dissimilarity, the similarity is decreasing and vice versa.

Under the condition dissimilarity \( A \) is defined as difference,

$$A = |X - Y| = \text{Dissimilarity}$$

similarity has to be defined as complement \( A_{\text{complement}} \). Therefore, with increasing distance \( D_A \) of the dissimilarity \( A \) from the minimum,

$$D_A = A - |X - Y|_{\text{min}} = |X - Y| - |X - Y|_{\text{min}}$$

similarity has to decrease according to the same distance from the maximum:

$$A_{\text{complement}} = |X - Y|_{\text{max}} - D_A = |X - Y|_{\text{max}} + |X - Y|_{\text{min}} - |X - Y| = \text{Similarity}$$

Accordingly, if the dissimilarity is moving to the maximum, the similarity is moving to the minimum and vice versa. Both the first and the second steps of approximation are two-dimensional representations of patterns only.

First step of approximation. The initial ideas on the mathematical function \( Z = f(X,Y) \) were developed in pursuit of quantitative science research. It has for decades been shown that the overwhelming majority of distributions of bibliometric data can be represented as a power function—that is, as a Zipf-distribution instead of a Gaussian distribution as used in psychology and the natural sciences.

For reasons of simplicity, a power function was chosen as the starting point for considerations:

As a first step of approximation we can say the interpersonal relations are at least dependent on a power function of the dissimilarity between persons.

Since, in case of “equals,” the value 0 cannot be raised to a negative power, 1 is added to the term \(|X - Y|\), resulting in the power function:

$$Z^{**} = \text{constant} \cdot (|X - Y| + 1)^{\alpha}$$

$$Z^{**} = \text{constant} \cdot (A + 1)^{\alpha}$$

If the parameter \( \alpha \) should be positive, then the idea of the proverb “Opposites attract” would be fulfilled in connection with the assumption of “Increase of interpersonal relations with increasing dissimilarity” (cf. example in Table 2 and Figure 1, right).
The proverb "Birds of a feather flock together," and extended version with the assumption of Wolf’s “Decrease of personal relations with declining similarity” or Marsden’s Unidimensional Social Distance Model, would all be complied with by the power function in which the parameter $\alpha$ is negative (cf. example in Table 3 and Figure 1, left).

**Table 2.** Example with $\alpha = +1$ and Constant = 1.

| $X - Y$ | $|X - Y|$ | $|X - Y| + 1$ | $(|X - Y| + 1)^\alpha$ | $I \cdot (|X - Y| + 1)^\alpha$ |
|---------|---------|-------------|----------------------|---------------------|
| -4      | 4       | 5           | 5                    | 5                   |
| -3      | 3       | 4           | 4                    | 4                   |
| -2      | 2       | 3           | 3                    | 3                   |
| -1      | 1       | 2           | 2                    | 2                   |
| 0       | 0       | 1           | 1                    | 1                   |
| 1       | 1       | 2           | 2                    | 2                   |
| 2       | 2       | 3           | 3                    | 3                   |
| 3       | 3       | 4           | 4                    | 4                   |
| 4       | 4       | 5           | 5                    | 5                   |

**Table 3.** Example with $\alpha = -1$ and Constant = 1.

| $X - Y$ | $|X - Y|$ | $|X - Y| + 1$ | $(|X - Y| + 1)^\alpha$ | $I \cdot (|X - Y| + 1)^\alpha$ |
|---------|---------|-------------|----------------------|---------------------|
| -4      | 4       | 5           | 0.2                 | 0.2                 |
| -3      | 3       | 4           | 0.25                | 0.25                |
| -2      | 2       | 3           | 0.3                 | 0.33                |
| -1      | 1       | 2           | 0.5                 | 0.5                 |
| 0       | 0       | 1           | 1                    | 1                   |
| 1       | 1       | 2           | 0.5                 | 0.5                 |
| 2       | 2       | 3           | 0.3                 | 0.33                |
| 3       | 3       | 4           | 0.25                | 0.25                |
| 4       | 4       | 5           | 0.2                 | 0.2                 |

Figure 1. Power Function of the Dissimilarity $Z^{**} = \text{constant} \cdot (A + 1)^\alpha$. On the left, the parameter $\alpha$ is negative: “Birds of a feather flock together” and “Decrease of interpersonal relations with increasing dissimilarity.” On the right, the parameter $\alpha$ is positive: “Opposites attract” and “Increase of interpersonal relations with increasing dissimilarity.”
A power function with only one parameter (unequal to zero) is either only a monotonically declining or a monotonically rising function, when referring to both proverbs: Either Yin or Yang. According to Chinese philosophy, Yin and Yang are the opposite poles of a single whole. There is neither an isolated, exclusive Yin, nor an isolated, exclusive Yang. All transitions occur with a direct and uninterrupted sequence. The natural order is secured by the dynamic equilibrium between Yin and Yang.

In order to fulfill the inherent requirement that both proverbs and their extensions be included in the representation, the second step of approximation will follow.

Second step of approximation. As mentioned above, with increasing dissimilarity, similarity is decreasing and vice versa. Dissimilarity $A$ and similarity $A_{\text{COMPLEMENT}}$ are two opposed varying factors and have to be inserted into the equation with one parameter each. It depends upon the parameters to what extent Yin has retracted itself in favour of Yang or vice versa.

As a second step of approximation, we can say that the interpersonal relations are at least dependent on both a power function of the dissimilarity between persons and another power function of the complement:

$$Z^* = \text{constant} \cdot (A + 1)^{\alpha} \cdot (A_{\text{COMPLEMENT}} + 1)^{\beta}$$

In an attempt to convey, in theory, a graphic idea of this function, a systematic parameter variation was made and the results are shown in Figure 2. It is a two-dimensional portrayal of patterns. In every box the difference $X - Y$ is always the abscissa, as in Figure 1, and $Z^*$ is the ordinate axis. In the middle of the abscissa is $X - Y = 0$. The relationships of the two parameters to each other determine the expressions of Yin and Yang in each of the patterns. While in the upper pattern with $\alpha = -1$ and $\beta = 0$ Yin is more likely to be in the foreground ("Birds of a feather flock together"), the pattern below with $\alpha = .5$ and $\beta = 0$ reveals that Yang is more likely to be accentuated ("Opposites attract").

Starting from the upper pattern in the direction of the pattern below, from pattern to pattern Yin has retracted itself in favour of Yang, for example, the right pattern with $\alpha = .75$ and $\beta = 1$.

As mentioned above, the mathematical function $Z = f(X,Y)$ to describe gestalts in social networks should depend on three pivotal aspects of the structure of social networks. Two of the three aspects are already included. However, if you still want to incorporate the third pivotal aspect called "edge effect"—that is, both forms of the U-curve rather than only the two proverbs—it is necessary to extend the formula according to the same principle (simplicity, conciseness, Yin/Yang) to the sum of $X$ and $Y$, that is, the formula that so far included only the difference between $X$ and $Y$. 
Figure 2. Product of Both the Power Function of the Dissimilarity and the Power Function of the Complement \( Z^* = \text{constant} \cdot (A + 1) \alpha \cdot (A_{\text{COMPLEMENT}} + 1) \beta \). Systematic variation of both parameters. In every box the difference \( X - Y \) is always the abscissa and \( Z^* \) the ordinate axis. In the middle of the abscissa is \( X - Y = 0 \). The relationships of the two parameters to each other determine the expressions of Yin and Yang in each of the patterns.

**Edge Effect**

*Third step of approximation.* Interpersonal relations \( Z \) at the main diagonal \( (X = Y) \) are more striking at the edges than in the middle, although the differences between \( X \) and \( Y \) did not vary:

\[
A = |X - Y| = 0 = \text{constant}
\]

The values of \( Z_{XY}, Z_{11}, \) or \( Z_{55} \) at the edges are higher than the values of \( Z_{22}, Z_{33}, \) or \( Z_{44} \) in the middle.

Whereas the differences between \( X \) and \( Y \) are constant, the sums are varying.

Therefore, when we put \( A = |X - Y| \) and the opposite \( B = X + Y \), the
following formula is obtained under the condition that $B_{\text{COMPLEMENT}}$ will be calculated according to the same principle as $A_{\text{COMPLEMENT}}$:

$$Z = \text{constant} \cdot (A + 1)^\alpha \cdot (A_{\text{COMPLEMENT}} + 1)^\beta \cdot \frac{(B+1)^\gamma}{(B_{\text{COMPLEMENT}} + 1)^\delta}$$

As a third step of approximation, we can say the gestalt of interpersonal relations can be described by the product of the four power functions: First of dissimilarity; second, of its complement; third, of the sum of the values of personality characteristics; and fourth, of its complement. Accordingly, we have obtained a function with four parameters and one constant. This function can encompass the complementary tendencies (Yin and Yang) in their dynamic interplay on two dimensions each (A and B).

What do the three-dimensional gestalts look like that are described in this form? In Figure 3 five prototypes of gestalts are shown. Proceeding in an example from $X_{\text{min}} = 1$ and $X_{\text{max}} = 5$, or from $Y_{\text{min}} = 1$ and $Y_{\text{max}} = 5$ respectively, you can obtain the patterns by way of variation of parameters, as shown in Figure 3. Such gestalts can also be generated with other values for minimum and maximum values of X and Y.

Figure 3. Prototypes of Gestalts in Social Systems.
In the center of the gestalt, the proverb "Birds of a feather flock together," along with the extended version "Decrease of interpersonal relations with declining similarity," becomes conspicuously visible, as does the U-curve with the edge effect. In the lower gestalt, this tendency is less apparent. "Opposites attract," with the extended version "Increase of interpersonal relations with declining similarity," on the other hand, has become more strongly perceptible.

The reversed U-curve is especially conspicuous in the upper gestalt. In the left and the right ones the U-curve has converted into a one-sided tilt. A large number of patterns could be drawn with the same simple function.

At first, in reviewing the hypothesis of social relations in science, the starting point is the social relations, especially in coauthorship networks. In the process of study, one might re-examine whether such or similar gestalts are also applicable outside this field.

The gestalts obtained from coauthorship networks might be more or less similar to those in Figure 3, but they will be somewhat more robust. However, this is not attributable to defective deviations, but rather to the discrete values on the X- and Y-axis in contrast to the first ones. The same applies to the gestalts estimated according to regression analyses.

**Social Structures in Collaboration in Science and Hypothesis**

This paper shall test the hypothesis whether or not the above-mentioned central specifics underlying the structure of personal relations are reflected in scientific communities.

In 1979, Donald deB. Beaver—disciple, assistant, and later coauthor of de Solla Price—developed jointly with R. Rosen a comprehensive and empirically tested theory on scientific collaboration, which in the second half of this century, had become perceptible in extended coauthorships. In their fundamental analysis, Beaver and Rosen referred also to several additional growth-exceeding aspects of structure-forming processes in scientists' communities. The political and economic elites, outside of the science institutions, had become the conduits of financial support in science, but they did not decide on the distribution of those funds among the scientists' communities. That was a task that was to be fulfilled by the scientific elite itself within the science system. This process had intensified the degree of stratification in science. It was significant to realize who collaborated with whom and how did this collaboration become recognizable within the entire scientists' community by way of headlines of publications.

In the natural sciences and medicine, the second half of the twentieth century has been marked by teamwork and coauthorship, with about 60–70 percent of published scientific papers being coauthored. The development towards collaboration and cooperation has become such a prevailing trend that it is highly imperative to study it so as to gain fundamental knowledge...
on the intensification of research, which will be indispensable given the probable deceleration of science growth in the future.

What do these structures look like? Beaver and Rosen gave some indications: There is an intensified stratification in science observable due to professionalization. The initially prevailing "Master-master collaboration" (that is, "Birds of a feather flock together") has shifted towards a "Master-apprentice collaboration" system (that is, "Opposites attract").

These studies were related to the nineteenth century. However, a continuation for the second half of the twentieth century appears possible. Enquiries would have to be conducted on the status of every scientist who had made a contribution to the coauthorship network analyzed. Something like that should be done in the future. Today, however, larger networks with several thousands of authors would require a considerable labor expenditure.

By contrast, a relatively small amount of labour is needed for the analysis of an appreciably large amount of bibliometrical data. Therefore, this study has tried to find out whether a scientist's productivity is a characteristic that generates behavioral patterns, as is done by his/her status (master, apprentice, etc.).

Productivity, which is determined quantitatively by the number of publications per author, is coupled with several criteria—such as ability, professional recognition, endurance, social rank, communication, associative relationship with a team, and many others—that might have an influence on who collaborates with whom.

Of course, the number of a scientist's publications is not identical with his status. However, this number nonetheless provides a correlative indication. Even if the correlations for individuals might be moderate or low, they are prone to increase with the number of persons studied. In addition, an elitist scientist has, on average, far more publications than a normal scientist. As a result, a bibliometrical analysis assumes a somewhat different function than the studies by Beaver and Rosen. Yet a comparison between them is possible. Apart from such a comparison, this study is generally concerned with pattern formation; that is, pattern formation is not dependent upon these differences between the studies of the nineteenth century and the bibliometric analysis.

Hypothesis

Three-dimensional gestalts obtained from international coauthorship networks of different science disciplines can be shown to be strictly mathematically describable as a mathematical function.

Data

Twenty bibliographies of the international literature of physics and medicine were analysed. These bibliographies were obtained by SCI and compiled by ISSRU Budapest. The following bibliographies were analyzed:
Ten bibliographies of the international literature of physics (each: five years time period), including theoretical physics, experimental physics, and cross-disciplinary physics. All the data for the ten physics bibliographies were compiled into a single count:

- Years: 1980–1989
- Total number of articles: 21,730
- On an average: 2.5 coauthors per article, maximum about 10
- Total number of coauthorships: 366,000

Ten bibliographies of the international literature of medicine (each: five years time period), including biochemistry, pharmacology, clinical, and biochemical analyses. All the data for the ten medicine bibliographies were compiled into a single count:

- Years: 1979–1990
- Total number of articles: 40,596
- On an average: 3 coauthors per article, maximum 10
- Total number of coauthorships: 361,000

**METHODS FOR THE ANALYSIS OF COAUTHORSHIP NETWORKS**

Three different kinds of matrices are, independently of each other, the basis for the search for gestals that arise between scientists due to coauthorships. It has to be shown that all the three matrices are relevant for gestals.

The matrix of relative frequencies of coauthorship relations $F_{XY}$ between scientists with $X$ and $Y$ publications per scientist is one of the three matrices.

The second one will be the matrix of observed frequencies of coauthorship relations $C_{XY}$, and the third one will be the matrix of a special interaction index $H_{XY}$, which is used in sociology for studies of this kind (cf. Wolf, 1996).

Each of $F_{XY}$, $C_{XY}$, and $H_{XY}$ will be used, acting as variable “Z” (relations between coauthors) of the mathematical function.

**Matrix of Observed Coauthorships: Matrix $C_{ij}$**

The relative frequency of coauthorships of scientists $F_{ij}$ with $i$ and $j$ publications per author is expressed by the relationship between observed coauthorships $C_{ij}$ with the statistically expected ones $W_{ij}$.

First let us find out the matrix of $C_{ij}$. Given is a bibliography (partly represented, names of authors A, B, C . . . )

1. A, B
2. C
3. A
4. D, A, F
5. D, E
6. G, H

etc.
The number of publications per author \(i\) is determined by resorting to the "normal count procedure." Each time the name of an author appears, it is counted (e.g., A three times, i.e., \(i = 3\): Once in the first article, and each once in the third and fourth article).

It should be noted here that the term "article" is used in relation to a work or paper which was jointly written by one or several authors, compare 1., 2., 3., . . . etc. articles in the bibliography. By contrast, the term "publication" refers to persons.

If the relations in the by-line of an article are recorded from the point of view of every individual author to all the other authors, then a symmetrical matrix is obtained. As an example, in the fourth article there is, from the viewpoint of author D with \(i = 2\), one relation recorded to author A with \(j = 3\) and to F with \(j = 1\). Furthermore, in the same article, from the viewpoint of A with \(i = 3\), there is a relation recorded to D with \(j = 2\) and to F with \(j = 1\). From the viewpoint of F with \(i = 1\), there is a relation recorded to D with \(j = 2\) and to A with \(j = 3\).

The same procedure has to be continued with all of the articles. Generally, from the hypothetically assumed complete bibliography—it is only partly represented in the upper example—it is the matrix of the observed coauthorship relations of each author to all the other ones: Matrix \(C_{ij}\).

Matrix of Expectation Values: Matrix \(W_{ij}\)

From the hypothetically assumed complete bibliography, Table 4 was established. \(A_i\) are the number of authors with \(i\) publications per author. For example, there are \(A_2 = 64\) authors with two publications per author. \(A_i\) is distributed according to Lotka's law (1926).

The product of \(i\) and \(A_i\) is the number of publications of all authors (or group of authors respectively) with \(i\) publications per author. For example, the number of publications of the group of authors with two publications per author is the following one:

\[ i \cdot A_i = 2 \cdot 64 = 128 \]

**Table 4.** Distribution of Authors and Publications of the Hypothetical Bibliography \((\Sigma_j j \cdot A_j = 540)\).

<table>
<thead>
<tr>
<th>Number of Publications per Author</th>
<th>Number of Authors</th>
<th>Number of Publications of All Authors ((A_i))</th>
<th>Relative Frequency of Publications of All Authors ((A_i))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(A_1)</td>
<td>(i \cdot A_i)</td>
<td>(f_i = i \cdot A_i / \Sigma_j j \cdot A_j)</td>
</tr>
<tr>
<td>1</td>
<td>167</td>
<td>167</td>
<td>0.30926</td>
</tr>
<tr>
<td>2</td>
<td>64</td>
<td>128</td>
<td>0.23704</td>
</tr>
<tr>
<td>3</td>
<td>39</td>
<td>117</td>
<td>0.21667</td>
</tr>
<tr>
<td>4</td>
<td>27</td>
<td>108</td>
<td>0.20000</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>20</td>
<td>1</td>
<td>20</td>
<td>0.03704</td>
</tr>
</tbody>
</table>
The relative frequency of publications of one group of authors $f_i$ with $i$ publications per author is the ratio of the number of publications of this group divided by the total sum of publications of all groups of authors. For example, the relative frequency of publications of the group of authors with two publications per author is the following one:

$$f_i = \frac{i \cdot A_i}{\sum_{j} A_j} = \frac{128}{540} = 0.237$$

Probability $p_{ij}$, on the assumption of independence, is that a publication of the authors’ group with $i$ publications per author coincides with a publication of the authors’ group with $j$ publication per author, equals $f_i \cdot f_j$:

$$p_{ij} = f_i \cdot f_j$$

A matrix of $p_{ij}$ will be established according to the usual rules and following a matrix of expectation values $W_{ij}$:

$$W_{ij} = f_i \cdot f_j \cdot T$$

with $T = \text{Total sum of coauthorships} (\sum_i \sum_j C_{ij})$.

**Classification of Data**

There are very large bibliographies, for example, with more than fifty publications per author. In order to avoid statistical fluctuations, the data are classified according to the logarithm of the number of papers. There is a conjecture by Price (1963) that the logarithm of the number of publications is of a higher degree of importance than the number of publications per se.

Both the line variable $i$ and the column variable $j$ can be separately classified according to the logarithm, which results in the conversion of the large matrix, initially available in a raw form, into a smaller one by summing up lines and columns (class $X = 1$ contains those authors with one publication per author; class $X = 2$, authors with two to three publications; $X = 3$, authors with four to seven publications; $X = 4$, authors with eight to fifteen publications; and $X = 5$, authors with sixteen and more publications—by analogy the same applies to $Y$).

This limitation to five classes was established in order to compare behavioural patterns of different science disciplines. However, in most bibliographies there are only very few authors to be found with more than thirty-two publications. But, since the patterns become more stable with an increasing number of individuals, classes with individual authors would distort the picture.

Both for matrix $W_{ij}$ and for matrix $C_{ij}$ it is possible to determine the appropriate sum of data for every cell, that is, resultant $C_{XY}$ and $W_{XY}$.

The data are classified now into $5 \cdot 5 = 25$ classes—15 of them are independent of each other because of symmetry.
The relative frequency of coauthorships $F_{XY}$ is

$$F_{XY} = \frac{C_{XY}}{W_{XY}}$$

**Matrix of Special Interaction Indices**

In some sociological studies of interpersonal relations in social networks of men (Wolf, 1996), a special interaction index is used. This index provides information on the factor by which the observed frequency in a cell of a matrix deviates from the occupancy of this cell, which would otherwise be expected in case of statistical independence from characteristics. In order to calculate this index, we have to convert the matrix of observed frequencies $C_{XY}$ into a new matrix using geometric mean. The special interaction index $H_{XY}$ is defined as:

$$H_{XY} = C_{XY} \cdot \frac{G}{G_X \cdot G_Y}$$

where $G =$ geometric mean of all matrix data

$G_X =$ geometric mean of the data in row $X$

$G_Y =$ geometric mean of the data in column $Y$

**Regression Analysis**

In order to calculate the correlation coefficients and error probabilities, the logarithm was taken of the mathematical function above so that it was possible to carry out the classic linear regression analysis. Fifteen out of twenty-five data of the matrix were only evaluated due to symmetry. With four parameters and one constant, a degree of freedom of $df = 10$ was obtained.

**Mixture of Bibliographies**

When several bibliographies are mixed with each other, per class, both the observed and the statistically expected values of these bibliographies are added. After it, the usual procedures are carried out.

**Three-Dimensional Gestalts in Coauthorship Networks in International Science**

In a former study (Kretschmer, 1996), the author showed that after regression analyses, the correlation between empirical and theoretical values is increasing with the rising number of mixed individual patterns and finally tend to one. The same holds good for the bibliographies with increasing scope of data; that is, the “tendency towards a good gestalt” will enhance.

Therefore, from a “mixture” of ten bibliographies of international physics (source: SCI), the following matrix of relative frequencies is obtained, acting as an example for other matrices, compare Table 5. The corresponding gestalt is shown in Figure 4, bottom, left.
Table 5. Relative Frequencies of Coauthorships $F_{XY}$ in International Bibliographies of Physics.

<table>
<thead>
<tr>
<th>X/Y</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.866</td>
<td>0.864</td>
<td>0.647</td>
<td>0.536</td>
<td>0.417</td>
</tr>
<tr>
<td>2</td>
<td>0.864</td>
<td>1.391</td>
<td>0.968</td>
<td>0.795</td>
<td>0.655</td>
</tr>
<tr>
<td>3</td>
<td>0.647</td>
<td>0.968</td>
<td>1.322</td>
<td>1.09</td>
<td>0.959</td>
</tr>
<tr>
<td>4</td>
<td>0.536</td>
<td>0.795</td>
<td>1.09</td>
<td>1.408</td>
<td>1.237</td>
</tr>
<tr>
<td>5</td>
<td>0.417</td>
<td>0.655</td>
<td>0.950</td>
<td>1.237</td>
<td>1.856</td>
</tr>
</tbody>
</table>

Note: Hints on $X,Y$ and $F_{XY}$ cf. section “Methods”

Regarding the gestalts of the relative frequencies of international physics and international medicine (a “mixture” of ten bibliographies each) separately, regression analyses were carried out with a view towards estimating the parameters and the constant for every behavioural pattern. Based on these estimates, the twenty-five values of $Z_{XY}$ of a matrix were again calculated. Figure 4 contains, at the right side, the behavioural patterns esti-

Figure 4. Observations and Estimations of Two Gestalts of Relative Frequencies $F_{XY}$. Above: International medicine. Bottom: International physics. This figure contains, at the right side, the estimations and, at the left side, the actually observed gestalts.
mated according to the regression analysis and, at the left side, the actually observed behavioural patterns.

From a "mixture" of these twenty bibliographies of international physics and medicine, with altogether some 62,000 articles, some 2.75 coauthors on an average per article, some 730,000 coauthorships, the following three gestalts were obtained (cf. Figure 5):

- Observed frequency $C_{XY}$ with $R = 0.997$, $P < 10^{-10}$
- Special interaction index $H_{XY}$ with $R = 0.994$, $P = 2 \cdot 10^{-9}$
- Relative frequency $F_{XY}$ with $R = 0.978$, $P = 9 \cdot 10^{-7}$

The gestalts of observed frequencies and special interaction indices could, if possible, provide the greatest concurrence with the curvilinear function but, presumably, twenty bibliographies do not appear to be conclusive enough to substantiate the assumption. Irrespective of it, this approach was used to verify still another three international "mixtures."

The total sum of coauthorships in these five gestalts amounts to some 880,000 taken from altogether forty-one bibliographies.

Since these five gestalts are all very similar to each other, even when compared with the gestalt of observed frequencies in Figure 5, the differences were clearly shown in a representation that was selected to find the logarithm to the base 10 in the $C_{XY}$-axis (cf. Figure 6).

Figure 6 shows the five gestalts of observed frequencies, with two of them contained as "mixture" in the previous figure (source of the first two: SCI, the other three are derived from other sources, e.g., MEDLINE, PSYCINFO, etc.).

Gestalts 1 and 2 are gestalts of physics: $R_1 = 0.993$, $P < 3 \cdot 10^{-9}$ and $R_2 = 0.988$, $P < 5 \cdot 10^{-8}$. Gestalts 3 and 4 are gestalts of medicine: $R_3 = 0.996$, $P < 10^{-10}$ and $R_4 = 0.998$, $P < 10^{-10}$. Gestalt 5 is taken from social sciences: $R_5 = 0.990$, $P < 2 \cdot 10^{-8}$.

At the same time the gestals in the left part of the figure were turned around $180^\circ$ and by $90^\circ$ in the right part.

Both gestalts of physics are similar to each other; the same holds true of both medicine gestalts. However, the socio-scientific one looks somewhat different.

Now the question is whether this is coincidental or whether there are differences in terms of "types." Only additional and comprehensive analyses can give an answer to these questions.

Most of the gestalts display very sharp peaks in the $Z$ dimension. What do those peaks mean? These peaks can be found at the edges of the main diagonal, that is, $Z_{11}$ or $Z_{55}$ can become striking. As mentioned above, one of the three pivotal aspects of general characteristics of structures in interpersonal relations in social networks can be explained as the emergence of the edge effect. On the one hand, it is maintained that the persons of the lowest and the highest group would be visibly exposed due to their social
Figure 5. Three Gestalts of the Type from International Medicine and Physics. Gestalts of observed frequencies ($C_{XY}$), the special interaction index ($H_{XY}$), and the relative frequencies ($F_{XY}$).

Figure 6. Gestalts of the Logarithms of Observed Frequencies ($\log C_{XY}$) from Five Types in International Science. $X$ and $Y$ are like usual and $\log C_{XY}$ are attached to the third dimension. Two gestalts are from physics (1 and 2), two from medicine (3 and 4), one type from social sciences (5). In the left part, the gestalts are turned around by 180°, and, in the right part, they are turned around by 90°.
position and thus developed a stronger sense of affiliation ($Z_{11}$ and $Z_{55}$) than people having a medium-level social status. In addition, those people at a medium status display a stronger orientation towards career so that they are reluctant to have frequent contacts with people of the same level ($Z_{22}$, $Z_{33}$, $Z_{44}$). On the other hand, it is also suggested that the choices of people who are either at the very bottom ($Z_{11}$) or at the top ($Z_{55}$) are blocked in one direction.

CONCLUDING REMARKS

The results of the studies have confirmed Metzger’s conjectures that the conciseness principle also has validity for social systems and is valid even with the same conciseness as in the psychology of perception.

The three-dimensional gestalts in coauthorship networks, which are widely spread over the entire world, are obviously real objects that owe their shape to the balancing interaction of forces, namely to the dynamic equilibria interacting between Yin and Yang in the sense of ancient Chinese philosophy.

Now let us revert to the theoretical considerations where we found that, for describing a change of gestalts, a mathematical function was derived from ancient Chinese thought. Several characteristic gestalts that were explained in this study were taken out and presented in Figure 7.

The upper and the lower gestalts are new ones. The upper one represents a pattern of a Dutch institute of physics; international coauthorships are included. The lower one represents a pattern of an institutional coauthorship network from which all coauthorships based on authors who are not employed in this institution were removed. In fact, it is the “Kaiser-Wilhelm-Institut für Kohleforschung” (Institute for Coal Research) of the 1920s and 30s. It is really a very small network with only 350 coauthorships. That's why the gestalt is not evenly proportioned like the others. Undoubtedly, it would be worthwhile conducting and continuing such studies also at other institutions in order to find out whether the other gestalts resemble those obtained from the coal-research institute. The same one is valid for the Dutch institute of physics.

Under the condition that the conciseness principle underlies not only the coauthorship network as presented here, but beyond it, a great number of social processes in scientific communities—such as citation networks or the spreading of information—could be developed in the direction of application in information science. For example, it could perhaps be employed in designing search algorithms in databases.

At present, there are some further theoretical developments, including the conciseness principle and the Yin/Yang teaching. Lotka's law (1926) states that scientists will be counted who have $i$ publications included in the bibliography. Couples of scientists will be counted under the condition of both the first scientist’s count who has $i$ publications, and the second scientist’s count who has $j$ publications included in the bibliography. The fol-
lowing question arises: Is there any regularity for the distribution of coauthor couples in journals? Is there a continuation of Lotka's law on the third dimension?

In conclusion, the author suggests considering whether or not the conciseness principle, in all its succinctness, is only verifiable in scientists' communities, or whether it can also be largely extended to other social systems (see Figure 8)?

ACKNOWLEDGMENTS

The author extends her appreciation to the Technology Foundation Utrecht (STW), the Netherlands, which had provided financial support. Work on this article was carried out partly at the Center for Science and Technology Studies (CWTS), Leiden University, the Netherlands.

The author thanks Wolfgang Glänzel (Budapest) and R. Wagner-Döbler (München) for making available the bibliographies in this paper.
Figure 8. Gestalt Taken from the Special Interaction Index (H_{xy}). Source from which the gestalt in this study was developed: Marsden (1981, Table 1, p. 4). The values from the table were symmetrized (2,450 data).

REFERENCES


Towards Research Performance in the Humanities

HENK F. MOED, MARC LUWEL, AND A. J. NEDERHOF

ABSTRACT
This paper describes a general methodology for developing bibliometric performance indicators. Such a description provides a framework or paradigm for application-oriented research in the field of evaluative quantitative science and technology studies, particularly in the humanities and social sciences. It is based on our study of scholarly output in the field of Law at the four major universities in Flanders, the Dutch speaking part of Belgium. The study illustrates that bibliometrics is much more than conducting citation analyses based on the indexes produced by the Institute for Scientific Information (ISI), since citation data do not play a role in the study. Interaction with scholars in the fields under consideration and openness in the presentation of the quantitative outcomes are the basic features of the methodology. Bibliometrics should be used as an instrument to create a mirror. While not a direct reflection, this study provides a thorough analysis of how scholars in the humanities and social sciences structure their activities and their research output. This structure can be examined empirically from the point of view of its consistency and the degree of consensus among scholars. Relevant issues can be raised that are worth considering in more detail in followup studies, and conclusions from our empirical materials may illuminate such issues. We argue that the principal aim of the development and application of bibliometric indicators is to stimulate a debate among scholars in the field under investigation on the nature of scholarly quality, its principal dimensions, and operationalizations. This aim

Henk F. Moed, Centre for Science and Technology Studies (CWTS), Leiden University, P.O. Box 9555, 2300 RB Leiden, the Netherlands
Mark Luwel, Science and Innovation Administration, Ministry of the Flemish Community, Boudewijnlaan 30, Brussels, Belgium
A. J. Nederhof, Centre for Science and Technology Studies (CWTS), Leiden University, P.O. Box 9555, 2300 RB Leiden, the Netherlands

© 2002 The Board of Trustees, University of Illinois
provides a criterion of "productivity" of the development process. We further contend that librarians are not infrequently requested to provide assistance in collecting data related to research performance assessments, and that the methodology described in the paper aims at offering a general framework for such activities, and can be used by librarians as a line of action whenever they become involved.

1. Introduction

The study presented in this paper focused on the fundamental questions: How does one recognize a "good" scholar? How does one recognize an "important" scholarly contribution? The approach adopted in this study can be defined as bibliometric. It aims at identifying characteristics of scholarly publications that can validly be assumed to reflect the "quality" or "importance" of a scholar or a scholarly work. Therefore, a first answer to the question "How does one recognize a 'good' scholar?" is: One should examine his or her scholarly publications. In other words, in a bibliometric approach, it is assumed that important contributions to scholarly progress are sooner or later communicated in scholarly publications. This is considered to be a universal characteristic of scholarly development in natural sciences, life sciences, social sciences, and humanities.

A bibliometric approach is a quantitative approach. It attempts to calculate statistics of quantitative aspects derived from scholarly publications. Bibliometric indicators result from the statistical analysis of bibliographic information retrieved from the scholarly literature. This determines both their strength and their limitations. The strength of the bibliometric method is that, once established, it can be applied in a uniform or objective manner, eliminating the influence of subjective or personal factors. On the other hand, being a statistical method, it cannot take into account all particularities or special features of the objects to be assessed. As a consequence, bibliometric data should always be applied in combination with qualitative knowledge about the scholars involved and the subdisciplines in which they are active.

Bibliometric indicators have been successfully applied in many subdisciplines in the natural and life sciences. Data from the Science Citation Index (SCI), produced by the Institute for Scientific Information (ISI), play an important role in analyses of research performance in these subdisciplines (e.g., van Raan, 1996; Van Den Berghe et al., 1998). Thus far, the social sciences and humanities have not often been subjected to such analyses. At the same time, the academic authorities of many universities have expressed the need to obtain an insight into the research performance of all faculties and in all fields of scholarship.

Fundamental differences exist between the natural and life sciences, on the one hand, and the humanities and social sciences, on the other hand, with respect to the research object, the methodologies applied, and the
structure of scholarly communication. As a result, those who are involved in the development of performance indicators for the humanities and social sciences are confronted with the following situation.

Firstly, they need to develop methodological tools to assist evaluation agencies or policymakers in carrying out their tasks, in the same way that the current SCI-based methodologies provide supplementary research assessment tools in the natural and life sciences. Secondly, this methodology should take into account the characteristics of the field of scholarship, the nature of the scholarly research object, and particularly the communication practices among scholars and the structure of the communication system in their fields. A study dealing with these challenges can indeed be considered an endeavour.

This paper attempts to describe a general methodology for developing bibliometric performance indicators. Such a description provides a framework or paradigm for application oriented research in the field of evaluative quantitative science and technology studies, particularly in the humanities and social sciences. It is based on a study on scholarly output in the field of Law at the four major universities in Flanders, the Dutch speaking part of Belgium. The background, setup, and methodological framework are presented in Section 2. It is followed by a concise review in Section 3 of earlier studies on research performance in this field of scholarship.

Section 4 presents a number of characteristic outcomes of the study. Its principal aim is to illustrate the methodology outlined in Section 2. A detailed overview of the study is presented in a research report by Luwel et al. (1999). The study illustrates that bibliometrics is much more than conducting citation analyses based on the ISI citation indexes, as citation data do not play a role in this study.

Finally, Section 5 gives a critical discussion of the methodology, in the light of the experiences collected in the study. This discussion includes a short overview of the comments of scholars and of the followup of our study, and summarizes the main features of our methodology.

2. BACKGROUND, SETUP, AND METHODOLOGICAL FRAMEWORK

2.1 Background and Setup of the Study

The study presented in this paper was a pilot study commissioned by the Flemish Inter-University Council (VLIR) for developing a methodology to assess research performance in the social sciences and humanities. The disciplines selected by the VLIR for this study were Law and Linguistics. This paper discusses only the study on Law. The Catholic University of Leuven, the University of Gent, the Flemish-speaking Free University of Brussels, and the University of Antwerp decided to participate in the study, which was partially funded by a grant approved by the Flemish Minister-President, who is also in charge of science and technology policy.
At the start of the project, in early 1997, a project team was set up, consisting of the research staff of the VLIR, researchers of the Centre for Science and Technology Studies (CWTS) at Leiden University (the Netherlands), and a staff member of the Science and Innovation administration of the Ministry of the Flemish Community.

The activity of the project team was supported by a university expert group, set up for each of the two disciplines, and composed of senior academic staff members of the departments of Law and Linguistics at the four participating universities. The expert groups assisted the project team during the elaboration of the project, and played an active role in their respective universities in a series of activities, such as data collection, the development of classification systems, and commenting on drafts of the final report.

The first stage of the project work plan was a clear boundary setting of the two disciplines. For the Law faculties, this operation was relatively simple. Academic staff data were extracted from the universities’ central administration databases, including year of birth, gender, starting and ending date of their appointments, rank, length of appointment (e.g., 40 percent, that is, two days a week), funding source, and year of Ph.D. granting.

In a subsequent phase, a questionnaire was prepared to collect quantitative data. It was sent to all researchers, both junior and senior, active in one of the four Flemish universities at the end of the year 1996. The members of the two expert groups were of the opinion that the study should not be limited to research activities only, but that all academic activities should be taken into account, analyzing also the fraction of work dedicated to research. The most important data, analyzed in this paper, were lists of publications.

In tandem with the analysis of the first questionnaire, a second questionnaire was elaborated, again in collaboration with the expert groups, in order to collect more qualitative information on leading publications, journals, publishers, and Flemish scholars in the two disciplines. The main objective was to obtain insight into scholars’ perceptions on scholarly work quality, and to assess to what extent the scholars’ opinions corroborated the outcomes of the quantitative indicators. For Law, this questionnaire was sent to professors working at Flemish, Dutch, and Belgian French-speaking universities, as well as to Belgian senior magistrates. Respondents were asked to indicate “outstanding,” “good, yet not outstanding,” and “less good” journals, and the names of Flemish scholars whose work is currently very important to their subdiscipline.

A draft report was sent to and discussed with the two expert groups, and the results of these discussions were incorporated into the final version of the report.

2.2 Methodological Framework

Our study was primarily a methodological one. Rather than making comparative evaluation statements on research performance at the four universities, it explores methods to provide a clear insight into scholarly research
activities and proposes indicators for measuring relevant aspects of scholarly performance. It examines the validity of such indicators and explores the type of data needed to construct them, taking into account the availability and reliability of such data.

In this study, the participants were confronted with the problem of lack of standardization in the publication practices of Law scholars. This is a problem in many subfields in the social sciences and humanities. By contrast, from interviews with scientists in molecular biology, it appears that this subfield has a strong consensus of how research materials should be published, and which journals are the most prestigious. All important research output is published in English, in international journals. There are some five to ten journals that are generally acknowledged as "top" journals (e.g., Van Den Berghe et al., 1998). Many publication lists of scientists have a standard format, and small contributions, such as meeting abstracts or editorials, are not even listed.

However, in the humanities, and particularly in Law, important contributions are often published in commemorative books with a narrow circulation. There are many types of publications, and publication lists of scholars are often not ordered by type. Publications are often in the mother language, and many activities have an applied nature.

In our study, a thorough analysis of the publication output was conducted. The quality of the bibliographic information was assessed. The scholars providing the publication data added several types of additional information to each publication, using classification systems of types of publications and subdisciplines. This additional information was examined carefully, from the point of view of its accuracy, embedded structural relationships, the degree of consensus among scholars, and the extent to which differences existed among subdisciplines.

Typical examples of more specific research questions were: How important is the role of books in the communication among scholars? How can one reliably measure the number of books published by a scholar during a given time period? How important is the role of journals? Are there differences among subdisciplines? In which ways do publications classified by juridical scholars as "substantial contributions" differ from "small contributions"? Do the two types of publications reveal different bibliometric characteristics? How consistently was this distinction made among scholars? Are there any criteria to discriminate between scholarly journals and journals of a more applied nature? Assuming that, in the field of Law, it is appropriate to make a distinction between a "scholar" and a "practitioner," are there any bibliometric indicators that can be used in helping to discriminate between the two types?

What is the perception of Flemish, Belgian French-speaking, and Dutch scholars on the quality of individual Law journals? Were there significant differences between the perceptions of Flemish scholars and those of their
colleagues abroad? What does a tentative ranking of journals look like, based on their quality, as perceived by scholars, and their international visibility? What is the position of Flemish journals in such ranking? To what extent do actual publication strategies of Flemish scholars conform to a "quality standard" as expressed in their own ratings of scholarly journals?

3. A CONCISE REVIEW OF EARLIER STUDIES ON RESEARCH PERFORMANCE IN LAW

Several authors have addressed the measurement of research performance in the social sciences and humanities from a general perspective (Cole, Cole, & Dietrich, 1978; Garfield, 1979, 1986; Cole, 1983; Nederhof et al., 1989; Kyvik, 1989; Finkenstaedt, 1990; Nederhof & Zwaan, 1991; Nederhof & Noyons, 1992; Hemlin, 1996; Hemlin & Gustafsson, 1996; Wood, 1998). Law, in particular, has been called "the birthplace of citation study" (Shapiro, 1992, p. 339). For instance, according to Shapiro, in 1894 a table showing the comparative citation frequency of the Federal, English, and State decisions was produced in Boston, and in 1817 a first count of the volume of English Law reports was made. Notwithstanding this very early start, a literature search revealed very few articles referring to the measurement of scholarly performance in Law (cf. Justiss, 1993).

Swygert & Gozansky (1985) studied the productivity of 1,950 U.S. senior Law faculty members (full-time appointed, full professors) by examining their publications in the Legal Resource Index (LRI) and the database of the Online Computer Library Centre, Inc. (OCLC) during three and four years, respectively. The coverage by LRI (mostly articles and book reviews) and OCLC (book titles) was deemed nearly complete. Swygert & Gozansky (1985, p. 378) included a wide variety of publications: "Articles, books, book reviews, casebooks, teacher manuals, practice manuals, textbooks, monographs, treatises, supplements and compilations, as well as edited and co-authored works," provided the entry was five pages or longer in length. Testimonials, obituaries, reports or proceedings, bibliographies, newspaper columns, recordings and any title labelled "bar review notes" were not included.

The results showed that 44 percent of the faculty members had no publications whatsoever, while 65 percent had no more than 1 publication. Only 15 percent had four or more publications. The mean number of publications was 1.5 per faculty member over a period of three to four years, or less than 1 publication in two years. A school or university published on average about 18 items, with the faculty at Chicago (mean = 5.1 publications per member), Cornell, and New York University ranking highest in average productivity, followed by Berkeley, Stanford, Yale, and Harvard (all with 3.0 publications or more per faculty member). Schools with less senior faculty members were less productive on average (as indicated by the Pearson correlation coefficient, r = 0.53). The authors assumed that smaller-sized
schools had a higher teaching load per head. It should be noted that the productivity of faculty members of lower age (the mean was fifty-one years), and striving for a tenured position, may well be considerably higher.

Other less extensive studies analyzed the productivity of institutions by recording author affiliation in journals of high prestige (e.g., Ellman, 1983; Sorensen, 1994).

Two publications related to research performance assessment in juridical research are of particular interest to the study presented in this report. The first is the November 1996 final report of the Inter-University Committee of the Flemish Faculties of Law, entitled "The Assessment of Performance in Juridical Research." This report presents a classification of scholarly publications in the field of juridical research. In our study, a classification scheme was applied that is principally based upon that of this committee. Therefore, our study can be viewed as a first large-scale experiment with this classification system.

According to the Inter-University Committee of the Flemish Law Faculties, the published book ranks first in the scholarly juridical publication output. A book is viewed as the result of an often individual and personal synthesis of legislation, jurisdiction, and juridical theory in a subdiscipline. A book often reflects continuous, intensive scholarly research, conducted for many years. In the Committee's view, the same is true for doctoral theses. Therefore, as a rule, a doctoral thesis deserves publication as a book.

The Committee also made a distinction between substantial scholarly contributions and scholarly contributions of a limited size, published in accepted scholarly journals, anniversary volumes, seminar reports, and collective works. Typical examples of the first type are: A leading article, a review on jurisdiction, or a thorough annotation. A short annotation, a thorough book review, or an intervention as panel member or participant in a conference are examples of scholarly contributions of a limited size.

The Committee did not succeed in developing a classification of scholarly journals in terms of their quality or reputation. The main impediment to such a ranking was that most Law journals show large variations in the quality of the papers published. In addition, some subdisciplines are covered by a limited number of national journals only, for which no definitive ranking could be made.

A second report that bears a high relevance to our study is the "Quality Assessment of Research—Rechtsgeleerdheid," published in April 1996, by the Review Committee on Juridical Research, set up by the Association of Universities in the Netherlands (VSNU). The report presents an assessment of research activities in Law at universities in the Netherlands. In the publication output assessment, the Dutch VSNU Committee applied several criteria to identify the most valuable scholarly works in the mass of publications listed. Firstly, the Committee made a distinction between first editions and later editions of single- or multiauthored books. Interestingly,
this aspect is not mentioned in the report of the Committee of the Flemish Law Faculties.

Secondly, in order to discriminate between substantial and small scholarly contributions, the VSNU Committee took into account the publications length as reflected in the number of pages. Publications with a length of more than five pages were regarded as "substantial" contributions. For each research programme to be assessed, the Committee regarded the number of single- or multiauthored books (first editions only), doctoral theses, and articles of which the number of pages exceeded five, as the most significant productivity measure. In addition, the total number of publications (of all types) was determined.

In its final report, the VSNU Committee expressed the need for clear guidelines and criteria for selecting and structuring the information on publication output. Such criteria should first of all specify the type of publications to be included in a performance or quality assessment. In addition, the Committee stressed that attempts should be made to distinguish between "genuine" scholarly contributions, on the one hand, and informative publications primarily aimed at providing social services, on the other. Genuine scholarly publications conform to criteria of methodological soundness, thoroughness, and significance. In the Committee's view, it is the first category of publications that distinguishes between a juridical scholar and a practitioner or a professional legal expert. Academic scholars should be primarily evaluated according to their contribution to scholarly progress, rather than to their practical activities.

The relationship between juridical research and practice is also addressed in the report by the Inter-University Committee of the Flemish Law Faculties. This committee stated that juridical research primarily serves the practice, a basic characteristic that creates difficulties in distinguishing between fundamental and applied juridical research.

4. Results

The core of our analyses can be denoted as bibliometric, and related to publications. In this section, the main findings are summarized related to the Flemish juridical scholars' publication output. A detailed account is given in the research report by Luwel et al. (1999).

4.1 Units of Analysis

We agree with McGrath's (1996) statement that it is crucial in any bibliometric study to define carefully its units of analysis. This study deals with several units of analysis. The first is the individual publication. The main aspect is the classification of individual publications. In view of the main interest of our study—research performance assessment—an attempt was made to rank the various types of publications according to their importance or size of contribution to scholarly progress. A second unit of analy-
sis is that of the journal. Journals were classified on the basis of characteristics of the publications included, and also on the basis of judgments by peers obtained from a questionnaire. The distinction between scholarly journals and journals of an applied nature or directed towards a broad audience is a crucial element. A third unit of analysis is the individual scholar. Here, the distinction between "scholar" and "practitioner" is important, based on an analysis of the type of publications made, the type of journals used, and also on quality judgments obtained from a questionnaire.

4.2 Publication Output: Classifications

In the first questionnaire, respondents listed their complete publication output during the 1992-1996 time period. The total number of publications listed amounted to 3,753. All publications were arranged into types. The classification of publications in Law applied in this study is largely based on the 1996 final report of the Inter-University Committee of the Flemish Law Faculties (see Section 3). The classification system is presented in Table 1.

In this system, a book is the most important publication, as it is often the reflection of continuous, intensive scholarly research, conducted for

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Book published as single author</td>
</tr>
<tr>
<td>2</td>
<td>Published doctoral (Ph.D.) thesis</td>
</tr>
<tr>
<td>3</td>
<td>Book published as coauthor</td>
</tr>
<tr>
<td>4</td>
<td>Unpublished doctoral (Ph.D.) thesis</td>
</tr>
<tr>
<td>5</td>
<td>Substantial scholarly contribution, published in accepted scholarly journals, anniversary volumes, seminar reports, and collective works, such as a leading article; review on jurisdiction; thorough annotation</td>
</tr>
<tr>
<td>6</td>
<td>Edited book or collective work</td>
</tr>
<tr>
<td>7</td>
<td>Published integral contribution to international conferences</td>
</tr>
<tr>
<td>8</td>
<td>Published abstract of lecture at international conferences</td>
</tr>
<tr>
<td>9</td>
<td>Published integral contribution to national conferences</td>
</tr>
<tr>
<td>10</td>
<td>Published abstract of lecture at national conferences</td>
</tr>
<tr>
<td>11</td>
<td>Scholarly contribution of a limited size, published in accepted scholarly journals, anniversary volumes, seminar reports and collective works, such as a short annotation; a thorough book review; an intervention as panel member or disputant on a conference</td>
</tr>
<tr>
<td>12</td>
<td>Teaching course notes</td>
</tr>
<tr>
<td>13</td>
<td>Scholarly edition of codes of Law, jurisdiction volumes, bibliographies</td>
</tr>
<tr>
<td>14</td>
<td>Research report circulated in the scholarly community</td>
</tr>
<tr>
<td>15</td>
<td>Internal research report or report on commissioned work</td>
</tr>
<tr>
<td>16</td>
<td>Published inaugural or valedictory lecture</td>
</tr>
<tr>
<td>17</td>
<td>Other publication, such as an introduction, editorial contribution, letter to the editor, commemorative article, correction, descriptive or introductory book review</td>
</tr>
<tr>
<td>18</td>
<td>Juridical publications for a wide audience</td>
</tr>
</tbody>
</table>
many years. In the view of the Committee, the same is true for doctoral theses. One of the key elements in the system is the distinction between substantial contributions (about 33 percent of all publications listed), small contributions (17 percent), publications for a wide audience (11 percent), and other publications (13 percent).

The classification system of publication types was not always applied correctly by the respondents. Many relevant examples of erroneous classifications were collected. At times, multiauthored books were classified as single-authored. In addition, respondents often listed both the unpublished and the published versions of their Ph.D. thesis. Further, it is questionable whether reports of advisory committees or committees preparing legislation can be qualified as books. The same is true for teaching course notes. In view of the great importance of books as publications in juridical research, the Inter-University Committee of Flemish Law Faculties—or any committee dealing with this issue—was suggested to specify more precisely the criteria to be applied in determining whether or not a publication should be classified as a book.

A main problem related to book publications (about 9 percent of the total number of publications listed) is that books can have different editions. In the data provided by the respondents, in 78 percent of the cases, no information was given on the edition number. Obviously, publishing the first edition of a book is a much greater achievement than publishing a slightly revised version of an existing book. It was suggested allowing only first editions or completely revised editions of existing books to be classified as genuine book publications. In our analysis of book publications, a Flemish online inter-university library catalogue was used. This has proven to be a most useful tool in verifying publication lists, particularly book publications or book chapters. As a rule, information on the edition number of a book is available in that catalogue.

Bibliometric characteristics of articles classified as substantial contributions were examined in more detail. Table 2 illustrates that 84 percent of substantial contributions had a page length greater than five. For the three other types this percentage is near 80 percent. Among the 16 percent of substantial contributions containing five pages or less, there were several with a page length of one or two. It is questionable whether such publica-

<table>
<thead>
<tr>
<th>Publication type</th>
<th>% Pub. with Num. Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;= 5</td>
</tr>
<tr>
<td>Substantial Contributions</td>
<td>16%</td>
</tr>
<tr>
<td>Small Contributions</td>
<td>77%</td>
</tr>
<tr>
<td>Other Publications</td>
<td>82%</td>
</tr>
<tr>
<td>Publications for Wide Audience</td>
<td>83%</td>
</tr>
</tbody>
</table>
tions can be marked as substantial contributions. It is worthwhile consid-
ering whether or not it is appropriate to set a minimum page length for a
publication in order to be classified as a substantial contribution. One could
even take into account differences in the number of printed characters (or
words) per page in the various sources.

Another important phenomenon observed in the publication lists was
that the same publication might be published twice by the same author, in
different sources. The two versions may be entirely identical or show only
small differences. A bibliometric tool was developed to identify candidate
identical publications, that is, publications published by the same author
that are probably identical. The method compares the titles of pairs of
publications, and determines the number of words two publication titles
have in common. Publications with similar titles are then selected. Howev-
er, prior to drawing definite conclusions, it is appropriate to collect print-
ed copies and compare these manually. In the class of books, doctoral the-
ses, and substantial contributions, almost 8 percent of the publications
written in Dutch, and listed by the same authors, were found to have very
similar titles. A detailed analysis of printed copies revealed that most of the
pairs were actually (almost) identical publications.

4.3 Publication Output in Journals

The role of journals was found to be less prominent in communicat-
ing research results in juridical research than it is in many fields in the
natural and life sciences. The percentage of journal articles among all pub-
lications listed by the respondents to the first questionnaire, and published
during 1992–1996, amounted to 59 percent. In the category substantial con-
tributions it was 60 percent. Nevertheless, this percentage was considered
sufficiently high to justify a separate analysis of journals.

In our analysis of journals, two statements of the above mentioned Inter-
University Committee of Flemish Law Faculties are of particular interest.
The first deals with the relationship between juridical research and prac-
tice. The second statement will be discussed in Section 4.4. The Flemish
Committee stated that juridical research primarily serves the practice, which
makes it difficult, if not impossible, to distinguish between fundamental and
applied juridical research.

The data collected in our study made it possible to distinguish between
scholarly journals and journals of a more applied nature, or journals direct-
ed to a wide audience. The distinction is based on an analysis of the classifi-
cation of publications into types given by the respondents themselves. By
arranging the classified publications by journal, one obtains an indirect
insight into the scholars' perceptions of the nature of the journals. A basic
assumption underlying this approach is that scholarly journals should con-
tain a certain minimum number of publications classified by the respon-
dents as substantial contributions.
Table 3 presents typical results from this analysis. The second, third, and fourth columns give, for each journal, the total number of publications, the number of substantial contributions, and the percentage of substantial contributions, respectively. The table shows that the journals Fiskoloog: Nieuwsbrief over Fiscaliteit en Belastingen (Newsletter on Fiscal Matters and Taxes), Balans: Nieuwsbrief voor Accountancy en Financieel Management (Newsletter on Accountancy and Financial Management), and en Milieurecht Info (Information on Environmental Law) include very few or no articles denoted by the scholars themselves as substantial contributions. These journals are typical examples of applied journals or journals directed to a wide audience.

In addition, findings from the first questionnaire on input, output, and recognition, and from the second questionnaire on quality perceptions, were combined. The number of journal publications made by respondents in the first questionnaire was compared to the number of times the respective journal was nominated in the second questionnaire. This analysis included only nominations made by Flemish scholars. A more complete picture of the quality perceptions of journals, including the views of Belgian French-speaking and Dutch scholars, will be presented in Section 4.4.

The last four columns in Table 3 give the total number of Flemish nominations and the total number of times the journal was qualified by Flemish respondents as “outstanding” (qualification A), “good but not outstanding” (qualification B) or “not often containing high quality contributions” (qualification C). It should be noted that there is a substantial overlap between the respondents in the first and the second questionnaire. Our findings enabled us to examine the consistency of their responses.

Table 3 presents the ten journals in which the respondents to the first questionnaire have published the largest number of publications during the 1992–1996 time period. The journals were ranked by descending total number of publications. It can be seen that journals in which the Flemish scholars published relatively few substantial contributions, or no such contributions at all, were hardly nominated by the Flemish respondents in the second questionnaire.

It should be noted that general journals tend to be nominated more frequently than more specialized ones. For instance, Rechtskundig Weekblad (Juridical Weekly) comprises many—if not all—juridical subdisciplines. Therefore, it is perhaps not surprising that so many Flemish respondents mentioned it. The data presented in Table 3 can be used as a first step in a process of evaluating and qualifying journals used by Flemish juridical scholars. In principle, it could be used to give weights to juridical journals, enabling one to calculate weighted indicators of publication output, taking into account the orientation and quality of the journal. A first attempt to assign such weights is presented below.
Table 3. Journals Used and Nominated Most Frequently by Flemish Scholars.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Rechtskundig Weekblad</td>
<td>456</td>
<td>135</td>
<td>29.6</td>
<td>42</td>
</tr>
<tr>
<td>Fiskoleeg: Nieuwsbrief voor Fiscaliteit &amp; Belast.</td>
<td>275</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>Tijdschrift voor Privaatrecht</td>
<td>122</td>
<td>39</td>
<td>32.0</td>
<td>16</td>
</tr>
<tr>
<td>Algemeen Juridisch Tijdschrift</td>
<td>91</td>
<td>18</td>
<td>19.8</td>
<td>10</td>
</tr>
<tr>
<td>Revue Historique de Droit Francais et Etranger</td>
<td>55</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>Recente Arresten van het Hof van Cassatie</td>
<td>51</td>
<td>34</td>
<td>66.7</td>
<td>8</td>
</tr>
<tr>
<td>Balans—Nieuwsbrief</td>
<td>50</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>Tijdschrift voor Rechtsdocum. &amp; -Informatie</td>
<td>50</td>
<td>0</td>
<td>0.0</td>
<td>1</td>
</tr>
<tr>
<td>Milieurecht Info.</td>
<td>47</td>
<td>5</td>
<td>10.6</td>
<td>0</td>
</tr>
<tr>
<td>Tijdschrift voor Rechtspersoon en Venmoetschap</td>
<td>39</td>
<td>29</td>
<td>74.4</td>
<td>6</td>
</tr>
</tbody>
</table>

Total Pub.: Total number of publications. Subst. Contr.: Number of substantial contributions. % Subst. Contr.: Percentage of substantial contributions (relative to total number of publications). Flemish nominations: A: “outstanding”; B: “good but not outstanding”; C: “not often containing high quality contributions.”

4.4 Ranking of Journals and Weighting of Publication Output

A second statement of the Inter-University Committee of Flemish Law Faculties concerning journals relates to journal quality. The Committee did not succeed in developing a classification of scholarly journals in terms of their quality or reputation due to the fact that most Law journals show large variations in the quality of papers published and some subdisciplines are covered by a limited number of national journals only.

An analysis of the data from the second questionnaire enabled us to make at least a first step in the process of evaluating and qualifying journals used by Flemish juridical scholars. The overall response rate was about 33 percent.

The distribution of the quality ratings per journal was examined, as well as the journals’ national or international visibility. Both aspects were quantified. The product of these two weights provides a third weight factor, which is assumed to indicate a journal’s quality, as perceived by the respondents’ nominations, and its visibility, as reflected in the geographical spread of the respondents.

The A, B, and C scores given by the 144 respondents were combined in a simple quality weight for a particular journal: Quality weight = \( (3 \cdot A) + (2 \cdot B) + (1 \cdot C) \) + \( (A + B + C) \). The quality weight varies between 1 and
C nominations) and 3 (only A nominations). For example, a journal with 6 A nominations, 2 B nominations, and 1 C nomination was weighted as follows: \((3 \cdot 6) + (2 \cdot 2) + (1 \cdot 1) + (6 + 2 + 1) = 23 + 9 = 2.56\). Overall, this journal was scored slightly closer to A than to B. A detailed overview of the method, including a discussion on possible biases in view of the modest response rate, is presented in Nederhof, Luwel, & Moed (2001).

The second weight involved the international visibility of journals. Here, the nationalities of the respondents nominating a journal were decisive. For instance, journals nominated more than fourteen times by at least two Belgian and two Dutch nominators received a weight of 2.0. Thus, four nominators can be sufficient for a journal to be weighted—because of its international visibility, and, it is assumed, its correspondingly larger potential public. A lower weight is assigned to journals nominated by at least one Belgian and one Dutch respondent.

To illustrate the application of journal weights, these have been linked to the substantive output of Flemish scholars. Table 4 lists ten journals in which the Flemish scholars have published the largest number of substantial contributions. The left end of Table 4 contains the number of nominations (total and from the three samples), and the number of A, B, and C nominations obtained in the questionnaire on quality perceptions. These data were used to compute a quality weight (Quality), an (inter)national visibility weight (Int. Vis.), and an index combining these two weights (Weight).

Table 4 shows that the two journals in which Flemish scholars published most of their substantial contributions, Rechtskundig Weekblad (Juridical Weekly) and Tijdschrift voor Privaatrecht (Journal of Private Law), were also the journals that obtained the highest weight. For example, a substantial contribution in one of these journals is weighted approximately 3 times as high as a single substantial contribution in Tijdschrift voor Rechtspersoon en Vennootschap (Journal of Corporate Body and Partnership).

These examples show that the application of journal weights—based on quality perceptions of international samples of scholars—to the output of Flemish scholars might yield quite differentiating results. A few publications in journals with high weights can weight more heavily than many publications in journals with lower quality and visibility ratings. Also, similar output levels can be weighted quite differently, depending upon the weights of the journals. In our view, our rankings provide a sound basis for a thorough discussion among Flemish juridical scholars on the quality of journals in Law.

4.5 International Orientation

The main publication language of Flemish publications in Law is Dutch. 81 percent of all publications were written in Dutch, and 10 percent in English. Interestingly, publications published in English were rather uneven-
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>57</td>
<td>42</td>
<td>12</td>
<td>3</td>
<td>35</td>
<td>17</td>
<td>5</td>
<td>Rechtskundig Weekblad</td>
<td>135</td>
<td>2.6</td>
<td>2.00</td>
<td>5.2</td>
</tr>
<tr>
<td>21</td>
<td>16</td>
<td>2</td>
<td>3</td>
<td>14</td>
<td>4</td>
<td>3</td>
<td>Tijdschrift Voor Privaatrecht</td>
<td>39</td>
<td>2.6</td>
<td>2.00</td>
<td>5.3</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
<td>2</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>Recente Arresten Van Het Hof Van Cassatie</td>
<td>34</td>
<td>2.3</td>
<td>1.00</td>
<td>2.3</td>
</tr>
<tr>
<td>13</td>
<td>7</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>9</td>
<td>2</td>
<td>Panopticon</td>
<td>30</td>
<td>2.0</td>
<td>1.75</td>
<td>3.5</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>Tijdschrift Voor Rechtspersoon En Vennootschap</td>
<td>29</td>
<td>1.8</td>
<td>1.00</td>
<td>1.8</td>
</tr>
<tr>
<td>26</td>
<td>19</td>
<td>7</td>
<td>0</td>
<td>14</td>
<td>6</td>
<td>6</td>
<td>T. Voor Bestuurswetenschappen En Publikrecht</td>
<td>22</td>
<td>2.4</td>
<td>1.00</td>
<td>2.4</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>Tijdschrift Voor Milieurecht</td>
<td>21</td>
<td>2.7</td>
<td>1.75</td>
<td>4.7</td>
</tr>
<tr>
<td>11</td>
<td>10</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>3</td>
<td>Algemeen Juridisch Tijdschrift</td>
<td>18</td>
<td>1.9</td>
<td>1.00</td>
<td>1.9</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>T. Voor Onderwijsrecht En Onderwijsbeleid</td>
<td>16</td>
<td>2.0</td>
<td>1.25</td>
<td>2.5</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>Notarieel En Fiscaal Maanblad</td>
<td>14</td>
<td>2.5</td>
<td>1.00</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Legend: Journals weights applied to journals with at least three substantial contributions.


Journals titles printed in bold are nominated at least twice by Flemish/Belgian French speaking and by Dutch scholars.
ly distributed among the various subdisciplines. In Information Technology Law and Informatics, Public International Law, Economics of Law, Private International Law, and European Community Law the share of publications in English was greater than 25 percent. Subdisciplines with more than 200 publications during 1992–1996, and with less than 5 percent of publications in English, were: Tax Law, Judicial Law, Contract Law, and Administrative Law.

A high percentage of publications in Dutch is often assumed to reflect the national (or regional) character and relevance of juridical research. It is indeed plausible to assume that the international orientation of a subdiscipline is related to the object of research in that subdiscipline. From this point of view, it is perhaps not surprising that subdisciplines such as International Law, International Private Law, and European Community Law show a relatively high percentage of publications written in English. In addition, Information Technology Law, Legal Informatics, and Law and Economics focus on issues with a growing international interest within the framework of globalization.

In the final report, we maintained that genuine scholarly research, regardless of the subdiscipline and the object of research, leads to results the relevance and implications of which go beyond a purely national viewpoint or interest. This may be less so for contributions of a more applied or practical nature. Therefore, outcomes of genuine scholarly research, even those primarily related to national aspects, deserve to be communicated—in an appropriate form—to scholars in other countries as well. This does not imply that all publications should be directed towards an international scholarly public, but rather that at least some publications should go beyond a purely national or local viewpoint and should be exposed to criticisms from a wide international scholarly audience.

If one is willing to agree with the line of reasoning outlined above, it follows that the international orientation or, more specifically, the extent to which research findings are communicated across national or cultural boundaries, is a relevant criterion of scholarly performance in all subdisciplines.

We concluded that the percentage of publications in English can be used as an indicator of international orientation, but that two comments should be made here. First, possibly other indicators are equally valid or even more valid for measuring this aspect of research performance. Perhaps the percentage of publications in non-Flemish media is a more appropriate indicator of international orientation. A further discussion on this topic with Law scholars could provide more insight. Secondly, we did not wish to imply that publications written in English are generally of better quality than publications in other languages merely because English was used as the publication language, nor did we maintain that all Flemish publications of good quality were published in English in the past, or should be published in English in the future.
4.6 Indicators of Research Performance

A detailed comparison was made of the results from the second questionnaire on nominations of Flemish scholars with several bibliometric indicators based on publications, calculated for those Flemish scholars who replied to the first questionnaire. For instance, the number of publications made by Flemish scholars receiving three or more nominations was compared with the number of publications by scholars nominated once or twice, or with that of scholars not nominated at all. Results are presented in Table 5.

Table 5 illustrates that scholars receiving three or more nominations have published a significantly higher number of books, Ph.D. theses, and substantial contributions than scholars who were not nominated at all in the questionnaire on quality perceptions. Analyzing the total number of pages produced, a significant difference was observed between the class of scholars without any nominations, on the one hand, and the classes of scholars with one to two or three to ten, on the other. With respect to the total number of publications or the total number of pages, no significant differences were found among the three classes of nominations.

If one considers the number of nominations received as a measure of scholarly quality, as perceived by colleagues or peers, our statistical analysis suggests that the number of books, Ph.D. theses, and substantial contributions is a more appropriate indicator of research performance than the total number of publications. This outcome provides an empirical confirmation of the indicative rank order of types of publications given by the Inter-University Committee of Flemish Law Faculties. It also gives grounds for the definition of books, Ph.D. theses, and substantial contributions as juridical core publications.

These findings also have implications for statements made by the Review Committee on Juridical Research, set up by VSNU, in their 1996 report “Quality Assessment of Research—Rechtsgeleerdheid” (see Section 3).

Table 5. Statistical Relationship Between Number of Publications and Number of Nominations

<table>
<thead>
<tr>
<th>Nr. Nominations</th>
<th>Nr. Scholars</th>
<th>Total Pub.</th>
<th>Core Pub.</th>
<th>Total Pages</th>
<th>Core Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-10</td>
<td>20</td>
<td>9.2</td>
<td>4.4</td>
<td>504</td>
<td>270</td>
</tr>
<tr>
<td>1-2</td>
<td>21</td>
<td>8.7</td>
<td>3.4</td>
<td>400</td>
<td>261</td>
</tr>
<tr>
<td>0</td>
<td>20</td>
<td>5.6</td>
<td>2.3*</td>
<td>321</td>
<td>143**</td>
</tr>
</tbody>
</table>

*: Significantly different from mean score in class with 3-10 nominations, according to Duncan's multiple range test with alpha = 0.05. **: Significantly different from mean score in class with 3-10 and class with 1-2 nominations.

Total Pub.: The total number of publications per year during 1992-1996. Core Pub.: The number of single- and multi-authored books, Ph.D. theses, and substantial contributions per year.

Total Pages, Core Pages: The average number of pages per year in all publications and in core publications, respectively.
This committee stressed the need to distinguish between "genuine" scholarly contributions, on the one hand, and informative publications primarily aimed at providing social services, on the other. Genuine scholarly publications conform to criteria of methodological soundness, thoroughness, and significance. In the view of the Committee, it is the first category of publications that distinguishes between juridical scholars—who should primarily be evaluated according to their contribution to scholarly progress—and practitioners or professional legal experts.

From this perspective, it was suggested to use the number of core juridical publications as defined above—that is, the number of books, Ph.D. theses, and substantial contributions—as an indicator for discriminating between scholars and practitioners. This can be achieved either by counting the number of core publications per scholar, or by following a more qualitative approach, aimed at visualizing publication profiles of individual scholars in terms of types of publications.

5. DISCUSSION AND CONCLUSIONS

5.1 Practical Conclusions

If the publication lists obtained in our study constitute a sufficiently representative sample, we conclude that in the field of Law the publication lists should be rather carefully screened, analyzed, and verified prior to any counting or calculation of performance indicators based on publication counts. It should be noted that the members of the expert committee were very surprised by the observed large percentage of (semi-)duplicates, and they considered this unacceptable.

Our findings enabled us to propose the following procedure for calculating bibliometric indicators, at least at the level of aggregates of scholars, such as departments or faculties:

1. Collect raw data per scholar on publication output in electronic form.
2. De-duplicate entries using a semi-automatic approach.
3. Identify book publications; look up all books in university library catalogues, checking authors and editions, and selecting only first or totally revised editions.
4. Identify Ph.D. theses, but avoid double-counting as a book.
5. Identify all publications of which the number of pages exceeds five.
6. Add up the number of items found under points 3, 4, and 5, determining the "raw" number of "core" publications.
7. Calculate a weighted number of core-publications, by weighting journal articles with the journal weights described in Section 4.3, and book publications by a factor obtained by dividing the number of pages by sixteen, the median page length of a substantial contribution.

In view of the findings obtained in our study, this approach was qualified as a good one, both in terms of validity and practical feasibility, which
could be applied if no better alternatives were available. In many places in
the final report, the Inter-University Committee of Flemish Law Faculties
was invited to comment on our findings.

a. Official comments by the Inter-University Committee of Flemish Law Faculties. In
May 2000, about ten months after publication of the final report, the Com-
mittee gave its comments, in an official letter to the VLIR. It should be not-
ed that the members of this committee are the deans of the Law faculties in-
volved. Since a deanship lasts normally two or four years, the members who
issued the comments were not the same as those who prepared the Commit-
tee’s report on the assessment of performance in juridical research in 1996.

Although the Committee was unhappy with the fact that the research
report was written in English, it expressed its approval of the work, and stated
that many results from it are useful for the development of performance evalua-
tion criteria. The Committee’s letter addressed three main points.

The first related to the statements in our report on international ori-
ентation (see Section 4.4). Although the Committee agrees that the inter-
national orientation of Flemish juridical research needs to be stimulated,
it issues a warning that this aspect should not be assessed merely on the basis
of publication language. It should be noted that this warning was already
included in the report’s section on comments of members of the expert
group participating in our study.

The Committee stated that contributions in English are often not of a
fundamental nature, but are rather popularizing works—for example,
aimed at providing an introduction to the Belgian or Flemish Law system
for a larger, foreign audience. Rewarding publication in English would stim-
ulate “legal journalism.” Publications in English should only be given a
higher weight when they are published in journals of which the quality
guarantees that they go beyond legal journalism.

A second point concerned rankings of journals. Although the Commit-
tee stated in its 1996 report that it is impossible to rank journals, it is now
willing to reconsider this. In its view, rankings should be primarily deter-
mìned by expert opinion, and based on criteria such as international ori-
entation, severity of review procedure, a journal’s circulation, and its cita-
tion impact.

The third major point related to the operationalization of the concept
of substantial contribution. The Committee argued that the page length
gives a certain indication, but that other criteria should be developed as well:
Descriptive-systematic, analytical, comparative, evaluative, innovative, crit-
ical, or interdisciplinary.

Finally, the Committee stated that it will continue to work on the de-
vlopment of criteria for measuring research performance in Law, and that
it would be regrettable if findings from our report would be applied “in a
premature way” in university research policy.

b. General methodological discussion. A fundamental assumption is that the
concepts of research performance and research quality do have a meaning in all fields of scholarship, particularly also in the social sciences and humanities. As a result, differences in research quality among individual scholars or groups of scholars do exist. To the best of our knowledge, none of the scholars involved in our study has questioned this assumption. This is, in itself, a significant outcome of our study.

The principal aim of the development and application of bibliometric indicators is to stimulate a debate among scholars in the field under investigation on the nature of scholarly quality, its principal dimensions, and operationalizations. This aim provides a criterion of productivity for the process. A development process in which such discussions do not take place is to be considered as unproductive and unsuccessful. This would particularly be the case when developers calculate quantitative indices, which are used by evaluators or policy makers for evaluating research and making policy decisions above the scholars' heads.

A productive process enables scholars to express their views on scholarly quality more explicitly and clearly than in the beginning. In other words, a productive process establishes conditions for a more profound reflection upon what is most valuable and less valuable in scholarly research. Applying this criterion, we are inclined to conclude that our study, and particularly the methodology applied, has been successful.

The relationship between the views and perceptions of scholars and the development of bibliometric indicators is rather complex. On the one hand, scholars in the field under study should participate in all stages of the developmental process. In fact, their views and impressions are indispensable for developing valid and useful performance indicators. On the other hand, validity and utility cannot be assessed merely on the basis of scholars' views. An indicator is not valid merely because scholars say it is. The developer of bibliometric indicators should have independent tools to examine and test scholars' perceptions. In addition, a view of perception is not a static entity, but may change during the process, particularly in view of outcomes of bibliometric analyses. Utility should be evaluated from the point of view of specific policy issues and objectives, which are expressed not only by scholars but also by policy makers.

The essential elements of our methodology can be summarized in the following points. First, one should collect documents containing statements of scholars in the field under study on how assessment of research performance should be conducted, and, of course, on how it should not be conducted. Reports on research assessments conducted in the past constitute the most fruitful basis for such an inventory. The analyst should identify the main aspects of research quality involved, issues that were raised, problems that remained unsolved, operationalizations that were applied or rejected.

Secondly, scholars from the field should be involved in all stages of the study. They should be stimulated to propose or develop—even prelimi-
binary—classification systems, and to structure their own research output accordingly. Such an effort, though time consuming, is essential for making progress towards standardization of research output.

Next, bibliometrics should be used as an instrument to create a mirror. While not a direct reflection, this study is a thorough analysis of how scholars in the humanities and social sciences structure their activities and their research output. This structure can be examined empirically from the point of view of its consistency and the degree of consensus among scholars. Relevant issues can be raised that are worth considering in more detail in followup studies and conclusions from our empirical materials can be derived that may illuminate such issues. It is essential to recognize the need to develop adequate classification systems for scholarly activities and research output prior to any comparative measurement of scholarly performance.

Finally, the analyst presents to the scholarly community what he or she believes is the "best" approach for structuring and measuring research output, in the light of the outcomes of the study. Given the constraints imposed on any study in terms of time and manpower, he/she should acknowledge that not all issues raised during the study can be solved during that study. It is essential that he/she exercises a sufficient degree of openness in his/her presentation, both towards the scholars and to policy makers.

It is up to the scholarly community and its committees to discuss and evaluate the outcomes of the study. The process summarized above may then start again. Thus, an interactive, open process is created for developing performance indicators in the social sciences and humanities.

5.2 Relevance for Bibliometric/Scientometric Theory and for Librarians

Our paper showed that the development of bibliometric research performance indicators in general, and in the humanities in particular, is a systematic, scientific, and even scholarly activity. It can be denoted as scientific as it embraces empirical-analytical approaches to the analysis of publication practices and quality perceptions of scholars in the field of study. The scholarly dimension is the opportunity for scholars to reflect upon their publication strategies and to sharpen and make more explicit their qualitative views.

The classification system of publications in Law explored in this study is of interest to librarians, even though it has a preliminary status and needs further clarification and operationalization. It should be noted that publication cultures in the humanities show specific national characteristics, and differ considerably among subfields. Therefore, the extent to which it can be validly extended to research outputs in other subfields of the humanities, or to publication activities in the field of Law in other countries is open to further research.

In our view, the principal relevance of our study to librarians should primarily be found in the following. Librarians are not infrequently request-
ed to provide assistance in collecting data related to research performance assessments, or even to participate as contributor in such assessments. Our methodology aims at providing a general framework for such activities, and can be used by librarians as a line of action whenever they become involved. It should also be noted that librarians are, in principle, well equipped to conduct the empirical-analytical tasks outlined in this paper, including development and testing of classification systems, analyzing their structural properties, and collecting data through questionnaires.

In view of this, librarians could make important contributions to the process of structuring research activities, particularly research publications in the humanities, by developing classification systems and by assigning weights to the various entities reflecting perceived quality or importance in the subfield under investigation. As argued above, such a process can only be fruitful if the scholars themselves are willing to participate.

From a general policy point of view, it is in the interest of the humanities that their scholars do actually participate in such processes. It ensures the development of adequate methods for indicating research performance, taking into account the proper characteristics of these fields of scholarship. This would generally increase research performance in the humanities.

ACKNOWLEDGEMENTS

The project presented in this paper has been partially funded by a grant approved by the Flemish Minister-President, who is also in charge of science and technology policy. The authors are grateful to V. De Samblanx, K. Verbruggen, L. J. van der Wurff, W. Geerts, J. Van Der Perre, F. Colson, and the members of the Flemish Law Expert Committee for their important contributions to the study.

REFERENCES


A Theory of Information Genetics:
How Four Subforces Generate Information
and the Implications for Total Quality
Knowledge Management

BOR-SHENG TSAI

ABSTRACT
This essay proposes a model called information genetics (IG) to elaborate on the origin of information generating. The model builds on a broad information generating force that is both cause and effect. Part I of this essay postulates this information generating force as the result of the interaction and intermediation among four subforces: Query, command, statement, and term-term bond. These subforces are described by a process called twisting-bonding/clipping-jointing. The effect of this process is elaborated by: (1) Analyzing the Information Generating Model (IGM); (2) Transfiguring the Möbius Strip into the Möbius Twist Model; and (3) Demonstrating the process of the Clipping-Jointing Model. These three models are defined, exemplified, and described in detail. In Part II, a Fuzzy Commonality Model (FCM) is introduced to describe and explain the formation of a network curvature and to measure the dynamics of the twisting-bonding/clipping-jointing process within any special subject information field. In Part III, a software program is developed through the FCM for citation data mining, infomapping, and information repackaging—the three key elements in total quality knowledge management (TQKM). The conceptual and data models are supported by practical examples and statistical data. Several information flows are displayed in parallel to show their twisting-bonding/clipping-jointing interaction and intermediation relationships. This paper discusses the significance and advantages of the information genetics models and their approachability and applicability for TQKM in infomapping and Web information representation. The meaning of the information genetics models is also examined from a global perspective.
PART I: THEORY OF INFORMATION GENETICS

Introduction

There is a profound question constantly reappearing in teaching and researching in information storage and retrieval.

"What is it that makes the 'UNIVERSAL' information generating, representation, and transfer happen?"

This question frequently recurs because any question-answering, problem-solving, and memory-recalling process (i.e., the process of incoming and outgoing thought itself, not the answer, problem, or memory) seems to be an enduring and endless task no matter how well, thoughtful, or diligent we conduct our information research activities.

To analyze this general question, it is necessary to break it into several subquestions:

1. What is the hidden driving force that causes information generating to occur?
2. Why does information generating occur?
3. How does information generating occur?
4. How can the information generating process in a subject field be efficiently and effectively monitored and measured?
5. How can an information generating force be harnessed for serving constructive purposes in any type of information business venture and endeavor?

The overall goal is to find out what the information generating force really is. Is there any hidden driving force that motivates and moves all types of information and thought processes and directs subsequent information representation and transferring conduct?

From computerized information processing, online and Internet searching, and Web-page design experiences, one has already learned that it is mainly a human interaction with a computer system that enables the information generating, representation, and transfer to happen. It is the computer's operating systems (i.e., control unit and arithmetic/logic unit) and its memory device (i.e., storage unit) in the CPU (central processing unit) that allow people to create, store, and retrieve files (see Figure 1). Therefore, a human endeavor properly interacting with a computerized information retrieval system and using proper communication protocol, logic, symbols, and operations, should successfully generate, represent, transfer, and flow information smoothly from place to place most of the time. Many times, people need a few trials to improve the quality of retrieved information and eliminate insufficiency, irrelevancy, inconsistency, uncertainty, pitfall, and inequity. However, in doing so, they can manage the work and get the job done eventually. So why should the above questions be so difficult to answer?
They are not so easy to answer because this "universal" information generating, representation, and transfer is not merely related to human or computerized information processing. It includes all forms and types of information processing in the "universe," both physical and cognitive. This "universality" of information processing, or the "phenomenon" involving the notion of information, has interested many researchers. An underlying question is: What is "information?" The next section reviews some leading definitions of "information."

**Definition of Information Revisited**

Jesse Shera (1970) considered information to be "a unit of thought," an "intellectual entity," and "the building block of knowledge." Brookes (1980) thought of information as an "entity which pervades all human activity," and suggested that "navigation maps" be used. Goffman (1970) pointed out that information science needs to establish "a set of fundamental principles governing the behavior of all communication processes and their associated information systems," regardless of the information phenomena that "are found in biological processes, in human existence, or in machines created by human beings" (p. 591). This point was supported by Pao (1989), who postulated that "information forms the foundation of all human existence" (p. 3). Devlin (1991) regarded information as "a basic property of the universe, alongside matter and energy (and being ultimately interconvertible with them)" (p. 2). He used a new term, *infor*, in parallel with electron, proton, neutron, photon, etc., and considered it as a semantic object, not a syntactic representation.

Many information researchers have also provided useful working definitions of "information." Shannon & Weaver (1949) viewed information as "a measure of the absence of uncertainty." Shannon & Weaver's application of entropy measurement stimulated chaos theorists to "redefine chaos as maximum information" (Hayles, 1989, p. 305). Conforming to Shannon & Weaver's view on information and entropy measurement, Goffman &
Warren (1980) regarded information as “the amount of information once the uncertainty is removed” (p. 22). Hicks & Essinger (1991) valued the reduction or closure of “cognitive load,” which they considered as “the burden being placed on the brain at any one time,” and “the cause of stress, fatigue and making mistakes” (p. 58). Similarly, Breuning (1990) believed that “information overload is an inevitable part of our democracy” and cautioned that “cognitive pitfall is thus an inevitable part of public choice” (p. 219).

On the other hand, Machlup (1983) considered information as “a process,” and knowledge “a state.” To Soergel (1985), information is simply “data useful for decision making.” Harmon viewed information, in terms of information measurement, as “energy that regulates other forms of energy” (Boyce & Kraft, 1985, p. 153), which can be viewed as a “meta-energy” in today’s language. Debons, Horne, & Cronenweth (1988) illustrated the nature of information in terms such as commodity, energy, communication, facts, data, and knowledge. Kim (1990) supported Rathsworth’s view on information, also defining it as a commodity, a process, a state of knowing, and an environment (from the system’s notions). Železnikar (1990) regarded hermeneutics as “the study of informational occurrence or informing, the interpretation of informing within informational cycles” (p. 5). Meadow (1992) considered information as “something that (1) is represented by a set of symbols, (2) has some structure, and (3) can be read and to some extent understood by users of information” (p. 1). Tague-Sutcliffe (1995) summarized the definition of information as “what the user understands from the record during the time user and records are in contact” (p. 12).

The above authors basically elaborated upon and interpreted what information may be, how it is processed, and how the use of information is measured. Although their definitions are helpful in understanding the nature of information, they do not address the phenomenon of information generating.

This author, therefore, suggests a switch from the usual targets on information processing, information seeking, and information measurement to the phenomenon of information generating. This entails study of information twisting-bonding/clipping-jointing, particularly at the beginning moment of information generating, namely, the early stage of information processing.

**Related Studies**

If this approach is adopted, it becomes apparent that our general research question has much to do with informational insufficiency, irrelevancy, inconsistency, uncertainty, pitfall, inequity, and other conduct. The following authors’ works are most useful elaborations on these issues: (1) Shannon & Weaver (1949) on uncertainty and entropy measurement; (2) Price (1963, 1965, 1971, 1976) on scientific communication, invisible col-

These studies focused on the recognition of the structures and patterns of effective information communication processes. They are inspirational for the author’s modeling of a new way to recognize the structures and patterns of an information generating process’s early stage.

**Conceptual Model: Information Generating (Q-C-S-T Chain)**

In order to answer and interpret the general research question and the five research subquestions listed above, a conceptual model, called *Information Generating* (IGM), with two supporting models, *Möbius Strip-Twist* and *Clip-Joint*, was developed. To support and explain the conceptual model, a data model called *Fuzzy Commonality* (FCM) was designed. The conceptual models and the data model describe and explain the origin of information generating and the continuous development and improvement of the quality of information processing—an approach toward a total quality knowledge management (TQKM). These models are useful in visualizing the cause and effect of the information generating force—the force considered responsible for information generating, representation, and transfer.
Information generating as a primary conceptual model. The IGM postulates that the informational twisting-bonding/clipping-jointing phenomenon—observed during the universal information generating, representation, and transfer process—is the result of the interaction and intermediation among the four information generating subforces: **Query**, **command**, **statement**, and **term-term bond**, denoted as Q-G-S-T or Q-T-S-C chaining (see discussion in Part II). Although these four subforces operate inseparably, as in a ring (Figure 2), **query** can be considered as the starting subforce, which initiates the information generating process. **Command** can be viewed as the instructional clipper or torch for trimming, editing, highlighting, moving, or executing operations that "subdivide," "melt," "bond," or "merge" the observed objects into smaller or larger units for further analysis, synthesis, and/or treatment. **Statement** can be regarded as the instructional marker, meta data, format, formula, or framework that is structured and used to direct, support, translate, transform, or measure the movement or the angle of the commanding subforce into a more understandable and manageable path. **Term-term bond** is the common glue or paste that would virtually joint together two subdivided fuzzy ends, sets, objects, words, or meta data.

These four subforces cooccur at the beginning of the information generating process, which can be portrayed graphically, as in Figure 2. More precisely, the interaction and intermediation among these four subforces cooccur when a loophole, distortion, inequity, or broken symmetry in an instruction, image, or sound induces a state of imbalance or disharmony—thus producing a state of urgency and/or intensity. This urgent need or discriminating/demanding angle is formed to converge (i.e., focus and merge inwardly) or diverge (i.e., spread and stretch outwardly) the tension. In other words, a loophole, distortion, inequity, broken symmetry, or interrupted harmony cooccurs with a discrepancy, difference, discrimination, or distance. This cooccurrence results in the formation of a discriminant

---

**Figure 2.** The Information Generating Model: The Q-T-S-C/Q-C-S-T Chain and the Network Curvature.
angle and the creation of a potential, tension, or urge for a change or re-
adjustment of the state from imbalance to balance. The original Q-G-S-T
chain on a two-dimensional coordination plane has thus transformed into
a three-dimensional spatial network curvature, as shown in Figure 2.

This potential, tension, or urge (for a state change or readjustment)
may be considered the original motivating cause of information generat-
ing. The IGM helps to answer the first two subquestions: (1) What is the
hidden driving force that causes an information generating to occur? (2) Why
does an information generating occur? The third subquestion—How does
an information generating occur?—can be answered by utilizing the Möbius
Strip-Twist and the Clip-Joint models.

Möbius Strip-Twist as a supporting conceptual model. The puzzle of the
Möbius Strip was queried and solved by German mathematician August F.
Möbius (1790-1868). As stated by R. N. Anshen (1986), the self-convergence
of the Möbius Strip "symbolizes the structural kinship, the intimate relation-
ship between subject and object, matter and energy" (p. xxiii). For construct-
ing a strip, a long rectangular paper is prepared. The paper has two oppo-
site surfaces/sides and two parallel edges (therefore, one side or edge will
never meet the other side or edge). One side is marked "0" meaning "not
coded" and the other side is marked "1" meaning "coded." The strip can be
constructed by twisting (command) this long rectangular paper (statement/
marker/meta data) one half of a turn and then jointing (term-term bond)
the two ends of the paper (Figure 3). This simple yet remarkably intelligent
manipulation forms a single-twisted strip (statement/marker/meta data) of
a continuous surface with one side and one edge (marked as 0 + 1). The
subdivisions can be formed by cutting (command) the strip into two equal
halves (Figure 3, step 1). This results in forming a double-twisted strip hav-
ing one-half the width but twice the length of the original (still marked as 0
+ 1) (Figure 3, step 2). The second equally cut subdivision of the double-
twisted strip forms two interconnected, double-twisted strips with one-quar-
ter of the original width, and their connected lengths are quadruple the
original length (marked as 0 + 1 & 0 + 1) (Figure 3, step 3). The third cut
on the two second double-twisted strips reproduces four one-eighth wide,
double-twisted strips (marked as 0 + 1 & 0 + 1 & 0 + 1 & 0 + 1). Theoretical-

---

Figure 3. The Formation of Möbius Twists-Bonds.
ly, the loops of self-division can be repeated indefinitely and the information cycle will not end until all possible contacts or cuts are exhaustively encountered, resulting in a total chaotic entanglement of the strip.

This behavior of endless loops of twisting-bonding and subdividing helps the observer comprehend the concepts of system development and generating processes. A simple mathematical formula can be derived from this behavioral pattern: \( T = 2^c \) (or \( c = \log_2 T \)), where \( T \) is the number of twists in the strip, and \( c \) is the number of cuts taken, beginning from 0 (Table 1). It is noted that each level of cut may be considered a recreation of a new generation.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|}
\hline
Level of Cuts & 0 & 1 & 2 & 3 & 4 \\
No. of Twists & 1 & 2 & 4 & 8 & 16 \\
\hline
\end{tabular}
\caption{Number of Twists Corresponding to Level of Cuts.}
\end{table}

**Clip-Joint as another supporting conceptual model.** The second model, Clip-Joint, is used to describe a maneuver that is based on a topological phenomenon called *transference of curves* (Cobb & Darling, 1983). The steps for jointing two paper clips are as follows. Firstly, a paper strip (statement/marker/meta data) and two paper clips (marker/indicator/index) are prepared. The paper strip is twisted into an "S" curve (Figure 4) and each paper clip is placed on the curved and overlapped section (term-term bond) of the paper strip as shown in Figure 4, step 1. The paper strip is then stretched (command) by grasping and pulling its two ends. The two paper clips will be jointed (term-term bond) together and leave the paper strip gradually (if you straighten the paper strip slowly; see Figure 4, step 2), or they will be suddenly hooked onto (term-term bond) each other and jump off the paper strip together instantaneously (if you straighten the paper strip sharply; see Figure 4, steps 3 and 4). It is noted that the clip-joint may be considered a simulation of cocitation with the paper strip serving as an intermediary.

![Figure 4. Joint of Clips.](image-url)
The Möbius Twist-Bond demonstration shows that the logarithmic growth of the number of twists increases extremely rapidly after a certain number of cuts (Table 1). The process of subdividing the preceding strip into two equal parts allows each to automatically inherit half of the genetic factors from its immediate predecessor. Figure 3 and Table 1 show the topology of the level of cuts and number of twists, based on a principle of equal division on each of the reproduced bands at each level, and multiple subdivisions linked together by the force of self-convergence of the twist-bond.

The demonstrations of transfiguring the Möbius Strip into the Möbius Twist, and jointing two paper clips (indices—analogous to the information resource locators or markers) through a paper strip (an intermediary—analogous to the searching tools used for finding the information resource locators or markers) help to see how the informational twisting-bonding/clipping-jointing occurred. The demonstrations help to see how straight lines in a two-dimensional coordination plane are twisted, joined, stretched, and subdivided into a three-dimensional network curvature. They also show how the transference of curves is formed along the band in-between the two twisted and curved areas inside the twist.

The Möbius Strip-Twist illustration describes the bonding of two encountered parental units, with each providing partial genetic factors, that parenthesize or nest (i.e., conceive) a new generation. Normally, after several rounds of rotation cycles, the twists-bonds/clips-joints become so heavily intertwined that the unit-unit relationship becomes ambiguous and, thus, unobservable and incomprehensible. The original face is eventually ignored and forgotten and its memory is consequently lost. To recover the original information, information specialists (or artificial agents) must be employed to recall the missing information lines or links. Thus, information retrieval activities occur.

The two supporting conceptual models demonstrated both the strips-bonding and the clips-jointing processes and illustrated how the informational twisting-bonding/clipping-jointing process occurs. They help to show not only the steps of the informational twisting-bonding/clipping-jointing process but also the results of self-convergence, transference of curves, and subdivision of strips. Both supporting models are therefore useful in answering the third subquestion: How does the information generating occur?

PART II: FUZZY COMMONALITY DATA MODEL

The IGM, the Möbius Strip-Twist, and the Clip-Joint are useful in explaining what an information generating (i.e., integrated twisting-bonding/clipping-jointing) force is, and why and how the force is originated from an instructional Q-G-S-T (counter-clockwise, top-down, or forward) and/or Q-T-S-C (clockwise, bottom-up, or backward) chaining process. For further elaboration, the FCM is introduced as a data model. The FCM is used
for explaining the formation of a twisted-bonded network curvature of a Q-C-S-T (or Q-T-S-C) Chain (Figure 2), as well as for measuring the effect of the dynamics resulting from the twisting-bonding/clipping-jointing interactivities. Overall, the FCM shows that cognitive ability, tendency, and habit may be cultivated and cumulated through a long-term forceful and influential information generating process (Figure 5).

The two circles of Figure 5 represent two consecutive sets of information, denoted as $S_{n-1}$ and $S_n$ respectively. The area labeled $OUT$ in $S_{n-1}$ represents an old/forgotten/familiar/outdated/ignored/outgone informational subset. The area labeled $IN$ in $S_n$ represents a new/fresh/unfamiliar/updated/stimulating/incoming informational subset. The overlapped (darkened) area labeled $\&$ represents a constant/familiarized/remembered/recognized/sustained/retained/recurred informational subset. The diagram portrays a continuing relationship (frequently having something in common) between the two adjacent sets in a long subject information series. It is the frequency of the commonality that helps maintain and strengthen the substance and continuation of such long-term bonding.

The bonding relationship is complicated. A set of simple mathematical formulas should help consolidate the logical sequence and clarify the thought process of the FCM:

\[
U = OUT + \& + IN = S_{n-1} + S_n - \&
\]

\[
S_{n-1} = OUT + \&
\]

\[
S_n = \& + IN
\]

\[
dS = IN - OUT = S_n - S_{n-1}
\]

\[
OUT = (U - \& - dS) \div 2
\]

\[
IN = (U - \& + dS) \div 2
\]

\[
\& = U + dS - 2 \cdot IN = U - dS - 2 \cdot OUT
\]

\[
P_c = \& + U
\]

---

**Figure 5. Continued Informational Twisting-Bonding/Clipping-Jointing.**
The term $U$ denotes the number of the union of the two encountered consecutive informational sets (i.e., a unified statement of two adjacent sets of populations). $S_{n-1}$ or $S_n$ denotes the two consecutive sets of information within a special subject information field (i.e., a collective statement of a set of population). $OUT$ denotes the number of the old/forgotten/familiar/outdated/ignored/outgone informational subset (i.e., the old statement). $IN$ denotes the number of the new/fresh/unfamiliar/update/stimulating/incoming informational subset (i.e., the new statement). $\&$ denotes the number of intersection or conservation of constant/familiarized/remembered/recognized/sustained/retained/recurred informational subset (i.e., the term-term bond). $dS$ denotes the number of difference or change between the two consecutive sets of information (i.e., the cognitively directed command). $P_c$ denotes the critical probability of two encountered consecutive informational sets and indicates the density and intensity of an information network's curvature.

The change or the difference ($dS$) between the two consecutive informational sets, resulting from the balance or coordination among $IN$, $OUT$, and the commonality bond $\&$ is the critical point at which information generating occurs. This common bonding or overlapping point $\&$ is the intersection or potential commonality of the two adjacent informational sets. The reason that the process of information bonding or overlapping is fuzzy is because it is continuously and dynamically shifting and changing. Further, it tends to chain, stretch, or branch inward or outward, thus turning the process into a function of connectivity or a state of multiplicity. The process eventually becomes fuzzy and incomprehensible regardless of all connections still being bonded and functioning.

The FCM explains this phenomenon of informational overlapping and fuzziness and helps answer the third subquestion: How does the information generating occur? The last two subquestions are: How can an information generating process in a subject information field be efficiently and effectively monitored and measured? How can such an information generating force be harnessed for serving constructive purposes in any types of information business ventures and endeavors?

In the next two sections, practical examples and statistical data are used to answer these two subquestions. The italicized words in the questions are the main focus points.

**Examples Reflecting the Conceptual Models**

The following practical examples were selected to reflect the IGM and its supporting models, Möbius Strip-Twist and Clip-Joint. It can be observed that all information processing, servicing, and seeking activities are involved in performing information twisting-bonding/clipping-jointing and are under the influence of the four information generating subforces, namely, the QT-S-C and/or QC-S-T chaining process.
Computing and information processing. As the information generating process involves memory recalling and transfer, examining the storage unit of a computing system is essential. Generally, there are six components in a computing system: Input unit, control unit, operational (arithmetic/logic) unit, primary memory unit, auxiliary storage unit, and output unit (see Figure 1). The input unit is the computer’s sensor or data collector. It serves as the gateway of the computer’s querying process. The control unit constitutes major functions of a computer. It commands or dispatches instructions for the formation of an information curvature. The operational (arithmetic/logic) unit includes arithmetic (+, −, ·, ÷, etc.), and logic (AND, OR, NOT, >, <, =, etc.) operations for conducting and satisfying any formula/nest-based querying (i.e., using parentheses for term-term bonding) activities. The primary memory unit is a computer’s active memory space, allowing humans to build a statement to direct a computer to perform a goal-oriented, information-seeking operation. The auxiliary storage unit provides extra memory space, allowing humans to store or restore a supporting statement needed for supplementing the operation of the primary memory unit. The output unit of a computing system represents all types of effective outcomes (i.e., network curvature) resulting from the interaction and intermediation among the above five units.

During any type of information querying or processing, be it a simple word process, a complicated online search, or a sophisticated human-computer interaction, an operating system is a prerequisite. One may use the operating system installed in a personal computer, such as a Disk Operating System (DOS), a Windows-based operating system, or a network operating system. In any case, to properly retrieve a file, organize a folder, contact a Web site, or communicate with others via computer, the operator of a computer system needs to use computer commands—such as open, logon, telnet, ftp, change mode/directory, make/remove directory, copy, move, cut, paste, delete, save, print, close, logoff, etc. The operator also needs to use computer statements—such as those functions used in the OOP, HTML, XML, VRML, etc. These utilities and devices support the processing or programming of information. Terms and programming lines are carefully selected and organized in logical order and processing sequence so they can be meaningful and readable to humans and/or computers. Without a proper chaining and interoperation of query, term-term bond, statement, and command subforces, an information communication activity (i.e., network curvature) cannot be successfully conducted and concluded.

Library and information services. The three significant functions or departments required in all library and information services include: (1) Library administration and management as a commanding center handling library business, (2) Technical services providing supporting statements to library users, and (3) Public services accepting library users’ queries. All three functions require the use of proper terms in interdepartmental or librarian-user
communications. During the information generating processes, these three functions may be expanded into four units: (1) Information acquisition and filtering unit, (2) Information programming and processing unit, (3) Information storage, retrieval, and packaging unit, and (4) Information displaying, publishing, and marketing unit. The information acquisition and filtering unit acts as a querying unit and an information selector and collector. The information programming and processing unit acts as a commanding unit and a central controller and coordinator. The information storage, retrieval, and packaging unit receives and stores packaged instructions into a specially organized depository for future recall or redistribution of the information packages to the intended patrons or destinations (with the support of programming statements). The information displaying, publishing, and marketing unit exhibits and publicizes effective outcomes (i.e., network curvature) from a variety of instructional contacts that lead to representations of information products or remarketing of information services (term-term bonding). In a fast-paced information environment, the four information generating subforces (QC-ST or QT-S-C chaining) may need to be simultaneously applied and coordinated among the above four units of an information organization. In other words, during an information generating process, a chain reaction derived from and driven by these four subforces will occur and will likely cooccur frequently.

Daily human information seeking, processing, and communication activities. People constantly process information on a daily basis. Different kinds of questions motivate people to mentally and/or physically move in various directions to find the appropriate answers to their information needs. During their querying for answers, they need to know how to properly communicate with resources and people. In order to communicate properly, one needs to bond different kinds of terms together to make a sensible statement. Once the decision-making moment has arrived, a command language will be delivered. In other words, an information process may begin with a query, employing various proper terminologies to derive a statement that expresses the needs or requests for using or issuing a proper command language that meets the needs or requests. This exercise is called QT-S-C (clockwise, bottom-up, or backward) chaining. It completes the first cycle of the information generating, representation, and transfer process. An information process may also start from a query and be immediately met by a command language that is supported by statements that use various appropriate terminologies. This logical sequence is called QC-ST (counterclockwise, top-down, or forward) chaining. It is noted that the QT-S-C chaining may be considered as a liberal/democratic induction process, while the QC-ST chaining a dictatorial/autocratic deduction process.

If the first information process proves unsatisfactory, the second and its follow-up query languages are then restated with a set of more suitable terminologies. A series of executable commands is eventually set in order. The
information process can repeat itself as often as needed, and the information seeking will not discontinue its cycle until the question is completely answered. On the other hand, it can be observed that, during a human information seeking process, some interpersonal communications might interact with each other in some strong command language and with some emotionally charged supporting statements. The way that the terminologies are used is critical, because the process could result in a constructive or destructive relation, evidence, or record—and, consequently, a smooth information network curvature, or a broken instructional symmetry.

PART III: SOFTWARE FOR CITATION DATA MINING, INFOMAPPING, AND INFORMATION REPACKAGING

Examples Reflecting the Data Model

To accomplish the above objectives, the FCM data model was used to build an instrument for data analysis in an Excel spreadsheet. The FCM can be used to monitor and measure the information generating process in a specific subject field. In this section, some statistical data are presented to test the FCM formulas.

Fuzzy Commonality approach. It has been demonstrated that the information generating force (i.e., the integrated twisting-bonding/clipping-jointing) may largely be influenced by the term-term bonding subforce (i.e., informational overlapping). This subforce is likely the one that makes possible the transformation of a two-dimensional coordination plane into a three-dimensional network curvature (Figure 2). But how does one monitor and measure this network curvature when the surface of the 3-D network is constantly shifting? In a nutshell, how does one make observable, visible, and countable the originally unobservable, invisible, and uncountable communication connections and contacting activities?

The making of the FCM-based statistical instrument. Eight mathematical equations in the FCM were programmed. The correlations among the equations mutually support and double-check related cells on the spreadsheet. The program can incorporate a 2-D or 3-D graphic presentation. The instrument is also programmed to perform linear regression analysis and citation data-mining tasks that show the variation of citation relationships and the state of continuing stability in a particular subject field (Frappalo & Capshaw, 1999; Tsai, 1999a, 2000b). Three practical examples are given below to support this data model. Using the FCM-based instrument, two sets of statistical data were collected and represented. These examples are intended to show how information is originally generated and carried over through time, and how query, command, statement, and term-term bond are functioning individually and chained collectively in traditional online searching and citation data mining processes.
Data Collection and Analyses and Test Results

Example 1: Information retrieval through online searching. A search for a specific topic and a specific author’s research works was conducted to show how an information package can easily be generated according to the IGM’s Q-C-S-T (counter-clockwise) and/or Q-T-S-C (clockwise) chaining process. First, a research question comes to a researcher’s mind or to a library’s reference desk (query). A question analysis or a reference interview (query) is then performed. The research requires a connection to the Dialog’s Web site, a Web version of Dialog online searching, at www.dialogclassic.com (command, term-term bond).

The initial search begins with the ERIC database (command) and expands and combines different representations of names for an author, for example, Henry H. Small (command and statement). After that, the search needs to select the expanded sets (statement) and select the topics, for example, information architecture, information design, and knowledge management, with proper logical (nesting) operation and vocabulary control (query, term-term bond, statement, and command). Finally, the researcher can type and display the selected set (command and statement), as well as filter, save, and print the search results (command and statement). He/she can represent and transfer the relevant search results to a remote request, personal database, or public Web depository (command, statement, and term-term bond). The information system may also allow a remote user to access and conduct a query on the Web depository (query and term-term bond).

Example 2: Information retrieval through citation data mining. The terms “filtering” and “farming” are the two key words in data warehousing and mining, or knowledge discovering processes. Farming is regarded as the follow-up of filtering. It engages in raising information crops and/or livestock in the cyberfield. In terms of knowledge farming (Fye, 1998), an intelligent agent (e.g., the FCM) is used as a filtering device to reduce size and time burden in extracting useful information from a data warehouse (e.g., a citation data collection) for the cultivation of a knowledge farm (e.g., expert directory and Web document depository) (Tsai, 2000b). By applying the previously described eight parameters \( (U, S_{n-1}, S_n, dS, OUT, IN, \& , P_e) \) in the FCM statistical instrument, publication statistics were identified, packaged, and delivered to a patron who wanted information about a group of researchers whose works deal with cardiovascular electrophysiology and muscle mechanics. To perform this research, a medical researcher, R. A. Brown, is identified and selected as the starting point for a medical study on “cardiovascular electrophysiology and muscle mechanics” (query). The Science Citation Index is then used to collect annual citation data of R. A. Brown from 1990 to 1997 (term-term bond). The eight years of Brown’s citation data are respectively consolidated in chronological and alphabetical order (term-term bond). The annual population of citation numbers \( (S) \) and the grand total of the population of all citation numbers that ap-
peared in the eight-year period (1990–1997) are determined, counted, and recorded (statement). The annual citation data from two consecutive years are then compared to determine the annual population of recurring citation members (\( \& \)) (term-term bond). Data sets for \( S \) and \( \& \) are consequently placed into the FCM statistical instrument (term-term bond). According to the logic and sequence of the mathematical formulas (i.e., automatic commands) of the FCM, the following operations, figures, and graphs are automatically and instantly assembled, calculated, discovered, and displayed (command, statement, term-term bond, and curvature): (1) Annual populations of the new citation members \( (IN) \) and the old citation members \( (OUT) \); (2) Number of change of the citation members’ annual population \( (dS) \); (3) Number of the citation members’ union population in two consecutive years \( (U) \); (4) Critical probability \( (P_c) \) of two consecutive years, which is a simple calculation of “\( \& + U \)” As detailed in Part II, \( P_c \) indicates the density and intensity of an information network’s curvature. In this case, it indicates the strength of common bonding (i.e., the population of recurrent citation members) in the two-year union population of citation members (Tables 2 and 3, and Figures 6 and 7).

Example 3: Mining personal dietary information, a knowledge discovery. The FCM-based statistical instrument can be used for diet watching (query). An actual example from a person’s six-week dietary monitoring (query) program for a total of forty-two days (from February 1 to March 14 in a given year) demonstrates this. First, the symbols of communication were used to record daily food consumption. For example, on February 1, this person’s diet includes fifteen items: Apple, banana, barley soup, cabbage, . . ., soybean milk, spare ribs, and turnip. The daily record is denoted as: \( D_{0201} = \{ Ap, Ba, Bs, Ca, Do, Ga, Ip, Ng, Pa, Pl, Po, Sh, Sm, Sr, Tu\} = 15 \) items. After the initial data recording, the recorder cumulated and integrated the daily records of seven days into a weekly record, for example, \( W_1 \) (for Week 1) and \( W_2 \) (for Week 2) (see page 538).

Table 2. Dynamics of R. A. Brown’s Citing Authors (SCI 1990–1997).

<table>
<thead>
<tr>
<th>Year</th>
<th>A</th>
<th>dA</th>
<th>IN</th>
<th>OUT</th>
<th>&amp;</th>
<th>U</th>
<th>P_c</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>145</td>
<td></td>
<td>167</td>
<td>139</td>
<td>6</td>
<td>312</td>
<td>0.0192</td>
</tr>
<tr>
<td>1991</td>
<td>173</td>
<td>28</td>
<td>135</td>
<td>163</td>
<td>10</td>
<td>308</td>
<td>0.0325</td>
</tr>
<tr>
<td>1992</td>
<td>145</td>
<td>-28</td>
<td>192</td>
<td>119</td>
<td>26</td>
<td>337</td>
<td>0.0772</td>
</tr>
<tr>
<td>1993</td>
<td>218</td>
<td>73</td>
<td>160</td>
<td>189</td>
<td>29</td>
<td>378</td>
<td>0.0767</td>
</tr>
<tr>
<td>1994</td>
<td>189</td>
<td>-29</td>
<td>172</td>
<td>176</td>
<td>13</td>
<td>361</td>
<td>0.0360</td>
</tr>
<tr>
<td>1995</td>
<td>185</td>
<td>-4</td>
<td>97</td>
<td>156</td>
<td>29</td>
<td>282</td>
<td>0.1028</td>
</tr>
<tr>
<td>1996</td>
<td>126</td>
<td>-59</td>
<td>97</td>
<td>97</td>
<td>29</td>
<td>305</td>
<td>0.0951</td>
</tr>
<tr>
<td>1997</td>
<td>208</td>
<td>82</td>
<td>179</td>
<td>148</td>
<td>20</td>
<td>326</td>
<td>0.0628</td>
</tr>
<tr>
<td>AVG</td>
<td>174</td>
<td>9</td>
<td>157</td>
<td>148</td>
<td>20</td>
<td>326</td>
<td>0.0628</td>
</tr>
</tbody>
</table>

Note: \( A \) = “the number of the annual population of citing authors.” \( dA \) = “the number of change of the annual population of citing authors.”
Table 3. Dynamics of Cited Journals of R. A. Brown’s Citing Authors (SCI 1990–1997).

<table>
<thead>
<tr>
<th>Year</th>
<th>J</th>
<th>dJ</th>
<th>IN</th>
<th>OUT</th>
<th>&amp;</th>
<th>U</th>
<th>P_c</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>80</td>
<td>—</td>
<td>40</td>
<td>31</td>
<td>49</td>
<td>120</td>
<td>0.4083</td>
</tr>
<tr>
<td>1991</td>
<td>89</td>
<td>9</td>
<td>54</td>
<td>38</td>
<td>51</td>
<td>123</td>
<td>0.4146</td>
</tr>
<tr>
<td>1992</td>
<td>85</td>
<td>-4</td>
<td>39</td>
<td>34</td>
<td>51</td>
<td>124</td>
<td>0.4113</td>
</tr>
<tr>
<td>1993</td>
<td>90</td>
<td>5</td>
<td>45</td>
<td>38</td>
<td>52</td>
<td>135</td>
<td>0.3852</td>
</tr>
<tr>
<td>1994</td>
<td>97</td>
<td>7</td>
<td>41</td>
<td>43</td>
<td>54</td>
<td>138</td>
<td>0.3913</td>
</tr>
<tr>
<td>1995</td>
<td>95</td>
<td>-2</td>
<td>41</td>
<td>44</td>
<td>51</td>
<td>136</td>
<td>0.3750</td>
</tr>
<tr>
<td>1996</td>
<td>92</td>
<td>-3</td>
<td>41</td>
<td>41</td>
<td>51</td>
<td>132</td>
<td>0.3864</td>
</tr>
<tr>
<td>1997</td>
<td>91</td>
<td>-1</td>
<td>40</td>
<td>38</td>
<td>51</td>
<td>130</td>
<td>0.3960</td>
</tr>
<tr>
<td>AVG</td>
<td>90</td>
<td>2</td>
<td>40</td>
<td>38</td>
<td>51</td>
<td>130</td>
<td>0.3960</td>
</tr>
</tbody>
</table>

Note: J = "The number of the annual population of cited journals." dJ = "The number of change of the annual population of cited journals."

Figure 6. 3-D Representation of Dynamics of R. A. Brown’s Citing Authors (SCI 1990–1997).

Figure 7. 3-D Representation of Dynamics of Cited Journals of R. A. Brown’s Citing Authors (SCI 1990–1997).
\[ W_1 = \{ \text{Ap, Ba, Bb, Bc, Bd, Bl, Bs, Ca, Cg, Cw, Do, Dp, Du, Eg, Fi, Fl, Ga, Go, Gt, Ip, Ng, Np, Ov, Pa, Pe, Pl, Po, Rd, Ri, Rr, Rs, Sb, Sc, Sh, Si, Sm, Sr, Sw, Tn, Tu} \} = 40 \text{ items} \]

\[ W_2 = \{ \text{Ap, Bb, Bc, Bd, Bl, Bs, Ca, Cg, Cw, Do, Dp, Du, Eg, Fi, Fl, Ga, Go, Gt, Ip, Ng, Np, Ov, Pa, Pe, Pl, Po, Rd, Ri, Rr, Rs, Sb, Sc, Sh, Si, Sm, Sr, Sw, Tn, Tu} \} = 31 \text{ items} \]

The recorder continued to count and record the number of items that appeared in each week, for example, \( W_1 = 40 \) items and \( W_2 = 31 \) items (statement). The recorder then compares the two adjacent weeks (i.e., \( W_1 \) and \( W_2 \)) and draws a line to connect each recurring item (twisting-bonding of terms). The number of the recurring items, for example, \( \mathcal{E}_{1,2} = 21 \) (quantity of strong bonds), and the number of the union population of these two weeks, for example, \( U = 50 \), were respectively determined. A set of Venn diagrams to show the bonding relationship between the two adjacent weeks, for example, \( W_1 \) and \( W_2 \) (denoted as \( W_{1,2} \)), can be drawn (Figure 8).

The recorder then inputs the data sets for \( S \) and \( \mathcal{E} \) into the FCM statistical instrument (term-term bond). According to the logic and sequence of the mathematical formulas (i.e., automatic commands) of the FCM, the following operations, figures, and graphs are automatically and instantly assembled, calculated, discovered, and displayed (command, statement, term-term bond, and curvature) (Table 4). The 2-D and the 3-D graphs are represented below (Figures 9 and 10). An interpretation of statistical data and graphs (information network curvature) may be conducted for the inquirer if necessary.

**Discussion**

1. *The results of examples, examinations, and data analyses were positive and supportive.* The practical examples and analyses of the statistical data supported the conceptual and the data models.

2. *The last two research subquestions regarding information monitoring, measurement, and harness were answered by the practical examples and statistical data.* This supports that the information generating forces, as separate subforces, can be qualitatively monitored and examined step-by-step (Haythornthwaite, Bowker, Jenkins, & Raward, 1999). It also demonstrates that a whole integrated force can be quantitatively measured by the

---

![Figure 8. Bonding Relations Between Two Consecutive Weeks.](image-url)
<table>
<thead>
<tr>
<th>Week</th>
<th>S</th>
<th>dS</th>
<th>&amp;</th>
<th>U</th>
<th>P_c = &amp; ÷ U</th>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>W_{1,2}</td>
<td>40</td>
<td>-9</td>
<td>21</td>
<td>50</td>
<td>0.4200</td>
<td>10</td>
<td>19</td>
</tr>
<tr>
<td>W_{2,3}</td>
<td>31</td>
<td>-5</td>
<td>16</td>
<td>41</td>
<td>0.3902</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>W_{3,4}</td>
<td>26</td>
<td>11</td>
<td>19</td>
<td>44</td>
<td>0.4318</td>
<td>18</td>
<td>7</td>
</tr>
<tr>
<td>W_{4,5}</td>
<td>37</td>
<td>-11</td>
<td>21</td>
<td>42</td>
<td>0.5000</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td>W_{5,6}</td>
<td>26</td>
<td>0</td>
<td>16</td>
<td>36</td>
<td>0.4444</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>TOTAL</td>
<td>160</td>
<td>-14</td>
<td>93</td>
<td>213</td>
<td>2.1865</td>
<td>53</td>
<td>67</td>
</tr>
<tr>
<td>AVG:</td>
<td>32.00</td>
<td>-2.80</td>
<td>18.60</td>
<td>42.60</td>
<td>0.4373</td>
<td>10.60</td>
<td>13.40</td>
</tr>
</tbody>
</table>

Note: S = # of significant food items. dS = change of # of significant food items. & = # of significant food items that coappeared in two consecutive weeks. U = total # of significant food items in two consecutive weeks. P_c = conditional probability indicating the ratio of the # of coappeared significant food consumption to the total # of significant food consumption in two consecutive weeks. IN = # of incoming original food consumption. OUT = # of outgoing original food consumption.

Figure 9. 2-D Graphic Representation of FCM-based Statistical Analysis.

Figure 10. 3-D Graphic Representation of FCM-based Statistical Analysis.
FCM-based statistical instrument during the information generating processes.

3. The results of the FCM-based statistical approach are essential. Eight food items (Ap, Eg, Go, Pe, Po, Rd, Ri, Sm) were found to constantly appear in the individual's weekly diet. From the two consecutive record sets on food consumption, certain interesting relationships between the IN and the OUT and between the dS and the U were observed and quantified. The values of $P_c (= \& + U)$ can easily be found and calculated. These values can indicate the strength of common interests (bond) or the frequency of cooccurrence (repetition) of an individual's dietary activities. They may also indicate the intensity, maturity, or stability level of an individual's interests, boundary, or habits in food intake.

In a nutshell, this approach enables an individual to identify eight food items that are essential to his/her weekly diet. The finding of $\&$ allows an individual to see the changes in the common food consumption in his/her diet. It also allows an individual to monitor the amount of his/her weekly food consumption for a certain period of time and to figure out (and, therefore, be able to adjust, if necessary) the ratio of the central tendency (appropriateness or relevancy) of his/her diet for a short term and/or in the long run.

4. The roles and the functions of the Q-TS-C chaining might be cooccurrent, coexistent, and integrative in nature. The information generating subforces may be mixed and integrated from time to time. Definitions of the terms, distinction, and clarity of situations may not always be readily available or observable. Without knowing the underlying motivation, or considering the consequences or long-term effects, the resolution is irresponsible, but may be critical to parties concerned with a temporary and convenient shortcut, reaction, or decision for: (a) Responding to a situation, (b) Answering a question, or (c) Fixing a problem. Unfortunately, this could lead to a gradual and eventual addiction to the fixed situation, resulting in a distortion of the factual situation. Thus, it is important to learn how to harness an information generating force for constructive purposes.

5. The IGM and the FCM exercises lead to a philosophical observation. The command is derived from the frequency of communications and the commonality of interests. This, in turn, leads to the formation of a decision, policy, angle, image, etc. Our daily information activities are ruled by a series (or chain) of routine commands. If a command is not based on well-informed sources, the resulting decision-making processes will likely not become constructive. As a result, the curvature of the Q-TS-C Chain may be distorted. A series of rank order would cause the angle to change its current degree and the subforces to move their position, resulting in the creation of a new cognitive direction, as well as a new working and learning environment. This observation strongly corresponds with and
supports the fact that the information generating force should, and can, be further harnessed for constructive purposes (i.e., molding a smooth information network curvature). This could include the development of a TQKM system, and the construction of an experts directory focusing on a special subject information field, need, or operation.

**Information Genetics Applied to Total Quality Knowledge Management**

The proposed information genetics (IG) theory can be applied to knowledge management. To ensure the quality and the continuous improvement of information products and services, the total quality management concepts and techniques may be added and integrated into the knowledge management approach (St Clair, 1997; Cronin, 2000; Gregory, 2000). This addition and integration is advantageous to the construction and the development of TQKM systems. The TQKM approach may include two key components: **Cognitive coordination** and **infomapping**. Cognitive coordination continually gathers expert information on a subject information field via citation data collection (White & McCain, 1998; Small, 1999c). Through citation data mining, **infomapping** captures and figures out the overall interrelationships in research collaborations and scholarly communications of a particular subject field during a certain time period (Fayyad, Piatetsky-Shapiro, & Smyth, 1996; Smith, 2000; Trybula, 1997). The integration of both cognitive coordination and infomapping can provide an overall picture of a special subject information field. The particular subject information field may then be identified and selected for content management, for example, document depository, information packaging, etc. (Guenther, 2000; Myburgh, 2000; Tsai, 2000a).

With IGM as a conceptual model and FCM as a data model, innovations can be developed for information retrieval and assembly techniques and processes, for example, citation data mining, infomapping, and information repackaging—the three key elements of TQKM (Schwarwalder, 1999; Chen, Sakaguchi, & Frolick, 2000; Johanssen, 2000).

**Applying the IGM in Cognitive Coordination and Infomapping**

Cognitive coordination and infomapping can be used to detect learning patterns in the teaching and/or learning process. Infomapping also enables information managers to recognize behavioral patterns in an information communication activity among a group of users, learners, librarians, intermediaries, instructors, and computerized information systems.

The above idea was realized in a newly implemented computer program called Distance TGE Tutorial Program (available at http://rand.pratt.edu/~btsai). This program assists students of the School of Information and Library Science at Pratt Institute to pass a computer literacy test called the Technology Gateway Examination (TGE). This computer-aided distance tutorial program cumulates monthly tutoring experiences of the TGE co-
ordinator (the author) at Pratt Institute’s School of Information and Library Science from 1997 to date. Taking the cumulative advantages from teaching and tutoring (i.e., cognitive coordination) experiences, an infomap for the construction of the program is readily outlined. The program covers operating systems, word processing, and the spreadsheet application for working on a personal computer. A step-by-step guide of instructions and examples with a correct answer key is provided online. A student can remotely connect to this Web site and prepare for the test at a distant location, at any preferred time, for multiple practice sessions. This step-by-step guide takes into consideration learners’ cognitive processes, as determined by instructing experiences, tutoring sessions, and a series of observations and surveys of students’ learning activities (Tsai, 1999a, 1999b, 1999c). The model used for the Distance TGE Tutorial Program can be applied to the development of a training program involving library research skills. It can also be applied to the creation of an intranet-based, staff-training module or an electronic collection development project on a local area network or a Web environment.


By applying the FCM, a software program can be developed for citation data mining, infomapping, and information repackaging—the three key elements of TQKM. Programming in the FCM-based statistical example, using citation data mining, was continued to construct a citation-based subject experts directory capable of linking a searcher to a Web-assisted document depository (Nicotera, 1999; Tsai, 2000b; Zwies, 2000). Three criteria are needed in this construction:

1. **Quantity** ($S$) The selected authors and journals must contribute a large number of publications (statements) to the subject literature during the designated observation period.
2. **Continuity or Stability** ($\mathcal{E}$) Contributions of selected authors and journals must constantly recur (term-term bond) in the subject literature from year to year.
3. **Changeability** ($dS$) The numbers of selected authors and journal populations must change from time to time, allowing dynamic shifts of population membership to occur, thus maintaining (commanding) the advantageous and competitive edge.

Overall, the theory of continuous quality improvement is the guidepost for the construction of this experts directory. Through the use of a filtering counter devised with a set of threshold values, lists of 99 authors and 99 journal titles were initially selected from the original 1,204 citing authors and 264 journal titles related to cardiovascular electrophysiology and muscle mechanics. By comparing these two primary tiers of author and jour-
nal populations with the populations of recurring citation members (♂) in both authors and journals, a core population of 36 citing authors and 31 cited journals was identified. This core is the basis for the creation of the subject experts directory (Figures 11 and 12).

This subject experts directory may include an author section and a journal section (Figure 12). Each section allows a researcher to click on an author’s name or a journal’s title and review the hyper-linked profile (Figure 13). To review the selected author’s publication summaries, the user clicks on the publication line that is linked to that author’s Web document depository (Figure 14).

THE MEANING OF INFORMATION GENETICS TO THE INFORMATION WORLD

The contribution of the IG theory to the information world is examined here from a global perspective. A theoretical research area on parallel instructional lineages is illustrated as follows.

Parallel Instructional Lineages

By observing the instructional lineages across five consecutive, cumulative, and cyclical formation periods (namely, preformation, information, transformation, uniformation, and conformation/reformation/deforma-

---

Derived from

Ricardo A. Brown's Citation Data*
1990-97

* Bibliographic citations collected from the Science Citation Index.

Figure 11. A Web-based Experts Directory.
BROWN RA: Ricardo A. Brown, Ph. D., Assoc. Prof., Dept. of Physiology, Wayne State U., Detroit, Michigan. Specialties: Cardiovascular Electrophysiology and Muscle Mechanics. Education: Ph.D. in Physiology and Biophysics, Howard U., Washington, D.C., 1988; Postdoc., U. of Cincinnati, 1988, National Institute on Aging, 1988-1990. Experties: cardiac electrophysiological effects of alcohol; respiratory adaptation during stress and aging; electromechanical effects of alcohol and its metabolite, acetaldehyde, on cardiac and vascular smooth muscle function. Research Interests: 1) studying the interaction between socially abused substances (e.g., alcohol, nicotine, and cocaine) and their active metabolites on the cardiovascular system, esp. on cardiac electromechanical function; 2) studying the above interactions under conditions in which the heart is already compromised, such as in diabetes mellitus or hypertension, using appropriate animal models of these disease processes. 3) studying these interactions at the cellular level using isolated cardiomyocytes to determine the underlying mechanism(s) employing intracellular calcium imaging, video-edge detection and whole cell patch-clamping techniques to measure changes in intracellular calcium transients, cell shortening and ionic currents, respectively. Teaching Areas: cardiovascular electrophysiology, electrocardiography, and cardiac muscle mechanics. Memberships: Am. Physiol. Soc.; Research Soc. Alcoholism; Am. Heart Assoc.

Click here to see R. A. Brown's Publications:
tion), seven information flows can be quickly sketched and displayed in parallel to show the vertical and horizontal interrelationships of the four twisting-bonding/clipping-jointing subforces that constantly cooccur in the invisible form of the Q-T-S-C Chain. Information generating, representation, and transfer can be perceived by comparing the following flows (Figure 15).

Figure 15 also illustrates that something is always striving to take control and is working back and forth to sort, subdivide, knit, connect, recluster, reorganize, cumulate, synthesize, and unite differences into commonalities. To go back to our fundamental research question in this study—“What is it that makes the ‘UNIVERSAL’ information generating, representation, and transfer happen?”—what is this something, and how does this mysterious force develop? This something may be the proposed informational twisting-bonding/clipping-jointing force, and can tentatively be named auto (self-regulate). As previously illustrated, this so-called “auto” or “self,” a virtual status in an appearance of a network curvature, may be derived from the four driving subforces, query, command, statement, and term-term bond. Figure 2 shows that their interrelationships may form a Q-T-S-C or Q-C-S-T Chain. A
<table>
<thead>
<tr>
<th>FORMATION</th>
<th>←PRE→</th>
<th>←IN→</th>
<th>←TRANS→</th>
<th>←UNI→</th>
<th>←CON/RE/DE→</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. DB:</td>
<td>Ch$→$</td>
<td>Field→</td>
<td>Rec→</td>
<td>File→</td>
<td>DB→</td>
</tr>
<tr>
<td>2. Book:</td>
<td>Letter→</td>
<td>Chap→</td>
<td>Book→</td>
<td>Class→</td>
<td>Library→</td>
</tr>
<tr>
<td>3. Image:</td>
<td>Pixel→</td>
<td>ImageMap→</td>
<td>Page→</td>
<td>DocCluster→</td>
<td>Bib/Inf-Base→</td>
</tr>
<tr>
<td>4. Music:</td>
<td>Notes→</td>
<td>Phrase→</td>
<td>Line→</td>
<td>Section→</td>
<td>Movement→</td>
</tr>
<tr>
<td>5. Bio:</td>
<td>Nucleus→</td>
<td>Cell→</td>
<td>Tissue→</td>
<td>Organ→</td>
<td>System→</td>
</tr>
<tr>
<td>6. Intellect:</td>
<td>Idea→</td>
<td>Data→</td>
<td>Inf→</td>
<td>Knowledge→</td>
<td>Intelligence→</td>
</tr>
<tr>
<td>7. InfoMapping/Pkg:</td>
<td>DataConv→</td>
<td>DataCompr→</td>
<td>DataTrans→</td>
<td>DataDecompr→</td>
<td>E-store/Data Warehousing→</td>
</tr>
</tbody>
</table>

Note: Ch$ = \text{character string}, \text{Rec} = \text{record}, \text{DB} = \text{database, Chap} = \text{chapter, Doc} = \text{document, Bib} = \text{bibliography, Inf} = \text{information, Net} = \text{network, Res} = \text{resource, Cont} = \text{continued, Pkg} = \text{packaging, Conv} = \text{conversion, Compr} = \text{compression, Trans} = \text{transfer, Decompr} = \text{decompression, Pub} = \text{publishing.}

Figure 15. Parallel Instructional Lineages.
cognitive approach to a subject information seeking and communication activity can be undertaken by:

1. Focusing on one of the above five information formation periods (i.e., preformation, information, transformation, uniformation, and reformation/conformation/deformation); and
2. Regrouping the data collected from the study on one of the above seven parallel instructional lineages into five major categories (i.e., query, command, statement, term-term bond, and network curvature).

The union of the IGM and the FCM demonstrates what is really happening. The ever-existing information generator responds to the information gaps formed from the difference, distance, and distinction between two points, poles, or posts. It then creates or changes images in our minds, in the computer's memory, or in cyberspace. The potential for a renewing and refreshing state may be derived from the urge for a change of structure noted by Belkin (1976), or from a difference noted by Dervin (1993). Both the change and the difference will continue. It is necessary to maintain continuing quality control and improvement, and to justify possible information distortion, discrimination, and division that could be built in or added during the information generating process. It is noteworthy that an information creation or change may turn out to be better or worse off than its immediate predecessors.

In this study, an effort has been made to answer the five research subquestions underlying the initial general research question. The answers in this paper might yield a better idea about what the mysterious force is now. They do not, however, answer another basic question: What kind of information universe are we examining for the "universal" information generating process? More research on cognitive information processing is needed to answer this question.

CONCLUSION
In this study, it was posited that the phenomenon of information generating basically originates from a slight twisting force. This information generating force may be derived from a perturbation caused by a crack of difference or discrepancy. The crack occurs when two lines composed of determinant points or dominant factors voluntarily or involuntarily meet and induce a discriminant angle. A new cycle of struggle for the generating, maintenance, recreation, or change of information thus starts.

A TQKM system can be developed by applying the IGM and the FCM, as demonstrated by several examples. These examples may be used as the bases for continuously improving the quality of information products and services. Programs such as a Web-based subject experts directory, a Web-based distance learning program, an intranet-based, staff-training module,
or an electronic collection development project, can be effectively created (Notess, 2000a, 2000b; Roberts, 2000; Rogers, 2000; Tsai, 2000a).

In sum, quantity \((S)\), continuity or stability \((\&)\), and changeability \((dS)\) may be theorized as the three fundamental principles and properties for any universal information generating (Tsai, 2000b). As shown in this study (Figures 6, 7, and 9), these principles and properties are generally in symmetric displaying, with \(S\) being an upper boundary indicator (statement), \(dS\) a lower boundary indicator (command), and \(\&\) a middle (in-between) stabilizer (term-term bond) of the network curvature. On the other hand, the critical probability \(P_c\) indicates the overall density, intensity, and tendency of the network curvature. They are the basic sources and guidelines for the establishment of various types of governance for many kinds of activities in the information universe (Dobransky & Wierman, 1996). The understanding of these basic principles and properties is important, useful, and beneficial to all. Library and information professionals are the general public’s introducers, providers, and gatekeepers of quality knowledge and information services and, as such, they need to understand the meaning of information generating from a global perspective.

ACKNOWLEDGMENTS

The author would like to express his sincere gratitude to Dr. William E. McGrath, Professor, Department of Library and Information Studies, State University of New York, Buffalo, for his suggestions on the structure of this paper; and to Dr. Anne Woodsworth, Dean of the School of Information and Library Science, Pratt Institute, and Ms. Paula Desko, Catalog Database Supervisor, Rockefeller University Library, for their reviews, comments, and editorial suggestions.

REFERENCES


The Institutionalization of Scientific Information: A Scientometric Model (ISI-S Model)

PETER VINKLER

ABSTRACT
A scientometric model (ISI-S model) is introduced for describing the institutionalization process of scientific information. The central concept of ISI-S is that the scientific information published may develop with time through permanent evaluation and modification processes toward a cognitive consensus of distinguished authors of the respective scientific field or discipline. ISI-S describes the information and knowledge systems of science as a global network of interdependent information and knowledge clusters that are dynamically changing by their content and size. ISI-S assumes sets of information with short- or long-term impact and information integrated into the basic scientific knowledge or common knowledge. The type of the information sources (e.g., lecture, journal paper, review, monograph, book, textbook, lexicon) and the length of the impact are related to the grade of institutionalization. References are considered as proofs of manifested impact. The relative and absolute development of scientific knowledge seems to be slower than the increase of the number of publications.

MODELS OF THE GROWTH OF SCIENCE
According to the information model of science suggested by Nalimov & Mulchenko (1969) one can assume that scientific research is an organized information generating system and that science is a system of organized knowledge. Scientific research is fed with information as input for generating information as output that is new (original) or restructured knowledge compared to the input.

The growth of science is preferably described in the literature by models based on the cumulative growth of publications. In each model the cumula-
The number of publications in a given year depends on the number of publications in the starting year, the rate of growth, and the length of the time period elapsed (Gilbert, 1978; Wolfram, Chu, & Lu, 1990).

The linear model calculates with constant increases during equal time periods. Rescher (1978) suggested, for example, a linear growth function for the first-rate publications. The exponential model predicts an exponential increase of publications without limits to growth (e.g., Price, 1963; Egghe, 2000; Gupta & Karisiddappa, 2000). The logistic growth takes into account that scientific research is not a closed system and physical, economic, intellectual, etc. limitations occur that may bring about an upper limit to the growth (e.g., Price, 1963; Egghe & Rao, 1992; Gupta, Praveen, & Karisiddappa, 1997).

The application of cumulative numbers of publications for describing the development of science is, however, inappropriate, since the method does not take into account the aging of information. The concept, "cumulative number of papers," would indicate that all information previously published was relevant (regarding currency or recency) in the year of the study. This cannot be valid, considering, for example, the decreasing percentage shares of references with years referenced in Science Citation Index or Journal Citation Reports (SCI or JCR) for any journal.

Several authors (e.g., Egghe & Rao, 1992; Egghe, 2000) try to describe the development of science with the assumption of exponential increase of publications and exponential decrease of the relevant information. Theoretically, the model may be correct but practically, the synchrony between the opposing trends cannot be justified for any period.

Rescher (1978) tackled the "Rousseau law," suggesting "that the historical situation has been one of a constant progress of science as a cognitive discipline notwithstanding its exponential growth as a productive enterprise" (p. 111).

The calculation of the annual increase and subsequent aging of publications may give only an approximation to the growth of scientific knowledge in different fields of the natural sciences. Science works with great redundancy; there are numerous parallel papers, and several results already published are republished as original works (Price, 1963; Merton, 1968).

Menard (1971) investigated the publication development of chemistry, geology, and physics. The number of papers in physics increased linearly up to 1914 and then showed an exponential growth. The number of publications on chemistry was found to increase exponentially from the beginning of this century. Menard found very fast development in some hot fields, such as particle physics, where the annual rate was 15 percent in the 1950s and 60s. Menard distinguished three types of subfields: Stable fields, which increase linearly or exponentially at very slow rates; fast, exponentially growing fields; and cyclic fields, with stable and fast growth periods alternating. In support of Menard's results, Vinkler (2000) found that the
mean publication growth (i.e., mean annual number of publications) of different scientific fields strongly depends on the time period selected. For example, for Chemical Abstracts, a 6 percent mean annual increase was calculated between 1962–1979, and only one percent from 1980–1992, whereas 4 percent was observed between 1993–1999. Consequently, one may conclude that there is no general law “governing” the publication growth of disciplines for longer periods. The (cumulative) increase (or decrease) in the annual number of publications depends on several factors within and without science. The time/number of publications functions may be valid only for the period studied and have no predictive power.

Several attempts have been made to describe the development of science with nonscientometric models (Kuhn, 1962; Goffman & Warren, 1980; Crane, 1972; Mulkay, Gilbert, & Woolgar, 1975; Mullins, 1973). Gupta & Karisiddappa (2000) distinguished four developmental phases where cognitive content, methodology, type of publications, social structure, and institutionalization of the scientific research is characteristically different. According to this model, the information in the first phase is published primarily in “innovative” documents and reprints, in the second phase in papers, in the third phase in specific journals and textbooks, and in the fourth phase in journal bibliographies. The main institutional frameworks of emerging disciplines are as follows: Informal (nonorganized) stage, small symposia, congresses and formal meetings, university departments.

**Growth of the Literature Characterized by the Relative Publication Growth Index**

For describing the publication growth of science, one may borrow an analogue from physics: The velocity of moving bodies is equal to the length of distance covered during a time unit. In scientometrics we may select one year as the time unit and the number of journal papers as the distance. Consequently, the annual number of journal papers published in a specific field of science may be accepted as *Publication Velocity* (PV) of the respective field (Vinkler, 2000).

For characterizing the relative growth of the scientific literature during a time period, the *mean Relative Publication Growth*, RPG*(t)* index has been introduced (Vinkler, 2000). The RPG*(t)* index relates the number of publications issued in a given year to that published during a preceding time period selected (t). The length of the preceding period (termed as relevance period) may preferably refer to two, five, ten, or twenty years. The length of period *t* may be assumed as the maximum age of recent, relevant (RR) papers. RR papers are the publications that may contain all the information required for generating new information. It may be assumed that papers referenced in scientific papers at a given time may contain such information.

The number of publications referenced during a period of seventeen to thirty years were followed in Chemical Abstracts (CA), Inspec Section A
(I), Psychological Abstracts (PA), Biological Abstracts (BA), Science Citation Index (SCI), and Mathematical Abstracts (MA). A relevance period of two years was applied. The RPG(2) indices were found as follows: CA (1962-1993), 0.53; I (1980-1998), 0.52; BA (1964-1993), 0.53; SCI (1980-1998), 0.52; PA (1960-1979), 0.56; MA (1952-1990), 0.55 (the time periods studied are given in brackets). It may be easily concluded that the RPG(2) values refer to an average yearly percentage increase of about 4, 3, 4, 3, 8, and 7 percent, respectively (Vinkler, 2002). The Pearson’s correlation coefficients characterizing the annual increase of papers in time were found significant, positive, and relatively high (> 0.92) for all cases. In contrast to this, the trends of the yearly RPG(t) values gave controversial patterns. In some cases, they were significant but negative; in other cases, they were not significant.

From the RPG(t) values calculated for the different disciplines the following conclusions may be drawn:

- The RPG(t) values depend on the length of the relevance period (t) selected; greater t values result in lower RPG(t) data;
- The greater the annual percentage increase of publications, the smaller the ratios between RPG(2)/RPG(5)/RPG(10);
- RPG(t) values calculated with similar t-data are similar for the different disciplines;
- The mean RPG(2, 5, 10) values are higher than the theoretically calculated ones (0.50, 0.20, 0.10, respectively), meaning that there is an increase in the relevant information production within the time periods studied;
- The very low standard deviation values may indicate relatively constant RPG(t) values for the time periods studied.

Latter findings indicate that the increase of the recent, relevant body of scientific information is slower than that of the total information.

For lower aggregation levels, the data referring to RPG(2) and (yearly percentage increase) between 1970–1998 were found as follows: Applied chemistry and technology, 0.533 (4.22 percent); biochemistry, 0.529 (4.05 percent); physical and analytical chemistry, 0.520 (2.94 percent); macromolecular chemistry, 0.525 (2.89 percent); organic chemistry, 0.505 (0.46 percent). For comparison, RPG(t) values were calculated for some fast developing topics, such as AIDS research, fullerenes, nanostructures, composites, antisense nucleotides, etc. The respective RPG(t) values were found to be significantly higher than those for whole disciplines (Vinkler, 2002).

The findings mentioned are in accordance with the concept recently suggested by van Raan (2000): Science can be regarded as a dynamic integrative system where the development results from the growth of several subsystems with very different publication velocities.

The models based on the concept of the cumulative or relative publi-
cation growth of science, which calculate with the number of papers published yearly, can give a simplified picture only. The aim of the present paper, however, is to describe the development of science by a scientometric model that integrates the production, evaluation, modification, and aging processes of scientific information.

**Main categories and general features of the institutionalization of scientific information, a scientometric model (ISI-S model)**

According to the central concept of the ISI-S model the scientific information disclosed may develop with time through various evaluation and modification processes toward a cognitive consensus of distinguished authors of a scientific field or discipline. The ISI-S model assumes permanent production, evaluation, and modification of scientific information. It describes the information and knowledge systems of science as a *global network of interdependent information and knowledge clusters* that are dynamically changing by their content and size. The content and size of the individual clusters are regulated by different assessment processes.

The definitions (below) and the categories (Table 1) of ISI-S suggested here should be regarded as approximations. The term "information" refers always to natural science information.

*Information in scientific publications* (e.g., papers, book chapters, conference lectures) is:

- Addressed to the respective scientific community;
- Reviewed by peers before publishing and revised by the authors, if necessary;
- Disclosed by generally accepted norms of scientific publication of the respective discipline.

Scientific publication is a means of *announcing priority* (Price, 1963; Garvey, 1979) and contains (or at least should contain) all the information required for *understanding and repeating* the results published (Vinkler, 1998).

The ISI-S model postulates five main information sets, which can partly overlap: Information in publications; information of short-term impact; information of long-term impact; basic scientific knowledge; and common scientific knowledge. The rank of the information clusters as mentioned represents the hierarchical grade of institutionalization (see below) of scientific information (Table 2 and Figure 1).

ISI-S postulates three main and several additional evaluation processes. The first process refers to *public access* of the information to be published, the second to the *relevancy* and *use of the information published*, and the third to its general acceptance as *part of the basic scientific knowledge* of a discipline (Figure 1).
Table 1. Survey of the Main Categories of the ISI-S MODEL.

<table>
<thead>
<tr>
<th>Forms of Scientific Information by Disclosing</th>
<th>Classes of Information Disclosed by Relevancy</th>
<th>Types of Impact of Information Published</th>
<th>Terms of Impact of Information</th>
<th>Types of the Processes</th>
<th>Classes of Evaluators</th>
<th>Main Evaluation Forms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-published, submitted, published</td>
<td>Relevant, non-relevant (faulty or redundant), aged</td>
<td>Manifested, latent, lack of impact</td>
<td>Short, long, very long</td>
<td>Scientific research; publication; absorption, evaluation, use, and modification of information</td>
<td>Peers, relevant authors, distinguished authors</td>
<td>Acceptance or refuse of publications submitted, recension written on publications, citing or neglecting publications</td>
</tr>
</tbody>
</table>

Remark: For respective explanations, see the text.

<table>
<thead>
<tr>
<th>Source of Scientific Information Evaluated</th>
<th>Evaluators</th>
<th>Type of Impact</th>
<th>Public Proof of Impact</th>
<th>Preferred Source of the Citation Proving Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture Submitted</td>
<td>Peers (relevant authors)</td>
<td>Acceptance and publication</td>
<td>STI, LTI</td>
<td>Citation</td>
</tr>
<tr>
<td></td>
<td>Relevant authors</td>
<td>Published in full-length (in conference proceedings)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Published as abstract</td>
<td>Relevant authors</td>
<td>STI</td>
<td>(Citation)</td>
</tr>
<tr>
<td>Journal Paper Submitted</td>
<td>Peers (relevant authors)</td>
<td>Acceptance and publication</td>
<td>STI, LTI, BSK</td>
<td>Citation</td>
</tr>
<tr>
<td></td>
<td>Relevant authors, Distinguished authors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Book, Monograph Submitted</td>
<td>Editors, peers (distinguished authors)</td>
<td>Acceptance and publication</td>
<td>STI, LTI, BSK</td>
<td>Citation</td>
</tr>
<tr>
<td></td>
<td>Reviewers, Relevant authors, Distinguished authors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Information in Computerized Data Banks</td>
<td>Relevant authors</td>
<td>STI, LTI</td>
<td>Citation</td>
<td>Journal paper</td>
</tr>
</tbody>
</table>

Legend: STI = short term impact. LTI = long term impact. BSK = basic scientific knowledge. Relevant authors may include distinguished authors as well.
Figure 1. Institutionalization of Scienometric Information. A Scienometric Model (ISI-S MODEL).
The evaluations described in ISI-S result in a binary digit: Go or stop, that is, green light to the information to be published or having been published, or red light, which means rejection, ignorance, or disregard.

According to ISI-S, the relevant information refers to a part of information published that is found by any of the relevant authors (see below) to be relevant for any professional or social reason. Relevant information may be absorbed or discarded as faulty or redundant. The information absorbed may exert an impact of short or long term. Information that cannot pass the reference threshold (Vinkler, 1998) may exert a latent effect on respective authors. The information with potential influence may be transferred later to information with manifested impact. ISI-S considers references in scientific publications as proofs of impact on science or scientific research. Over longer periods, the information absorbed may progress into basic scientific knowledge. The “relevancy status” of the information in publications depends on several factors—for example, time elapsed between publication and the possible assessment, quality, topic, type of information.

Information evaluated by relevant authors (see below) may be proven nonrelevant, faulty, controversial, or redundant. Faulty results generally receive no or only some citations (Cole & Cole, 1968), whereas controversial information may obtain many citations, but only within a short period of time (e.g., “cold fusion” literature; see Bockris & Hodko, 1990). Through reevaluation processes the information types mentioned may later become relevant.

The aging of information is a very complex process (see Alvarez, Escalona, & Pulgarin, 2000). Aged information refers here to information that is completely replaced by new results. Any publication may be partly or completely aged after a shorter or longer period. A long-term lack of references to publications referenced earlier may serve as proof of aging.

The scientific information published or to be published may undergo modifications, which result in:

- Minor changes, that is, the essence of the publication remains relevant, only its form, validity, reliability conditions, etc. are changed;
- Major changes, that is, only the problem tackled or some details (e.g., methods, data, arguments, etc.) remain relevant;
- Complete aging, that is, the publication becomes nonrelevant.

Aging and modifications run parallel in opposite directions. Each modification of information is connected by reassessment and disclosure of new publications. The text referencing may reveal the modifications in the original (i.e., referenced) information suggested by the author referencing.

According to ISI-S, the impact of the scientific information published may be defined as absorption and application of pieces of knowledge in science in any form. It should be noted that the length of impact strongly
depends, for example, on the discipline, type, topic, and quality of information, and the developmental grade of the respective field.

Information of short-term impact refers here to the body of information that influences scientific research of a topic for a short term. Information of short-term impact very rapidly undergoes modifications. “Short term” in several natural science disciplines may refer to about five to ten years (Vinkler, 1999), during which time a majority of the papers becomes aged completely (i.e., not referenced any more). Preferred sources of information of short-term impact are conference lectures and journal papers. Manifested proofs of short-term impact information are references, preferably in journal papers and conference proceedings (Table 2).

Information of long-term impact refers to the body of information published that influences scientific research of a topic, field, or discipline for a long term. During this period the original information may undergo modifications. The information that has influence for a long period may represent an intermediate stage towards the status of basic scientific knowledge. The long-term impact period may cover ten to twenty years (Alvarez, Escalona, & Pulgarin, 2000), strongly depending on disciplines. Preferred sources of long-term information are reviews, monographs, and books. As manifested proofs of long-term impact, references preferably in secondary information sources (e.g., reviews, monographs, books) can be accepted (Table 2).

Basic scientific knowledge contains pieces of information that proved to be valid for a relatively very long period. It represents the incorporated, institutionalized, generally accepted body of information of a thematic unit (e.g., discipline, field, topic) that may have a fundamental influence on science and scientific research of the respective discipline, field, or topic for a relatively very long period. Basic scientific knowledge represents a part of the contemporary knowledge of mankind. Some of this knowledge is taught in university courses. Cognitive consensus of distinguished authors of broader thematic units is a necessary prerequisite for regarding information as basic knowledge. Preferred channels of basic scientific knowledge are secondary information sources, such as reviews, monographs, books, university textbooks, and special lexicons. Manifested proofs for this knowledge are references, preferably in the sources mentioned. Publications containing the original information accepted as basic knowledge are frequently not referred to directly. Referencing to names, initials, etc., or to reviews or books, is preferred (Table 2).

According to ISI-S common scientific knowledge is a part of the general and special knowledge of mankind originating entirely from basic scientific knowledge. Preferred channels of common scientific knowledge information are general lexicons, popular science books, and secondary and general school books. The aforementioned information sources refer preferably to monographs and books.
ISI-S assumes a direct relation between the length of the impact of information published and the grade of institutionalization (see below). The assumption mentioned involves the acceptance of ranking information by institutionalization grades.

ISI-S postulates three main categories of evaluators as follows:

- **Peers** deciding on the acceptance or rejection of the publications (or lectures) submitted;
- "**Relevant authors**" deciding on relevancy and application of the information published by their own individual professional and social viewpoints;
- "**Distinguished authors,**" who decide on relevancy by their individual viewpoints, but take into account worldwide professional (scientific) standards and interests of a whole thematic unit.

The assumed role of distinguished authors does not ignore the Ortega hypothesis, that is, to produce vast amounts of natural science data and to perform a great deal of experiments requires the activity of many researchers. But, each scientometric distribution (e.g., publication frequency or measure of citedness) reveals the Matthew effect of the first type (Merton, 1968)—that is, a few scientists publish very frequently and receive relatively many citations—and the second type (Vinkler, 1997)—that is, publishing in journals with a relatively high Garfield (impact) Factor) is a necessary but not sufficient requirement for attaining a Relative Subfield Citedness index higher than unity.

The assessment process of information performed by relevant authors refers to the activity of researchers (i.e., "relevant authors") working in similar fields as that of the publications to be assessed and surveying regularly pertinent information disclosed. The main goal of the assessment process is to keep abreast of the current literature and to survey previous information in order to obtain recent, relevant knowledge. The relevant authors are fellow scientists who potentially absorb, evaluate, and use information published and issue new publications themselves.

According to ISI-S, distinguished authors are those relevant authors who publish not only journal papers, but reviews, monographs, and books as well. They are editors or members of editorial boards, and they deliver invited and plenary lectures at international conferences on fields related to those of the publications to be assessed. The main goal of the assessment process performed by distinguished authors is to review and evaluate pieces of information disclosed that refer to a scientific topic, field, or discipline, and to integrate them into the relevant knowledge body. They play a decisive role in the evolution of science, converting information into knowledge.

The influence exerted by distinguished authors on scientific research and science must be much greater than that made by relevant authors. It may be stated further, that the impact of secondary information sources (e.g., reviews, monographs, and books) on the development of science is
significantly greater, on an average, than that of journal papers (see, e.g., the difference in the average numbers of citations obtained per item).

**Referencing as the Main Evaluation Process Toward the Incorporation and Institutionalization of Scientific Information**

Considering the frequency and strength of scientific authors' motivations toward referencing, a model, the *Reference Threshold Model (RTM)*, was established (Vinkler, 1998). Based on empirical data, it has been concluded that about 60–70 percent of total publications that might have exerted any impact (to any extent) on the publishing author, will be given in the reference list. It was found that the majority of references in scientific journal papers acknowledged the application of information in publications referred to. The motives for referencing may be divided into professional (i.e., scientific) and connectional (i.e., social) motivations. Connectional relevancy may refer, for example, to personal relations that may motivate the referencing attitude. Mean Normalized Reference Threshold values were found to be about three times as high for references made for connectional reasons as those made for professional goals. Therefore, it may be concluded that the referencing process is governed primarily by professional (i.e., scientific, information) factors, whereas nonprofessional reasons play a relatively negligible role. The main goal of referencing is to provide readers with appropriate information and to document borderlines between the results obtained by the researchers referenced and those of the authors referencing.

According to the central concept of ISI-S, evaluation of the information disclosed is performed by researchers working on the same field worldwide. The references in scientific publications may be regarded as manifested proofs of the impact of information. Atkinson (1984) suggests that the reference represents "the smallest meaningful unit of bibliography" (p. 109). Consequently, between the documents referencing and referenced, a cognitive coupling exists that is manifested by the bibliographic unit termed as reference.

**References, Evaluations, and Institutionalization**

According to ISI-S, publications not cited during longer time periods may be regarded as aged, nonrelevant, or of latent impact. Pendlebury (qtd. in Hamilton, 1991) found that the ratio of papers not referenced in a five-year period after publication strongly depends on discipline, and it ranges, for example, in chemistry, from 18.6 percent (in organic chemistry) to 78.0 percent (in applied chemistry). Bourke & Butler (1996) reported that 15.0 percent of the papers published in natural science journals in 1976–1980 were not cited at all between 1980–1988 and only 14.1 percent received more than twenty-five citations. The ratios mentioned (and not mentioned here) indicate that scientific research works with great redundancy and
produces a great number of publications with no or very low impact. Consequently, we must build blocks into ISI-S containing information with latent impact and nonrelevant and aged information at each stage of the process toward incorporation (Figure 1).

As is well known, reviews, monographs, and books contain more references than journal papers. The average citedness of these items exceeds that of papers. Bourke & Butler (1996) reported average data as follows: 64.3 (citations per book) and 13.7 (citations per paper).

A survey of journal papers of twenty eminent Hungarian chemists showed that papers cited by both journal papers and books obtained, on an average, 3.55 times more citations than those cited exclusively by journal papers. This example also points to the importance of books in the institutionalization process of information (see Table 1).

Most of the references in journal papers in natural sciences (Earle & Vickery, 1969: 82.0 percent; Singh & Arunachalam, 1991: 90.8 percent; Bourke & Butler, 1996: 62.9 percent) were found to refer to journal papers.

1,756 references (from Barton & Ollis, 1979; Sykes, 1994; and Brown & Grushka, 1998) were selected randomly. The ratios of references referring to journal papers, reviews, books, and reports or data banks were found: 90.47; 2.73; 6.39; and 0.41 percent, respectively.

From Römpp's Chemie-Lexikon (1981) 606 references were selected randomly, of which 89.4 percent refer to books or monographs and only 10.6 percent to journal papers.

From the Dictionary of the History of Science (1981) 176 references were selected randomly and classified as journal papers and books. The former class represents only 7.95 percent, whilst the latter 92.05 percent.

Several university textbooks were reviewed. Most of the books contain no direct references to the respective publications but do give the “Relevant Literature” under which different numbers of references are listed. In the textbook Organic Chemistry (K. Lempert, Budapest, Műszaki Könyvkiadó, 1976, in Hungarian), for example, 268 references are given, 34.3 percent of which refers to books and monographs and 65.7 percent to journal papers.

The above findings (and others not given here) indicate that the institutionalization process of information proceeds from journal papers through reviews, monographs, and books to professional and general lexicons. The rank of the publications mentioned is consistent with the lifetime of information.

Merton (1968, p. 462) writes on the “institutionalization of evaluative judgements” in science. In his view, evaluation systems play a very important role in any field of the society; for example, critics in art, supervisors in industry, coaches in sports, etc. The refere system of scientific journals involves the systematic use of judges to assess the acceptability of manuscripts submitted for publication. Garvey (1979) characterizes the role of the peer
review system as a *formal assessment* system that critically examines the papers against the standard set by the current state of knowledge in a discipline. Garvey (1979) writes about the process of institutionalization of scientific information in publications as follows: “Between the time an article is published and the time it is cited in another article a great deal of digesting, interpreting, and evaluating of its content takes place which serves to integrate the ‘new’ information in that article into the existing body of scientific information. This is all part of the continuous filtering and integrating which synthesizes scientific information into knowledge” (p. 93). Garvey & Griffith (1971) stress the importance of the evaluative steps in citing and reviewing published research and the synthesis in reviews and books as establishing the knowledge base of disciplines.

**Information Processes in the ISI-S Model Toward Incorporation**

The processes in ISI-S toward institutionalization are summarized in Figure 1. The goal of scientific research is to generate scientific information that might develop into knowledge. Publication is an essential and inevitable part of scientific research; therefore, only information published or to be published is tackled by the ISI-S. The evaluation processes of possible (future) publications begin with submitting for publication. The publications submitted may be refused or accepted by some (limited number of) peers or reviewers and editor(s). The procedure is formal and organized and takes a relatively short time. The names of the reviewers are generally not disclosed. One of the most important features of the peer assessment system of journals is that, after reviewing the papers submitted, the respective authors may have the opportunity to survey their paper once again and make corrections, taking into account the suggestions made by the peers. If a publication is refused (several times by different journals), most of its information will be lost or significantly modified (see Figure 1). The information in publications accepted is given an opportunity to exert impact.

The *second main evaluation process* proceeds through researchers (both relevant and distinguished authors) working on similar fields as the publishing authors. These experts may form an invisible college. According to the calculation of the present author, each paper on a standard scientific topic of average size may arouse interest in about 50–200 readers (potentially citers), on an average. Referencing (i.e., citation) represents an unofficial, nonorganized informal (i.e., private) assessment process made by a nonlimited number of evaluators during nonlimited time periods as a result of which the respective paper figures in or is omitted from reference lists.

The information published may be absorbed by the research environment and can be assessed as relevant or nonrelevant (see Figure 1). Relevant information, may or may not exert impact. The impact exerted may be
manifested or latent (Table 1). The manifested impact may be of short term, long term, or very long term (basic scientific knowledge) (Figure 1).

The ISI-S model assumes constant dynamic assessment processes; that is, nonrelevant information may become relevant and that of latent impact may be transformed to information of manifested influence at any time through reassessing processes. The manifestation of the reassessment is proven, according to ISI-S, by making references in new publications. Constant dynamic assessment processes also refer to information once found to be relevant. In the course of time, aging of information takes place, which may bring about modifications or complete neglect. The reactivation of information (nonrelevant, relevant, or no impact), however, may rarely occur.

The sources and authors of the referencing documents are clearly distinguished by ISI-S. References made by distinguished authors writing reviews, books, or monographs, not only journal papers, are regarded as proofs for long-term and significant influence. Greater numbers of references and longer terms of influence may be accepted as proofs for higher grades of institutionalization (i.e., incorporation).

The third main evaluation process, performed preferably (or exclusively) by distinguished authors, implies information of long-term impact (see Figure 1). The information passed through the filter of distinguished authors may become part of the basic scientific knowledge of a thematic unit.

According to ISI-S, the highest degree of the institutionalization process is represented by the transfer from basic into common scientific knowledge. One may assume basic scientific knowledge to be the origin of information arriving at this level, exclusively.

**Concluding Remarks**

The scientific information institutionalized is controlled and verified several times and is generally accepted. It exerts influence over relatively very long terms. The changes of whole paradigms (Kuhn, 1962) or essential modifications of the scientific knowledge of a field or discipline may bring about changes in the respective part of the common scientific knowledge. The amount and type of knowledge in the set of basic scientific knowledge to be introduced in the set of common knowledge may depend on the developmental stage of both knowledge sets and the requirements, possibilities, and goals of the society in the given time period.

Figure 1 and Table 2 may give only an approximate picture of the functioning of the complex organism of the information and knowledge systems of science and scientific research governed by the different evaluation processes. The results obtained by the ISI-S model described here strongly supports Garvey's (1979) view: "The contrast between the rapid growth of science (in terms of manpower and quantity of information) and the slow processing of scientific information into scientific knowledge becomes
apparent” (p. 20). According to ISI-S, both the relative and absolute development of science seems to be slower than that indicated by the increase of the number of publications.

The results obtained by the ISI-S model many contribute to a better understanding of the information processes in science. ISI-S may also contribute to substantiate decisions on subscribing to journals by a library taking into account the Garfield (impact) Factor data of the journals. It may serve as proofs to understanding the importance of references-citations in assessing research results and converting information into knowledge.

REFERENCES
About the Contributors

JUDIT BAR-ILAN is a faculty member of the School of Library, Archive, and Information Studies at the Hebrew University of Jerusalem. She has a Ph.D. in Computer Science from the Hebrew University. Her research interests include informetrics, information retrieval, analysis of Internet data, e-learning, and user interfaces.

MANFRED BONITZ began his career in nuclear physics, and then migrated in 1970 to the fields of informatics, information, scientometrics, and scientific communication. Since then, he has produced more than 150 publications, most notably the *Atlas of the Matthew Core Journals*, which presented his Matthew Core Journals, based on his discovery of the Matthew Effect for countries. He is a member of several scientific societies and of the Editorial Advisory Board of *Scientometrics*.

JACK D. GLAZIER is Associate Professor of Library and Information Management at Emporia State University. He holds a doctorate in Sociology from the University of Missouri. His areas of interest include cultural pluralism and its impact on library and information science. His most recent publication was an invited paper in *Anales De Documentacion*, University of Murcia, Spain. He is currently working on two monographs, one on school reform and the second on current trends in library and information science.

WOLFGANG GLÄNZEL is Senior Research Fellow at the Library of the Hungarian Academy of Sciences in Budapest, Hungary, and mentor for mathematics at the Budapest Distance Education Centre of the University of Hagen, Germany. He is (co)author of more than 100 publications dealing with bibliometrics and research evaluation and guest editor of several issues of *Scientometrics* and *Research Evaluation*. He is the first President of the Research Association for Science Communication and Information in
Germany and the Secretary-Treasurer of the International Society for Scientometrics and Informetrics. In 1999, he received the international Derek de Solla Price Award for outstanding contributions to the quantitative studies of science.

ROBERT GROVER has been a professor in the School of Library and Information Management at Emporia State University since 1990, and was appointed dean in 1998. After receiving his Ph.D. from Indiana University, he was a faculty member at the University of Southern California (1976–87), and director of the School of Library and Information Science at the University of South Florida (1987–1990).

WILLIAM W. HOOD is Senior Lecturer at the School of Information Systems, Technology and Management, University of New South Wales, where he lectures in information retrieval, information technology, and database design and management. He has recently completed his Ph.D., with a dissertation examining the distribution of bibliographic records on the topic of Fuzzy Set Theory in the available online databases. His recent publications include “The Literature of Bibliometrics, Scientometrics, and Informetrics” (Scientometrics, 2001) and “The Scatter of Documents over Databases in Different Subject Domains” (Journal of the American Society for Information Science and Technology, 2001), both with C. S. Wilson.

HILDRUN KRETSCHMER is acting as Honorary Professor at the Henan Normal University, China, and as Private Lecturer at the Free University Berlin, Germany. She was a founding member and the first President of the International Society for Scientometrics and Informetrics (I.S.S.I.), chair of the 4th International Conference on Bibliometrics, Informetrics, and Scientometrics, Berlin, Germany (1993), and a member of the International Program Committee of the Biennial World Conferences on Scientometrics and Informetrics. She is Associate Editor of the international journal Scientometrics.

MARC LUWEL is currently Senior Policy Advisor of the Flemish Minister of Education in Brussels, Belgium. He is author of a number of publications focusing on the assessment of Flemish universities and other research institutions.

WILLIAM E. McGRATH is Professor Emeritus, Department of Information and Library Studies, State University of New York at Buffalo. Prior to teaching at SUNY–Buffalo, he was Dean of Libraries, University of Massachusetts, Lowell; Director of Libraries, University of Southwestern Louisiana (now University of Louisiana); Head Librarian, South Dakota School of Mines
& Technology; and Science Librarian, University of New Hampshire. He has published many papers in library and information science including several on theory and explanation.

LYNNE (E.F.) McKECHNIE is Associate Professor, Graduate Program of Library and Information Science, University of Western Ontario. Her current research, funded by a grant from the Social Sciences and Humanities Research Council of Canada, focuses on how elementary school children use public libraries. Her recent publications include articles on the information rights of children and young adults (forthcoming, *Family Law Quarterly*, with Margaret Anne Wilkinson), gaining access to participants for information behavior research (*LISR*, with Robert Carey and Pamela McKenzie) and the treatment of gay and lesbian themed fiction for young adults in prominent LIS reviewing journals (with Paulette Rothbauer), which won an award as the best article published in *Collection Building* in 2000.

HENK F. MOED is a senior staff member at the Centre for Science and Technology Studies, Leiden University, the Netherlands. He is the author of numerous articles dealing with quantitative assessment of research performance, development, and application of science and technology indicators and creation of scholarly literature databases for bibliometric analysis.

A. J. NEDERHOF is a senior staff member at the Centre for Science and Technology Studies, Leiden University, the Netherlands. He is the author of numerous articles dealing with quantitative assessment of research performance, development, and application of science and technology indicators and creation of scholarly literature databases for bibliometric analysis.

BLUMA C. PERITZ is Professor of Information Science in the School of Library, Archive, and Information Studies at the Hebrew University of Jerusalem and is its former director. She has a Ph.D. and an MLS in Information Science from the University of California, Berkeley. Her field of research includes bibliometrics and scientometrics. She served as President of the International Society of Scientometrics and Informatics from 1997–1999.

KAREN E. PETTIGREW is Assistant Professor at The Information School, University of Washington. She holds a doctorate in Library and Information Science from the University of Western Ontario. Her current research, funded by the Institute of Museum and Library Services, focuses on designing context-based tools for evaluating community programming in public libraries (http://www.si.umich.edu/libhelp/). Her recent publications include “Facilitating Community Information-Seeking Using the Internet”

RONALD ROUSSEAU is Professor at the KHBO, Department of Industrial Sciences and Technology, and guest Professor at the Antwerp University, School for Library and Information Science. He has written numerous articles dealing with citation analysis, research evaluation, informetric models, information retrieval, library management, concentration and diversity, applications in ecology, and high school and undergraduate mathematics. He is a member of the American Society for Information Science and Technology, and an active member of ISSI, the society organizing biennial international conferences in the fields of scientometrics and informetrics. He received the Derek de Solla Price award in 2001.

RICHARD P. SMIRAGLIA is Professor at the Palmer School of Library and Information Science, Long Island University, where he teaches courses in knowledge organization and research methods. He is the author of numerous books and articles on bibliographic relationships, works as entities for information retrieval, and music bibliography and cataloging. He is Editor of the Soldier Creek Music [Cataloging] Series, and is past Editor of Library Resources & Technical Services and of the Music Library Association's Technical Reports. His most recent monograph is The Nature of A Work (Lanham, MD: Scarecrow Press, 2001).

BOR-SHENG TSAI is Associate Professor in the School of Information and Library Science, Pratt Institute, Brooklyn, New York. Prior to joining the faculty, he worked as a cataloger, an acquisitions librarian, and a reference librarian. He also designed a funded computer-assisted multilingual tutorial system for the Bilingual Multicultural Education Program, Cleveland Public Schools. His research and publication interests include: Bibliometrics and informetrics, information storage and retrieval, infomapping in knowledge management, information architecture, Web-assisted distance learning, networked information resources management, and the development of electronic collections and virtual learning environments.

PETER VINKLER is scientific secretary and head of the Biocomplex Research Department of the Chemical Research Center, Hungarian Academy of Sciences, Budapest, Hungary. He is the author of numerous articles and book chapters dealing with essential metal complexes and scientomet-
rics and informetrics. He also serves as head of the Central Chemistry Li-
brary and as Associate Editor of *Scientometrics*.

CONCEPCIÓN S. WILSON is Associate Head of the School of Information Systems, Technology, and Management at the University of New South Wales, where she instructs in various aspects of information management including, information retrieval systems, health informatics, and knowledge generation (informetrics and bibliometrics). She has recently cochaired the 8th International Conference on Scientometrics and Informetrics in Sydney. She also serves as an information management consultant to various government agencies such as the New South Wales Cancer Council. Her recent publications include "Informetrics" (*ARIST*, 2001) and "The literature of Bibliometrics, Scientometrics, and Informetrics" (*Scientometrics*, 2001), with W. Hood.
NOW AVAILABLE

Clinic on Library Applications of Data Processing 1998 proceedings

Successes and Failures of Digital Libraries
Edited by Michael Twidale and Susan Harum
$30.00*

Past proceedings are also available:

1997 Proceedings
Visualizing Subject Access for 21st Century Information Resources
Edited by Pauline Atherton Cochrane and Eric H. Johnson
$30.00*

1995 Proceedings
Geographic Information Systems and Libraries: Patrons, Maps, and Spatial Information
Edited by Linda C. Smith and Myke Gluck
$30.00*

Send orders to: GSLIS Publications Office, Room 24, 501 E. Daniel Street, Champaign, IL 61820. Prepayment required; Visa, MasterCard, American Express, Discover and checks (payable to the University of Illinois) accepted. Information regarding other publications can be obtained by writing to the above address or can be accessed at our Web site: http://www.lis.uiuc.edu/puboff

*Price does NOT include shipping. Within the United States, the shipping cost is $3 for the first book, $1 for each additional book in the same order. Outside of the United States, the shipping cost is $5 for the first book, $1.50 for each additional book in the same order. (We ship Fourth Class Library Rate.)
Now Available from the Graduate School of Library & Information Science Publications Office

PAPERS IN HONOR OF PAULINE AHERTON COCHRANE
Edited by William J. Wheeler
$30.00

Send orders to: GSLIS Publications Office, Room 24, 501 E. Daniel Street, Champaign, IL 61820. Prepayment required; Visa, MasterCard, American Express, Discover and checks (payable to the University of Illinois) accepted.
Information regarding other publications can be obtained by writing to the above address or can be accessed at our Web site:
http://www.lis.uiuc.edu/puboff

*Price does NOT include shipping. Within the United States, the shipping cost is $3 for the first book, $1 for each additional book in the same order. Outside of the United States, the shipping cost is $5 for the first book, $1.50 for each additional book in the same order. (We ship Fourth Class Library Rate.)
INDEXING AND ABSTRACTING IN THEORY AND PRACTICE
2nd edition

By F. W. Lancaster

SECOND EDITION FEATURES

MULTIMEDIA SOURCES AND THE INTERNET

Award-winning author F.W. Lancaster has revised his widely used text to address growing complexities in the field. Featured in the second edition of Indexing and Abstracting in Theory and Practice:

- New multimedia sources chapter
- New indexing within the Internet chapter
- Updated chapters on text searching, automatic processing methods, and the future of indexing and abstracting
- Nine updated chapters on basic principles and theories
- Modified practical exercises

In addition to use as a text, Indexing and Abstracting in Theory and Practice holds value for managers of information services and others concerned with indexing, abstracting, and all related issues of content analysis.

Orders must be prepaid to
The University of Illinois
Major credit cards and checks accepted
ISBN 0-87845-102-1
426 pages
cloth
$47.50 plus shipping
"Library Trends has become the premier thematic quarterly journal in the field of American Librarianship."

*Library Science Annual*

Both practicing librarians and educators use *Library Trends* as an essential tool in professional development and continuing education. They know *Library Trends* is the place to discover practical applications, thorough analyses, and literature reviews for a wide range of trends. See for yourself the breadth of topics covered in the forthcoming issues.

- **Midlife Career Decisions of Librarians**
  (Spring 2002) Edited by Daniel Phelan and Richard Malinski

- **Services to the Labor Community**
  (Summer 2002) Edited by Deborah Schmidte and Elizabeth Ann Hubbard

- **Teaching and Assessing Information Skills**
  (Fall 2002) Edited by Hannelore Rader

- **Economics of Libraries**
  (Winter 2003) Edited by Lewis-Guodo Liu and Bryce Allen

Institutional subscription price $94 (plus $7 for international subscribers). Individual subscription price $66 (plus $7 for international subscribers). Student subscription price is $28 (plus $7 for international subscribers). Single copies are available for $25.00, including postage. Order from the University of Illinois Press, Journals Department, 1325 S. Oak St., Champaign, IL 61820-6903, Telephone 866-244-0626, Mastercard, Visa, American Express, and Discover accepted.