Interdisciplinary Research in the Sciences: Implications for Library Organization

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Accounts in both the popular media and scientific literature attest to the increasingly interdisciplinary character of scientific research. The twentieth century has seen the emergence of problem-centered and mission-oriented research in which discoveries and developments in one discipline are synthesized into the research of a very different field, often with dramatic and life-altering results. This paper uses techniques of citation analysis to examine information use by scientists in a university chemistry department and offers a measure of the interdisciplinarity of the research they publish. The chemists whose published research was examined were found to make use of many journals that class outside the discipline of chemistry; over 49 % of the journals cited in a sample of their recent publications are classed in other disciplines. This study will consider implications for university libraries attempting to provide information services to scientists engaged in interdisciplinary research.

Universities are organized according to the disciplines represented among their faculties and programs, and the academic department is the basic unit in the structure. The research libraries that serve universities frequently mirror this structure in their organization of materials and services. Thus, in the sciences librarians maintain chemistry or mathematics or physics libraries with focused collections intended to meet most of the needs of the faculty and students in the particular discipline. An alternative organizational structure is the centralized science library that may exist in lieu of or alongside departmental libraries and that serves some larger number of disciplines. A considerable body of literature argues the advantages and limitations of each of these types of organization, and a recent article by Leon Shkolnik analyzes both sides of this ongoing debate.[1]

During the twentieth century new fields such as biophysics, molecular biology, and the environmental sciences have emerged. In these fields scientists trained in diverse disciplines come together to work on problems or projects that demand a broad-based perspective or to apply techniques developed in one field to research in another. These research teams frequently share a mission-oriented focus and may hope to solve important health-related problems or to develop new materials or procedures for some particular market. They are often more applications-oriented than their

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parent disciplines whose research is more basic or theoretical in nature. Evidence of this trend is seen in the establishment of interdisciplinary units on university campuses with titles including "center," "committee," or "institute," as well as in increasing university alliances with profit-sector organizations either through collaborative activities or through grants from corporations in support of university-based research. The fact that universities now are establishing patent offices and sponsoring the development of research parks to aid in technology transfer also supports this observation.

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On many campuses the increase in the amount of interdisciplinary research carried out by faculty and their graduate students has resulted in new and different needs for library collections and services. This interdisciplinary research has generated information needs that differ in significant ways from those of twenty years ago. Scientists may be using information from more than one field or in nonjournal formats such as patents or standards. University libraries can expect in the future to serve increasing numbers of users whose needs may not be confined by the boundaries of a single well-established discipline and who may experience difficulties in using information sources and services organized on a discipline-based model.

DESCRIPTION OF THE PROBLEM

The purpose of this research is to investigate the extent of interdisciplinary research among faculty in a single university department. The method chosen, described in more detail in a following section, will be that of citation analysis, utilizing the recent publications of the faculty studied. This project is intended to serve as a test of the technique that will subsequently be used to study the information needs of a larger group of faculty on campus. The information obtained will be useful in planning a new library to support research in the sciences and in designing library services appropriate for the specific user community.

DISCUSSION OF PREVIOUS RESEARCH

A. L. Porter and D. E. Chubin observe that "the absence of data on interdisciplinary research has been a bane to the study of this phenomenon."[2] In fact, a literature search that attempts to identify studies of interdisciplinarity is in itself an illustration of some of the problems of interdisciplinary research. Sociologists of science, information scientists, science librarians, and science policy specialists are some of the authors of research papers treating the topic. Their articles appear in a wide variety of journals and conference proceedings, including publications in the basic sciences. The materials cited in this paper were found through use of the library and information science indexing services, *Science Citation Index*, *Social Sciences Citation Index*, and through citations in other papers. The scatter of this literature, and thus the need to consult more than one secondary service, is a feature common to other interdisciplinary investigations.

Thoughtful authors who deal with this topic are careful to define the terminology they use. A recent book by Julie Thompson Klein provides in-depth discussion on the nature of interdisciplinary discourse and devotes several chapters to definitions of *interdisciplinarity*. This volume also includes an extensive classified bibliography that Klein considers to be a representative sample of a far larger body of literature. Klein begins her analysis with a discussion of the terminology that has been employed by various authors and notes her preference for the terms *interdisciplinary* and *integrative* for work that seeks to "accomplish a range of objectives:

- to answer complex questions;
- to address broad issues;
- to explore disciplinary and professional relations;
- to solve problems that are beyond the scope of any one discipline;
- to achieve unity of knowledge."[3]

Klein's definition seems to apply to many problems under investigation at present in numerous university research facilities. Projects concerned with cures for a disease or focused on space exploration or the environment, for example, are typically multiperson efforts, and a team frequently brings together individuals whose training reflects several disciplines. In a medical laboratory there may be a physiologist working cooperatively with a biochemist; perhaps a specialist in bioengineering collaborates as well.

A. J. Meadows explores diffusion of information across scientific disciplines and distinguishes *interdisciplinary* and *trans-disciplinary* activity. He prefers the term *interdisciplinary* when referring to the "integration of information from two different sources to create something new."[4] By contrast he uses *trans-disciplinary* to describe the use of information, techniques, or equipment developed in one field by practitioners in another. He cites the use of computers by both historians and physicists and observes that no relationship between the subjects is implied by this sharing. Meadows' definition of interdisciplinary research is congruent with Klein's, and he finds interdisciplinary information transfer to be of primary interest. That is also the emphasis in this article.

Talmon Pachevsky employs the term *complex* to describe those scientific fields that "have been born at the junction of different branches of knowledge and as a result of the integration of the component [*sic*] entirely new sciences have come into existence." He considers bionics, engineering psychology, and molecular biology to be examples of highly integrated fields. He uses *interdisciplinary* to characterize an intermediate level of integration below that of *complex sciences* for fields that represent "only the sum of the initial interconnected scientific branches."[5] He goes on to speak of a still lower level of integration within a particular field between branches and subdivisions of that science. His use of terms differs slightly from that of Meadows and Klein, but he is concerned with very similar issues. His article reports on a questionnaire-based effort to assess the shortcomings of discipline-oriented information systems in the sciences. While his focus was on problems encountered in small developed and developing countries, his findings speak to issues common to all interdisciplinary research.

Rustum Roy chose 1960 as the "birth date" of interdisciplinary research on campuses and described the situation prior to that as characterized by a balkanization of knowledge, with many "fiefdoms, each with its army (departmental faculty), local dialect (journals), and religious establishment (professional societies)."[6] With the New Frontier and the Great Society came an increased public awareness of societal problems, a resulting availability of public funding to address these problems, and the expectation that universities would share this mission and shape appropriate research agendas. Roy asserts that societal problems require an "interdisciplinary" or "multi-disciplinary" approach. He contrasts these two terms by providing operational definitions: "Interdisciplinary activity on a campus is a day-to-day interactive mode of research (or study) where, in order to do the best work, each researcher's work demands the use of ideas, concepts, materials, or instruments from one or more disciplines."[7] Klein's and Meadows' definitions correspond closely. Roy contrasts this definition to multidisciplinary research where a mission-oriented problem is broken down into "separate (typically disciplinary) components to be carried out by separate investigators with different skills" and where the synthesis of the results is not the responsibility of the primary investigators but rather accomplished by others at a secondary managerial level. Roy's interdisciplinary activity is of greater interest here because it is characterized by such features as interaction and co-authorship among scientists and by local program management.

Another approach to the study of interdisciplinarity is L. L. Hargens' survey that measured patterns of migration among disciplines and specialties. The population sampled in this study was defined as "all those who had earned doctorates in the sciences, engineering, and humanities during 1938-80 and who were residing in the U.S. in 1981." A 70% response rate provided data from 39,547 respondents. Analysis suggested that the respondents were representative of the entire population. Hargens was able to track migration streams, mapping among disciplinary groups major patterns of movement that seemed consistent with previous research that had utilized data collected from citation studies or from analyses of field similarities. Hargens did not address the issues of information needs that are the focus of the present paper, but he did validate the phenomenon of interdisciplinarity and provide corroborating evidence that complements other approaches.[8]

Greg Marlowe provided a case study of diffusion of scientific knowledge across discipline boundaries when he recounted chemist W. F. Libby's interactions with American archaeologists. Informal contacts and collaboration from 1946 to 1948 ultimately led to the application of carbon-14 dating techniques to the determination of the age of archaeological artifacts. Marlowe's account, drawn from Libby's correspondence and interviews with some of the individuals involved, describes the difficulties the scholars encountered with unfamiliar concepts and terminology. Marlowe emphasizes the catalytic role of a key foundation official known to be "risk-taking" in support of cooperative and cross-disciplinary research.[9]

One of the more extensive studies of cross-disciplinary information use is found in Paul Metz' work that examines library circulation data at a large state university. Metz analyzes data obtained from an online circulation system that included information on library patrons' academic status and departmental affiliation as well as records on the library materials each had checked out during the two-day period selected for study. This provided a detailed library use "snapshot" that was subjected to a statistical analysis that enabled Metz to understand better who uses research libraries and what materials are in greatest demand. Metz devotes much of his effort to assessing faculty use of subject literatures, the extent to which such usage crosses discipline boundaries, and the implications for library organization and collection development. This study also provides a thoughtful discussion of the differences between information obtained from circulation statistics and that derived from citation analyses.[10] Metz regards the two approaches as complementary, and that is the view taken here as well. Each method provides a part of the larger picture and, taken together, can inform us more accurately on the elusive and complex concept of *use*.

Other scholars investigating interdisciplinary research have employed unobtrusive measures that are in the public domain, analyzing citations in the published literature. Citation analyses are based on the assumption that authors' practices of referencing literature in their writings reflect in some fashion the utility of the cited materials. The fact that citation behavior is motivated by many factors is acknowledged, and use of data collected by this method should be interpreted in the context of other complementary information.

A recent citation study that addresses questions of cross-disciplinary information use examines indexing of physics literature by major secondary services in other disciplines. K. E. Clark and W. R. Kinyon studied coverage of physics journals by such services as *Chemical Abstracts (CA), Science Citation Index, Engineering Index,* and *Mathematical Reviews*. Inclusion of citations to physics journals was considered to measure the importance of physics to the discipline represented by each service.[11] Such a study looks outward from a single field to measure the influence of that discipline on others.

The opposite perspective is provided in Jin M. Choi's study that analyzes the journal literature in anthropology in order to assess its intellectual dependence on other fields. Choi analyzed citations in core anthropology journals during two one-year periods separated by a span of twenty years and concluded that disciplinary communication patterns appeared stable over the time period studied. She also looked at subspecialties within anthropology to identify intradisciplinary communication patterns and found evidence of isolation of subdisciplines from one another. She characterized anthropology as a "receiver" discipline because her analysis revealed that 70 percent of the literature cited was generated in other fields, including history, biomedical sciences, and linguistics.[12]

Katherine W. McCain also considered the information needs of a single specialty, the history of technology, and sampled articles from a core journal in that field to assess patterns of information use by scholars. She differentiated between primary and secondary sources cited and focused on the interdisciplinary nature of secondary source citations because she hoped to trace the flow of information across discipline boundaries. Her findings also were intended to provide useful data for collection development in the humanities. The historians of technology she studied appeared to behave like other groups of humanist scholars in their preference for monographic over serial sources; they drew on numerous other disciplines and cited works from such diverse fields as economic history, archaeology, and technology itself.[13]

McCain and James E. Bobick employed citation analysis of faculty publications, doctoral dissertations, and preliminary doctoral qualifying briefs to assess journal use in the Biology Department at Temple University. Their study described collection maintenance and development decisions in the Biology Library and demonstrated the utility of citation analysis in a departmental library setting.[14]

The present study also employs citation analysis to measure the extent of interdisciplinary research activities in a group of university-based scientists. Interdisciplinary information use by members of a science department was investigated, using an indicator of interdisciplinary research first described by Daryl E. Chubin, Alan L. Porter, and Frederick A. Rossini.[15] Chubin's methodology employs a bibliometric measure, *citations outside category*, derived from the literature generated by the group studied and/or the literature citing a paper or group of papers as an indicator of cross-disciplinary research activity. His studies made use of the massive Institute for Scientific Information database both to examine specific fields of research and to characterize the qualities of those heavily cited papers that have come to be known as *citation classics*. Chubin believes that this indicator of interdisciplinarity offers potential for application to "micro-level" studies such as those focusing on "the research program of a particular laboratory." That suggestion is explored in this paper in which the measure *citations outside category* is used to investigate the information needs of faculty in a university department through an analysis of citations by these scientists in current publications.

This research leads to an improved understanding of the detailed information needs of a particular user community and is intended to provide information useful for planning improved information services for the scientists in the department studied. This paper also discusses problems likely to occur when scientists' interests and information needs cross traditional discipline boundaries and considers implications for science libraries attempting to provide information services to scientists engaged in interdisciplinary research.

BACKGROUND

The population to be studied is the Chemistry Department at the University of Illinois at Chicago (UIC), part of the

University of Illinois system, a Research I university with enrollment exceeding 24,000, offering doctorates in 50 fields. The UIC Library is a member of the Association of Research Libraries and is organized along broad discipline lines into the Main Library, the Library of the Health Sciences, the Science Library, the Architecture and Art Library, and the Mathematics Library. The Science Library, located in one of the science buildings, serves faculty, staff, and students in chemistry, physics, biology, and geology. It subscribes to approximately 1,600 journals and serials and holds over 150,000 monographs, dissertations, documents, and technical reports in book and microform. Its reference collection contains the major indexing and abstracting services that fall within its subject scope and includes most of the important science reference sources such as Gmelin, Beilstein, and the Sadtler spectra collections. Online search services (fee-based) are routinely provided as part of a full public services program.

The collection, planned to serve the needs of UIC chemists, has been developed with the guidance of an acquisitions policy statement first articulated in 1971 by the science librarian with assistance from the faculty. A collection analysis self-study project completed in 1982 for the UIC Library measured the effectiveness of collecting practices and offered suggestions for enhancing the strengths of the collections in years to come. Chemistry was one of three disciplines selected for detailed study. Users saw journals as the most important component of the collection.[16] The self-study employed several techniques including citation analysis to measure the strengths and weaknesses of the journal collection. A comprehensive recent review article containing 721 citations served as the basis for the analysis which measured the percentage of the items cited that were available in the UIC Library. Because faculty judged the coverage of the starting article as representative of their interests, this assessment was considered a measure of the relationship between the existing collections and local needs. The study task force determined that the library held 80 percent of the journal and serial titles and 65 percent of the books cited in the review article. This study recommended that the library continue to monitor the faculty's need for journal publications and to develop lists for all the scientific disciplines whose research is supported by the campus collections. The present research reinforces that recommendation.

The study reported in this paper proposes to use a technique that measures cross-category citations:

- to determine the extent of interdisciplinary research in a university science department, in this case the chemistry department;
- to evaluate the scatter of sources supporting these chemists' research;
- to compare the findings in this environment to data reported in the literature;
- to suggest implications for library organization and services that follow from these findings.

METHODOLOGY

The university's staff directory provided a roster of faculty in the chemistry department. It listed 28 individuals with rank of professor, associate, or assistant professor. These individuals were the subjects for this study. Excluded were several others designated as visiting or emeritus faculty because expectations for publication may be different for them than for those on the tenure track.

The University of Illinois Libraries have access to Current Contents databases over the campus computing network, and a search of these databases produced a list of articles authored by the chemistry faculty members. A total of 22 faculty had published 119 articles in the journals indexed by Current Contents over the two-year period covered by the online files. This represents an average output of 5.41 articles per publishing faculty member over the most recent two years. The range for this group was from 1 to 14 articles.

From this population of 119 articles a stratified sample was drawn. For each author up to 3 articles were included, using all an author's publications during the period if there were 3 or fewer. For those authors with more than 3 articles, 3 were selected at random from the total output. Only research articles were included in the sample; review articles were excluded if encountered. Some articles in the sample were categorized as *notes* or *communications* by the database but their length and number of references fell within the range for those classed as *articles*. The sample drawn for analysis comprised 59 articles.

The typical article in the population studied was coauthored by three scientists and had 33.89 references in its bibliography. The number of references in the sample articles ranged from 0 to 88; two articles had no references so the sample of citations for analysis was drawn from 57 articles. The references in these 57 articles (1,932 total) provided a sample population to evaluate the extent of chemists' interdisciplinary information use.

FINDINGS

The 59 articles in the sample were published in 26 different journals whose titles are listed in table 1. Each journal was identified with a broad subject category using the assignment in *Ulrich's International Periodicals Directory*, 27th edition, and this information is shown in the same table.[17] The distribution of disciplines represented is shown in table 2 and, even at this level, appears to display a high level of interdisciplinary interest. Less than 60 percent of the sample articles authored by chemistry department faculty were published in journals that *Ulrich's* classifies as chemistry.

Each paper in the sample was obtained and the references analyzed as follows. First, each cited work was classified by format of publication: journal article, monograph, conference proceedings, reference work (i.e., table, handbook, data compilation, etc.), government document, dissertation or thesis, technical report, computer software, or unpublished document.[18] It should be noted here that the designation *conference proceedings* was reserved for compilations of papers presented at symposia or conferences that were not published as a regular issue of a journal. Included in the category are those proceedings appearing as occasional supplements to a journal, as an irregularly published monographic series, or as an edited collection not in series. Conference proceedings were counted this way in order to measure use of a class of materials that would not be acquired automatically with a journal subscription; library selectors would need to make individual purchase decisions to add these materials to a collection. Furthermore, it was assumed that use of the category *conference proceedings* as defined here would provide collection managers with information on the importance of this type of material.

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Another category requiring definition is *unpublished document*, which includes all those references to items that were "in preparation," "in press," or "unpublished," as well as to those identified as a *personal communication*. No doubt some of these works have seen subsequent publication, although perhaps bearing a title differing from that cited in the reference. Others may not be published and may prove difficult to locate, possibly only available through direct communication with the author who has provided the reference. Table 3 summarizes the formats of materials cited in the sample articles.

Each journal cited was assigned to an *Ulrich's* subject category (in the same manner as were the source journals in which the citing article appeared), and a summary of that data is provided in table 4. Although the subjects in this study are affiliated with a chemistry department, their use of the journal literature extends beyond their own discipline. When citing journals outside their primary field, these scientists appeared to make most use of journals in physics and biology, but also occasionally cited materials in a number of other fields.

TABLE 1
JOURNALS IN SAMPLE POPULATION
(N = 59 ARTICLES)

Journal	Discipline*
Applied Spectroscopy	Physics
Biochemical & Biophysical Research Communications	Biology
Biochemical Journal (3 articles)	Biology
Biochemistry	Biology
Biochimica et Biophysica Acta (2 articles)	Biology
Biopolymers (2 articles)	Chemistry
Chemical Physics Letters (2 articles)	Chemistry
Chemicke Listy	Chemistry
Inorganic Chemistry (4 articles)	Chemistry
Journal of Catalysis	Chemistry
Journal of Chemical Physics (12 articles)	Physics
Journal of Electron Spectroscopy and Related Phenomena	Physics
Journal of Labelled Compounds & Radiopharmaceuticals (2 articles)	Chemistry
Journal of Molecular Structure	Chemistry
Journal of Organic Chemistry (2 articles)	Chemistry
Journal of Organometallic Chemistry	Chemistry
Journal of Physical Chemistry (2 articles)	Chemistry
Journal of the American Chemical Society (5 articles)	Chemistry
Journal of the Chemical Society–Chemical Communications	Chemistry
Nucleic Acids Research	Biology
Photochemistry and Photobiology (3 articles)	Chemistry
Physical Review B Condensed Matter	Physics
Polyhedron	Chemistry
Reaction Kinetics and Catalysis Letters	Chemistry
Synlett (2 articles)	Chemistry
Tetrahedron	Chemistry
Tetrahedron Letters (3 articles)	Chemistry
Tribology Transactions	Engineering

**Ulrich's* subject classification

For each of the 57 articles in the sample the data on journal citations were entered into Microsoft File in a spreadsheet format which computed the index *citations outside category* (COC) where the citations outside category were calculated for each article as follows:

COC=(J- CH - UC) / (J - UC)

where:

J = total journal citations
CH = # chemistry journal citations
UC = # unclassified journal citations[19]

The COC, proposed here as an index of interdisciplinarity, ranges from 0 to 100% for the articles in the sample, with a mean of 49%. In other words, the articles studied here, published by a group identified through departmental affiliation as chemists, cited only 51% of their journal references from chemistry journals.

The citations to journals in the sample were sorted by discipline in order to obtain details on the most frequently cited journals. In the field of chemistry, the 10 most frequently cited titles are shown in ranked order in table 5. For comparison, the ranking obtained from the Chemical Abstracts Service list of "1000 Most

TABLE 2
CHEMISTS' PUBLICATIONS BY DISCIPLINE
(N = 59)

Discipline	No. of Journals	%
Biology	8	13.6
Chemistry	35	59.3
Engineering	1	1.7
Physics	15	25.4

TABLE 3
FORMATS OF MATERIALS CITED SUMMARY
(N = 1,931 CITATIONS, 57 ARTICLES)

Format	No. of Citations	%
Journals	1,685	87.26
Monographs	122	6.32
Conference proceedings	36	1.86
Dissertations	17	0.88
Unpublished	28	1.45
Other*	43	2.23

* Other includes government documents, handbooks, tables, technical reports, and software.

TABLE 4
DISCIPLINES OF CITED JOURNALS SUMMARY (N = 1,685 JOURNAL CITATIONS, 57 ARTICLES)

Discipline	No.	%*
Chemistry	782	47.36
Physics	481	29.13
Biology	304	18.41
General science	35	2.11
Other†	49	2.97
Unclassified‡	34	

* Percentages are based on the number of classified journal citations, 1,651.

† Other includes aeronautics, astronomy, ceramics, engineering, metallurgy, mathematics, environment, pharmacy, and medicine.

‡ Unclassified journals are not listed in *Ulrich's International Periodicals Directory*.

Frequently Cited Journals" is provided. That ranking is based on coverage analysis of two volumes of *Chemical Abstracts*, volumes 109–10 (July 1988–June 1989), a period that corresponds closely to the publication dates of the articles in the sample. Additionally, the ISI Impact Factor (most current value, as appearing in *Journal Citation Reports*) is shown to provide an indication of the frequency with which the "average" article in that journal is cited in a year. (Institute for Scientific Information analyses have determined that the average scientific paper is cited about 1.7 times per year.) The impact factor is the ratio between citations and citable items published and is useful in comparing larger or more frequently issued journals to smaller or less frequently issued ones. The highest impact factor in the volume of *Journal Citation Reports* consulted was 48.313 for the *Annual Review of Biochemistry*.

Tables 6 and 7 provide comparable data on the five most frequently cited journals in the fields of biology and physics. All other disciplines whose journals were cited were represented by much smaller numbers of references; no analysis of titles seemed called for under such circumstances.

DISCUSSION OF RESULTS

This study examined the citation practices of a group of chemists associated with a single university department. Classification by discipline of the journals cited in a sample of their recent publications allowed calculation of *citations outside category* as a measure of the interdisciplinarity of their research. The findings of this study may prove useful in comparing these chemists to other larger groups of scientists and may illuminate specific interdisciplinary relationships that will suggest changes or improvements in library services to this group. This section discusses the implications of the data reported in tables 1–7.

Table 3 provides data on the formats of materials cited by chemists and confirms that the single most important information source is the scientific journal:

TABLE 5
MOST FREQUENTLY CITED CHEMISTRY JOURNALS*
(IN RANKED ORDER)

Journal	No. of Citations	*CA* Rank	ISI Impact Factor
Journal of the American Chemical Society	133	6	4.566
Inorganic Chemistry	66	26	2.691
Journal of Organic Chemistry	51	19	2.344
Chemical Physics Letters	49	23	2.289
Chemical Physics	45	133	1.884
Journal of Physical Chemistry	40	14	3.139
Journal of the Chemical Society (all sections)	36	98†	2.254†
Tetrahedron Letters	34	9	2.080
Chemical Communications (Chemical Society)	27	27	2.418
Photochemistry and Photobiology	24	311	2.130

* A total of 99 titles classifying in chemistry were cited in the sample articles, 782 total citations. The top five journals account for 44% of the total chemistry citations.

† Rank for *Perkin Transactions*, highest ranked of sections.

TABLE 6
MOST FREQUENTLY CITED BIOLOGY JOURNALS
(IN RANKED ORDER)

Journal	No. of Citations	*CA* Rank	ISI Impact Factor
Biochemistry	66	18	4.006
Journal of Molecular Biology	34	131	6.555
Journal of Biological Chemistry	26	1	6.491
Nucleic Acid Research	21	17	4.298
Proceedings of the U.S. National Academy of Science	19	7	10.032

* A total of 47 titles classifying in biology were cited in the sample articles, 304 total citations. These top five journals account for 54.6% of the citations in biology.

TABLE 7
MOST FREQUENTLY CITED PHYSICS JOURNALS*
(IN RANKED ORDER)

Journal	No. of Citations	*CA* Rank	ISI Impact Factor
Journal of Chemical Physics	236	4	3.588
Physical Review (all sections)	46	2†	3.820†
Molecular Physics	23	279	1.964
Surface Science	22	65	2.917
Journal of Physics (all sections)	15	122‡	2.173‡

* A total of 52 titles classifying in physics were cited in the sample articles, 481 total citations. These top five journals account for 71% of the citations in physics.

† Rank for *Physical Review B*, highest ranked of sections

‡ Rank for *Journal of Physics B*, highest ranked of sections

over 87% of the citations in the sampled articles were to journal articles. (Next most important, as measured by frequency of citation, were books). These figures fall within the range established by earlier work. Herman H. Fussler analyzed citations in the writings of chemists and physicists in one of the first studies of this type and determined a serial citation rate for chemists of 93%.[20] Charles H. Brown reported 94% citations to serials in his monograph published several years after the Fussler article.[21] Penelope Earle and Brian Vickery collected data from over 65,000 citations in a sample of books and journal articles produced over the course of a year by authors in the United Kingdom. For scientific fields the serial citation rate they measured averaged 82%.[22] Although the serial citation rate is lower in this present sample than those reported for chemists by Fussler and Brown, it does not appear that the scientific journal is about to be replaced by any other publication format. Furthermore, the professional association continues to be the most important publisher of chemical journals: the American Chemical Society with its *Journal*, *Inorganic Chemistry*, *Journal of Organic Chemistry*, and *Journal of Physical Chemistry* and the *Chemical Society*, London with its *Journal* and *Chemical Communications*. Other important publishers include the large international firms of Elsevier and Pergamon which have specialized in scientific publication and whose market is primarily libraries rather than individual scientist subscribers.

Table 4 provides summary data on the journal citations in the entire population reporting aggregate counts for the 57 articles with references. (Two articles had no references thus reducing the citation analysis sample to 57 articles.) It shows a high degree of interdisciplinary use of journals by the chemists in this sample. As a group, these scientists frequently cite not only the journals identified with their own discipline but also other titles identified with biology and physics. In addition, they make occasional references to journals in a number of other scientific fields. As in the study by Porter and Chubin there is practically no citation across broad field categories, i.e., to works outside the sciences.

The proposed measure of interdisciplinarity, citations outside category, ranges widely from 0 to 100% but averages 49% for the 57 papers in the study. As a group, these chemists are not discipline-bound in their use of information; and their reading, as measured by the works they cite, is not confined to only those items classified as chemistry.

A typical university chemistry department, such as the one studied here, includes individuals belonging to most of the major chemical specializations. Perhaps cross-disciplinary information use is more prevalent in some specialties of chemistry than others, and that question was examined in a preliminary way with the data gathered for this study.

The high level of interdisciplinary information use measured for these chemists appears to argue against the narrow departmental library type of organization.

There are 13 papers in this sample with COC values below 10%. This subset of the population includes authors whose information needs seem to be more focused on the materials within their parent discipline than those of their departmental colleagues. Do these individuals belong to any particular branch of chemistry? To explore this question, the *ACS Directory of Graduate Research* was consulted for information on faculty specialization. This resource provides statistical compilations descriptive of the doctoral- and master's-granting departments of chemistry in the United States; details on enrollment, academic programs, students, and faculty are supplied for individual departments. The faculty listed are categorized in the directory according to the major subdivisions of the field of chemistry. Those faculty in this sample whose papers had COC values below 10% are identified with either organic or inorganic chemistry. At the other end of the COC range are 9 papers with calculated COC values of 85% or greater; these authors are identified with either physical chemistry or biochemistry, specialties that, by their names alone, appear to be more interdisciplinary in nature.

The directory was used to categorize each member of the sample, and average COC values for each of the specialties represented in the UIC Chemistry Department were calculated:

Biochemistry 85%
Inorganic chemistry 29%
Organic chemistry 24%
Physical chemistry 64%

Centralization of science collections and coordinated collection development offers enhanced potential to supply a campus with the maximum number of unique journal titles.

A more detailed analysis of interdisciplinarity variation by specialty is beyond the scope of this paper and would require a more extensive analysis of a larger set of citations. Nonetheless, these preliminary findings suggest that such an investigation might reveal significant differences in use of materials by particular specializations.

Of course, these data also reflect some of the ambiguities inherent in any effort to organize knowledge along disciplinary lines. Unsurprisingly, physical chemists are likely to make heavy use of the physics literature, and biochemists rely a good deal on publications in the field of biology. These latter two specialties are examples of interdisciplinary fields of chemical research that have grown increasingly important during the present century. A perusal of the *ACS Directory of Graduate Research* demonstrates that these are now well-established specialties in chemistry and are represented, in varying percentages, in almost every department listed in the directory. The presence of interdisciplinary specializations such as these makes it more difficult to define a narrow set of library resources appropriate for chemists and, if studies such as this one are employed, it is clear that chemists' information needs are seen to overlap with those of physicists and biologists. This has implications for library organization, and that issue will be addressed in the following section.

Tables 5 to 7 list the most heavily cited titles in chemistry, biology, and physics; these journals must be considered among the most important for this particular group of chemists. If one compares these ranked lists with other measures of use that describe a larger universe of publishing scientists, both similarities and differences appear. The *Chemical Abstracts* rankings are derived purely from article counts and therefore rank highest larger, more frequently published journals. Some of these chemists' most frequently cited journals are among the largest; others, however, rank much lower on the *CA* list and may reflect specialization strengths within this particular department. ISI impact factors attempt to correct for sheer volume and size and can be used, in conjunction with other measures, to judge relative utility of titles. Almost without exception the most frequently cited journals are high impact; this is particularly so for the physics and biology titles. In fact, the *Journal of Chemical Physics* and the *Journal of Biological Chemistry* place near the top of any of the rankings.

CONCLUSIONS: IMPLICATIONS FOR LIBRARIES

This study of citations to the journal literature by the chemists of a university department has produced findings that should prove useful in the improvement of science library services. This group of scientists, representative of many chemistry departments in research universities, makes use of a variety of resources but, as for previous generations of scientists whose information use has been documented earlier, they continue to rely most heavily on the primary journal, whether published by a professional association or by a major commercial publishing house. Their information needs cannot be met with journals that class only in chemistry; they also use materials that might just as well be claimed by physicists and biologists.

The high level of interdisciplinary information use measured for these chemists appears to argue against the narrow departmental library type of organization. A chemistry library, narrowly defined and stocked, would only partially meet their needs; a broader, divisional science library seems better suited to support their highly interdisciplinary research. When universities have operated with a departmental library structure, there has often been considerable duplication of materials; a chemistry library for these chemists would very likely feel pressure to duplicate some titles held in a physics or a biology library. If acquisitions budgets were open-ended and available titles less numerous, then duplication of subscriptions might be a reasonable approach to meeting need. Few institutions can now claim that extensive, or indeed any but minimal, duplication represents the wisest deployment of scarce resources. In these times of declining material budgets, however, centralization of science collections and coordinated collection development offers enhanced potential to supply a campus with the maximum number of unique journal titles.

Another type of difficulty that may be encountered by scientists engaged in interdisciplinary research concerns the use of secondary services to identify materials relevant to their research. Many of the oldest and largest indexing and abstracting services are discipline-based; they frequently are published by professional associations and have developed to meet the needs of scientists in the parent discipline. Although a service such as *Chemical Abstracts* attempts to cover the field of chemistry comprehensively, economic factors eventually limit size and scope for any service. Journals in other disciplines may be indexed selectively; less important titles may be covered by fewer services or with longer time lags. For some scientists a comprehensive literature search is likely to require the use of more than one index in order to locate all relevant literature. The emergence in recent years of cross-disciplinary indexes serves those well for whom a "match" occurs: e.g., *Pollution Abstracts* or *Environmental Bibliography*, but there are many more interdisciplinary fields than there are currently indexing services to assist their research.

Given this reality what can science libraries do to assist the growing numbers of interdisciplinary researchers? Several services seem capable of bridging discipline boundaries and merit consideration.

Online databases offer capability for searching the electronic equivalents of several indexes and abstracts simultaneously. Although variations in both indexing vocabulary and authors' terminology occur across the files, a carefully designed search strategy will likely offer appreciable time savings over manual use of the same indexes. Furthermore, the availability of master indexes to a vendor's files allows a strategy to be tested for retrieval effectiveness prior to entering the databases. For example, use of Dialog's DIALINDEX can be an important early step in identifying databases likely to contain relevant citations. Recent enhancements to retrieval software now offer the ability to reduce duplication in multifile searches, and this feature, while not always able to eliminate all duplication, does result in lower print costs. Smaller libraries may also benefit from online services in that these services provide access to large costly files that might not be justifiable as subscriptions. Any library may discover an online database for which it holds no paper equivalent and which seems particularly suited to support an interdisciplinary query.

End-user searching can be an attractive alternative to mediated searching for scientists working at research fronts, a frequent location of interdisciplinary investigations. When a field of study is growing rapidly, terminology tends to be in flux, and indexing vocabularies may be unresponsive to effective strategy development. In such situations suitably trained scientists can find it most efficient to be directly involved in information retrieval; they may then make relevance judgments while online and modify strategies to reflect their assessment of citations found. Science librarians can serve as resource persons and consultants to these end-user searchers and may also direct them to suitable thesauri and search guides.

Science libraries that operate in a decentralized environment with several departmentalized collections serving the sciences will very likely hear complaints from their users engaged in interdisciplinary research; these are the patrons whose journals and indexes are scattered over two or more campus locations. These may also be the patrons most inconvenienced by cancellations of duplicate journal subscriptions: what was once in the library in their building can now be consulted only by a trip across campus. Services to consider that address these problems include:

- intracampus exchange programs for new journal issues or title pages for browsing use;
- photocopy services employing campus mail, couriers, or use of telefacsimile transmission to provide timely document delivery of needed materials between sites;
- use of campus local area networks for e-mail to remote libraries for transmission of reference questions, online search requests, delivery of books or journals, circulation services, interlibrary loan initiation, etc.

Of course, these enhancements bear a price tag, and few library budgets are sufficiently expansive to launch such new services without careful projections of staffing and equipment needs. Even if user fees must be assessed, however, for many patrons the convenience factor can encourage use of departmental or grant funds.

Finally, the importance of being aware of new research initiatives on campus cannot be underestimated. In this regard, library committees and faculty liaisons are sources of valuable early information on new research centers developing on campus. It can be much too late if a library learns from a university press release that an interdisciplinary research center has been established. Such programs have been planned without librarian input on available library resources to support them or without opportunity for library staff to begin long-range planning for acquisition of materials or development of support services.

DIRECTIONS FOR FURTHER RESEARCH

This study was intended to be the first in a multipart investigation of science departments' information use. The methodology described above will be utilized to study the publications of those other departments whose faculty and students are considered the primary constituency of a divisional level science library. The findings will support planning for improvements in library services in the following areas:

- developing document delivery services to minimize inconvenience in use of materials located at other campus libraries;
- allocating science library shelving to most heavily used titles and shifting less-used ones to storage sites;
- identifying journals suitable for addition to the collections or for cancellation.

This study should provide a better understanding of the relationships among the various science disciplines in the university environment and will inform those involved in planning new facilities for the scientific research community.

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18. The date of publication was noted as well, although those data were not utilized in the analysis reported here. All the citation data were entered into Microsoft File to allow for statistical analysis as described in the section to follow.
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