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| National Library of Medicine |
| Evaluating the Impact of NLM-Funded Research Grants: |
| A Role for Citation Analysis? |

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# Abstract

**Objective**

This project was undertaken to design and pilot test a methodology based on citation analysis for evaluating the impact of NLM informatics research funding.

**Methods**

A sample comprised of all R01 grants funded by the National Library of Medicine (NLM) during the years 1995-2009 was drawn from the CRISP database, and publications resulting from these grants were located using PubMed. Three databases that allow for cited reference searching, Web of Science, Scopus, and Google Scholar, were explored for their coverage of informatics research. Preliminary testing using a selection of grant publications representing both clinical informatics and bioinformatics was conducted to determine the number of cited references for each of these publications, as well as the extent of coverage within the citation indexes.

**Results**

Between 1995 and 2009, NLM funded 214 R01 grants. These grants resulted in a total of 1,486 publications with citations in PubMed, or 6.94 publications per grant on average. Selection of seven research grants for further study produced a sample of 70 publications, and citations referencing the majority of these publications were found in all three databases considered. A total of 1,765 unique citations were retrieved, for an average of 25.21 citations per article. Numbers of citations ranged from a low of zero to a high of 221. Searches in Web of Science retrieved 57.68% of these citations, searches in Scopus retrieved 61.81%, and searches in Google Scholar retrieved 85.21%. Significant, but not complete, overlap in coverage between these databases existed. Supplementing the standard for citation searching, Web of Science, with use of Scopus provided increased access to conference proceedings; supplementing with Google Scholar increased access to non-journal literature as well as to the most current research. Preliminary research indicated that Web of Science may provide better coverage of bioinformatics research, while Scopus may better cover clinical informatics; Google Scholar may provide the most comprehensive coverage overall.

**Conclusions**

Scientific publications are a common outcome of NLM-funded informatics research, but the production of publications alone cannot ensure impact. As one measure of use, citation analysis could represent a viable indicator of research grant impact. A comprehensive citation analysis has the potential to provide useful feedback for NLM Extramural Programs and should make use of all three databases available, as each provides unique resources.

# Background

In 1955, Eugene Garfield proposed “a bibliographic system for science literature that can eliminate the uncritical citation of fraudulent, incomplete, or obsolete data by making it possible for the conscientious scholar to be aware of criticisms of earlier papers” [1]. This science citation index, developed in 1963, has spurred the use of citation analysis, not just as a mean of identifying potential problems in the scientific literature, but also as one of a range of bibliometric techniques for evaluating the impact of scientific publications. Bibliometrics is a quantitative method of describing publication patterns, and bibliometric indicators have been applied in assessing the productivity or impact of researchers and their research areas or institutions.

One expected outcome of scientific research is peer-reviewed publication of the results, and the most basic bibliometric measure is a simple count of the number of publications produced. This measure may provide an indication of productivity, and evidence exists that quantity is associated with quality in terms of publication [2]. However, it does not in itself indicate the impact of the research on the scientific field, as the publication of an article does not necessitate its use by other researchers. Citation analysis is a second bibliometric technique that provides a quantitative means of assessing this impact.

Citation analysis is a key method in the subfield of bibliometrics known as evaluative bibliometrics. This field focuses on “constructing indicators of research performance from a quantitative analysis of scholarly documents,” and citation analysis uses citation data to create “indicators of the ‘impact’, ‘influence’, or ‘quality’ of scholarly work” [3]. One such indicator derived from citation analysis is the citation count, or number of citations to a publication, researcher, research group, or journal within a particular period of time. The use of citation counts in research evaluation relies on several assumptions. It first must be assumed that researchers cite previous work which has influenced their own in their publications. It is further assumed that higher quality research will have a greater impact on the field and be cited more frequently than research of lesser quality [4]. Finally, it is often assumed that a citation indicates a positive endorsement of the research cited. Despite controversy over the validity of these assumptions and other limitations of the technique, methods of citation analysis are frequently used in evaluating the performance of researchers or research groups [5-6].

Several resources are currently available to facilitate citation analysis and provide citation counts at the individual article level. Garfield’s Science Citation Index, the original citation index, has been incorporated into and is accessible through Web of Science provided by Thomson Reuters. As the first resource to provide cited reference searching, this database is a standard in citation analysis [3]. Overall, it offers access to over 10,000 high impact journals in 256 disciplines and over 110,000 conference proceedings in its six citation databases. Named areas of coverage include biological sciences, medical and life sciences, physical and chemical sciences, and engineering. When using the cited reference searching function, access is limited to two of the databases, the Science Citation Index Expanded and the Social Sciences Citation Index. Science Citation Index Expanded includes more than 7,100 journals in 150 disciplines, with coverage back to 1900, while the Social Sciences Citation Index covers more than 2,474 journals in 50 disciplines dating back to 1956. The Arts & Humanities Citation Index and the Conference Proceedings Citation Index are not available for searching cited references [7]. A complete title list can be found at http://science.thomsonreuters.com/mjl/.

In addition to Web of Science, two other databases have recently been developed which provide citation counts. Launched in 2004 and produced by Elsevier, Scopus claims to be “the largest abstract and citation database of research literature and quality web sources” and to offer the “broadest coverage available of Scientific, Technical, Medical and Social Sciences literature” [8]. It covers almost 18,000 journals with approximately 38 million records. Among other items, coverage includes about 16,500 peer-reviewed journals, 3.6 million conference papers, and 350 book series. Records date from 1823 forward, but only records from 1996 to the present include references. Of the 19 million records in this time period, references are available for 78% [8]. A list of titles covered is available at http://info.scopus.com/detail/what/titles.asp.

Finally, since 2004, Google has been providing links to citing references within Google Scholar. Google Scholar applies the popular Google search technology to locate scholarly literature online. Although the specific titles included, the dates of coverage, and the numbers of resources crawled are not available, Google indicates that it does provide access to a variety of resources including “peer-reviewed papers, theses, books, abstracts and articles, from academic publishers, professional societies, preprint repositories, universities and other scholarly organizations” [9].

Each of these citation indexes serves a similar function in citation analysis, and previous research has investigated the overlap in coverage and the potential benefits of searching in more than one database. Research comparing the content of Web of Science and Scopus has indicated that “in science-related fields the overwhelming part of articles and reviews in journals covered by the WoS [Web of Science] is also included in Scopus” [3]. Approximately 97% of science papers found in Web of Science were also found in Scopus, making Web of Science “almost a genuine subset of Scopus” [3]; the opposite, however, was not true, with Scopus containing approximately 50% more papers than the other database. Furthermore, Scopus was shown to have better coverage in the areas of health sciences, allied health, and engineering and computer science, while Web of Science performed better in clinical medicine and biological sciences [3]. Significant overlap has also been demonstrated in the titles indexed by Web of Science and Scopus, with the two databases having 7,434 journal titles in common in a 2008 study [10]. However, because Scopus indexed more titles, it provided access to 6,256 unique journal titles, while Web of Science could only claim 1,467 unique journal titles. In addition, Scopus purports to have 100% overlap with MEDLINE titles [8], while many MEDLINE titles were not available in Web of Science [10].

Research comparing the coverage of all three databases has been conducted using articles published in the *Journal of the American Society for Information Science and Technology*. This study found that Web of Science provided the best coverage for older material, while Google Scholar best covered newer material [11]. A second study in information science reported that “Scopus and Google Scholar increase the citation counts of scholars by an average of 35% and 160%, respectively” over Web of Science, but the specific increases varied by research area within the general research field [12]. Finally, a study conducted on biomedical material found that, for a recent article, Scopus provided 20% more citing articles than did Web of Science and, for an older article, Google Scholar was particularly disappointing. The authors reported strengths for each citation index, with Web of Science offering more detailed citation analysis, Scopus wider journal coverage, and Google Scholar access to more obscure resources [13]. No studies were located which evaluated the citation indexes specifically in the field of informatics.

## Objectives

The popularity of citation analysis within the information sciences as an evaluative tool has prompted the National Library of Medicine’s (NLM) Extramural Programs (EP) Division to consider whether bibliometric techniques might prove useful in assessing the outcomes of NLM-funded research. Each year NLM funds millions of dollars worth of biomedical informatics and bioinformatics research through its grant programs, and EP is interested in identifying methods to quantify the impact of this funding on scientific research. This project proposed to explore the potential of bibliometrics, and in particular citation analysis, in evaluating the outcome and impact of the informatics research funded by NLM. Assuming that publication counts represent a valid measure of research productivity and citation counts a valid measure of impact, the study aimed to develop a methodology for bibliometric analysis specific to the field of informatics, and to assess the feasibility of such analysis, by exploring the productivity and impact of a selection of NLM-funded research grants. Specifically, it was designed to address questions of whether peer-reviewed publications are an outcome of NLM-funded informatics research and whether such publications are cited. Additionally, the extent of coverage of the three citation databases available was to be determined to evaluate the utility of each database for a citation analysis in the area of biomedical informatics.

# Methodology

For this project, a small-scale citation analysis was conducted using the following procedures. Information was initially gathered about citation analysis generally, and about the citation databases specifically, to guide preliminary decisions related to the design of the study. Samples of NLM-funded grants were then selected to test the study design. Data indicating the productivity and impact of these grants were collected, and the extent of coverage of the citation databases was assessed.

## Sampling

An initial sample comprised of all new R01 grants funded by NLM from FY1995 to 2009 was drawn for assessment of the productivity of NLM-funded research. This sample was compiled using the CRISP database available through the National Institutes of Health’s (NIH) Research Portfolio Online Reporting Tool (RePORT) at http://report.nih.gov/crisp/CRISPQuery.aspx. The search parameters used were:

* Award Type = New
* Activity = Research Grants
* Institutes and Centers = NLM – National Library of Medicine
* Fiscal Year = 1995 – 2009

Default settings were used for the remainder of the search options. Each fiscal year was searched individually, as this was determined to be the most efficient way to separate the sample by year of funding. Search results included all new research grants awarded by NLM in a given fiscal year. These results were copied into an Excel spreadsheet and manually edited to exclude grants not meeting the R01 criteria. The final sample was composed of 214 grants.

A second sample was selected for analysis of the impact of the research and exploration of the utility of the citation databases. Dr. Valerie Florance, Director of Extramural Programs, purposively selected seven NLM grants for this analysis from the 214 grants collected in the initial sample. Grants were selected from the center of the study time period; in the two main areas of informatics research funded by NLM, clinical informatics and bioinformatics; and ignoring grants producing very large numbers of publications. Older grants were avoided in case citation patterns had changed over time, while the newest grants were not considered as time needed to be allowed for a paper to be cited. Grants associated with no publications were not selected for obvious reasons, and those resulting in very large numbers of papers were avoided as they did not seem representative of typical grant output. Five of the grants selected were issued for clinical informatics research and two were for bioinformatics research, with the clinical informatics grants issued in 2000, 2001, 2002, 2005, and 2007, and the bioinformatics grants in 2001 and 2003 (see Table 1).

| Grant Number | Fiscal Year of Funding | Research Area |
| --- | --- | --- |
| 1R01LM006866-01 | 2000 | Clinical Informatics |
| 1R01LM007179-01 | 2001 | Clinical Informatics |
| 1R01LM006789-01A2 | 2001 | Bioinformatics |
| 1R01LM007222-01 | 2002 | Clinical Informatics |
| 1R01LM007938-01 | 2003 | Bioinformatics |
| 1R01LM008374-01 | 2005 | Clinical Informatics |
| 1R01LM009520-01 | 2007 | Clinical Informatics |

Table 1. Sample of R01 grants selected for evaluating the impact of NLM grant-funded publications and exploring the coverage of three citation indexes, Web of Science, Scopus, and Google Scholar.

## Data Collection

To assess research productivity, PubMed was searched to locate publications resulting from each of the R01 grants included in the initial sample. A search was conducted for each grant number in the form “LM######” in the Grant Support field, and the numbers of publications retrieved were recorded in an Excel spreadsheet. Searches were performed originally on May 11, 2009 and updated on July 6, 2009.

To analyze impact and to assess the extent of database coverage, the publication results retrieved by the PubMed searches for the seven grants comprising the second sample were saved in My NCBI, and the authors, journal title, and publication year of each paper were recorded in separate Excel spreadsheets. Searches were then conducted in Web of Science, Scopus, and Google Scholar for each of the publications associated with these grants. Web of Science was searched by author name and journal title, and the appropriate paper identified from the Cited Reference Index. Scopus was searched using the PubMed Identification Number (PMID) for each article, and Google Scholar was searched using the full article title and the advanced options to search for an exact phrase in the title of the article. For each publication, the number of references citing the work retrieved in each of these databases was recorded. References were counted only if they were clearly identifiable as referring to the grant-funded article and accessible so that additional information could be gathered. Four pieces of data were recorded for each citation in the Excel spreadsheets: whether the citing article and original article shared a common author, the title of the journal in which the citation appeared, the publication year of the citation, and the databases in which the citation was found. All data was collected between July 20 and August 18, 2009. The results of the searches from Web of Science and Scopus were saved in EndNote Web, and results associated with each article in each database were printed as a bibliography to allow for comparison of results across databases; results from Google Scholar were only printed.

## Data Analysis

In terms of productivity, the numbers of publications resulting from grants funded were grouped by fiscal year of the funding and descriptive statistics calculated. To address impact, the total number of citations to each article in the smaller sample was determined by combining the results of searches in the three citation databases. As the content of the databases overlaps, a manual comparison of the citation results from each database was conducted for each article and duplicates were eliminated. Each citation was counted only once regardless of the number of databases in which it appeared. Citations were then grouped by grant number and by research area, clinical informatics or bioinformatics. The number of citations for the sample as a whole, as well as in each of these groups, was determined, and descriptive statistics were again calculated. The extent of database coverage was calculated by dividing the number of citations to an article retrieved using the database under consideration by the total number of citations to that article retrieved using all the databases as determined above. This figure indicated the portion of all citations that would be located using a single database. This calculation was performed for the sample as a whole, as well as for citations grouped by grant number and type of informatics.

# Results

Data related to the productivity and impact of NLM-funded research grants, as well as to the utility of each citation database, were evaluated and the results of these three evaluations are grouped accordingly.

## Productivity

Between FY1995 and 2009, NLM funded 214 new R01 grants. Research performed with the support of these grants resulted in a total of 1,486 publications indexed in MEDLINE, an average of 6.94 publications per grant. Excluding the 18 grants issued in FY2009, which have produced no publications to date, increased this average to 7.58 publications per research grant. Including FY2009, a total of 76 grants produced no publications in MEDLINE, while 1 grant was associated with 109 publications.[[1]](#footnote-1)

The number of grants issued and the number of publications resulting from them varied widely over the 15 study years, as shown in Table 2 and Figures 1 and 2 (see also Appendix 1). The largest numbers of grants were funded in FY1995 and 2007, while the largest number of publications resulted from grants funded in FY2003. The average number of publications per grant also fluctuated, reaching a peak in FY2003 at 20.21 publications per grant (Figure 3). Grants awarded in FY2003 produced 19.04% of all publications associated with the grants in this sample.

| Fiscal Year | Number of Grants | Number of Publications | Average Publications/Grant |
| --- | --- | --- | --- |
| 1995 | 23 | 191 | 8.30 |
| 1996 | 6 | 21 | 3.50 |
| 1997 | 18 | 121 | 6.72 |
| 1998 | 17 | 74 | 4.35 |
| 1999 | 15 | 144 | 13.09 |
| 2000 | 17 | 179 | 10.53 |
| 2001 | 10 | 47 | 4.70 |
| 2002 | 17 | 146 | 8.59 |
| 2003 | 14 | 283 | 20.21 |
| 2004 | 7 | 95 | 13.57 |
| 2005 | 11 | 88 | 8.00 |
| 2006 | 9 | 56 | 6.22 |
| 2007 | 23 | 37 | 1.56 |
| 2008 | 13 | 4 | 0.31 |
| 2009 | 18 | 0 | 0 |
| Total | **214** | **1486** | **6.94** |
| Total - 2009 | **196** | **1486** | **7.58** |

Table 2. Number of NLM-funded R01 grants grouped by fiscal year of the funding award and the associated number of publications and average publications per grant, FY1995-2009.

Figure 1. Number of NLM-funded R01 grants grouped by fiscal year of the funding award, FY1995-2009.

Figure 2. Number of NLM grant-supported publications indexed in MEDLINE grouped by fiscal year of the funding award, FY1995-2009.

Figure 3. Average number of publications indexed in MEDLINE per NLM-funded R01 grant grouped by fiscal year of the funding award, FY1995-2009.

The smaller sample of 7 grants accounted for 70 of the total publications, an average of 10 publications per grant. Actual productivity per grant ranged from a low of 3 publications to a high of 21 as shown in Table 3. 41 of these publications were in the area of clinical informatics, an average of 8.2 publications per grant, while 29 were in bioinformatics, an average of 14.5 publications per grant.

| Grant Number | Fiscal Year of Funding | Research Area | Number of Publications |
| --- | --- | --- | --- |
| 1R01LM006866-01 | 2000 | Clinical Informatics | 9 |
| 1R01LM007179-01 | 2001 | Clinical Informatics | 3 |
| 1R01LM006789-01A2 | 2001 | Bioinformatics | 8 |
| 1R01LM007222-01 | 2002 | Clinical Informatics | 20 |
| 1R01LM007938-01 | 2003 | Bioinformatics | 21 |
| 1R01LM008374-01 | 2005 | Clinical Informatics | 4 |
| 1R01LM009520-01 | 2007 | Clinical Informatics | 5 |

Table 3. Sample of NLM grant-supported publications indexed in MEDLINE retrieved for citation analysis and grouped by grant number.

## Impact

The 70 articles resulting from the funding of the sample of 7 grants were cited a total of 1,765 times, an average of 25.21 citations per article. The number of citations to each article varied widely (see Appendix 2), with 13 articles having no citations and one article attracting 221 citations.[[2]](#footnote-2) Grouping articles by grant number, the number of citations per grant ranged from a low of 3 to a high of 832 (Table 4), and the average number of citations per article ranged from 0.75 to 104.00 (Figure 4). Grouping articles by type of informatics showed that the grants in clinical informatics resulted in articles that were cited 832 times, for an average citation rate per article of 20.29. Articles in bioinformatics had 933 citations, for a rate of 32.17 citations per article (Table 5 and Figure 5).

| Grant Number | Number of Articles | Number of Citations | Average Number of Citations/Article |
| --- | --- | --- | --- |
| 1R01LM006866-01 | 9 | 323 | 35.89 |
| 1R01LM007179-01 | 3 | 312 | 104.00 |
| 1R01LM006789-01A2 | 8 | 101 | 12.63 |
| 1R01LM007222-01 | 20 | 183 | 9.15 |
| 1R01LM007938-01 | 21 | 832 | 39.62 |
| 1R01LM008374-01 | 4 | 3 | 0.75 |
| 1R01LM009520-01 | 5 | 11 | 2.20 |
| Total | **70** | **1765** | **25.21** |

Table 4. Number of citations to NLM grant-supported publications in MEDLINE and average citations per article grouped by grant number.

Figure 4. Average number of citations per NLM grant-supported publication indexed in MEDLINE grouped by grant number.

| Grant Number | Number of Articles | Number of Citations | Average Number of Citations/Article |
| --- | --- | --- | --- |
| Clinical Informatics | 41 | 832 | 20.29 |
| Bioinformatics | 29 | 933 | 32.17 |

Table 5. Number of citations to NLM grant-supported publications in MEDLINE and average citations per article grouped by type of informatics.

Figure 5. Average number of citations per NLM grant-supported publication indexed in MEDLINE grouped by type of informatics.

## Database Evaluation

In terms of the extent of coverage of informatics research offered by each of the three citation indexes, Google Scholar retrieved significantly more citations than either of the other two databases. Of all the citations located during the study, the use of Google Scholar alone would have retrieved 85.21% of the citations; Scopus alone would have retrieved 61.81%; and Web of Science, 57.68% of the citations (Figure 6). Percentages do not total to 100% because of the overlap in database coverage. As shown in Table 6, database coverage, when calculated as the percentage of citations retrieved using an individual database out of the total citations retrieved in all databases, varied widely by grant and by database, although Google Scholar almost consistently outperformed the other two databases. Scores ranged from a low of 0% for Web of Science with grant number 1R01LM008374-01 to a high of 92.90% coverage for Google Scholar for grant number 1R01LM007222-01, but again percentages are not mutually exclusive because an individual citation was frequently found in all three of the databases.

Figure 6. Overall citation coverage of informatics research by three citation indexes, Web of Science, Scopus, and Google Scholar, as a percentage of total citations retrieved. Percentages do not total to 100% because of overlap in database coverage.

| Grant Number | Web of Science (%) | Scopus (%) | Google Scholar (%) |
| --- | --- | --- | --- |
| 1R01LM006866-01 | 59.75 | 69.97 | 79.26 |
| 1R01LM007179-01 | 44.55 | 64.74 | 88.78 |
| 1R01LM006789-01A2 | 75.25 | 79.21 | 85.15 |
| 1R01LM007222-01 | 28.42 | 44.26 | 92.90 |
| 1R01LM007938-01 | 66.71 | 59.50 | 84.50 |
| 1R01LM008374-01 | 0 | 66.67 | 66.67 |
| 1R01LM009520-01 | 27.27 | 45.45 | 90.91 |
| Total | **57.68** | **61.81** | **85.21** |

Table 6. Citation coverage of informatics research by three citation indexes, Web of Science, Scopus, and Google Scholar, as a percentage of total citations retrieved and grouped by grant number. Percentages do not total to 100% because of overlap in database coverage.

Grouping by type of informatics, Google Scholar retrieved the highest percentage of clinical informatics articles (85.94%), while Web of Science retrieved the lowest (46.51%; Table 7). For bioinformatics, Google Scholar located 84.57% of the total citations found, while Scopus located 61.62% (Figure 7). Overlap between the three databases in terms of citations was significant, but not complete, and each database retrieved unique resources for at least some of the articles searched.

| Grant Number | Web of Science (%) | Scopus (%) | Google Scholar (%) |
| --- | --- | --- | --- |
| Clinical Informatics | 46.51 | 62.02 | 85.94 |
| Bioinformatics | 67.63 | 61.62 | 84.57 |

Table 7. Citation coverage of informatics research by three citation indexes, Web of Science, Scopus, and Google Scholar, as a percentage of total citations retrieved and grouped by type of informatics. Percentages do not total to 100% because of overlap in database coverage.

Figure 7. Citation coverage of informatics research by three citation indexes, Web of Science, Scopus, and Google Scholar, as a percentage of total citations retrieved and grouped by type of informatics. Percentages do not total to 100% because of overlap in database coverage.

# Discussion

This study aimed to begin development of a methodology for quantitatively evaluating the effects of NLM research funding in the area of informatics by investigating three important factors. First, the question of whether the informatics research funded by NLM results in traditional peer-reviewed publications was addressed. A count of the number of such publications represents one means of assessing the productivity of the research and an indication of whether further citation analysis would be appropriate. If no, or very few, publications are produced with grant funding in informatics, citation analysis might not be an effective means of evaluating the impact of that funding. This study has demonstrated that NLM-funded informatics research does result in the publication of journal articles indexed in MEDLINE, at a rate of approximately seven articles per grant issued. Within the secondary sample, bioinformatics grants tended to produce more articles on average than clinical informatics grants, but this was likely influenced by the purposive selection process.

Not all grants result in the publication of journal articles, while others result in very large numbers of articles. This variation is perhaps to be expected as, even within a general research field such as informatics, the focuses and intended outcomes of research projects can vary significantly. For example, many of the grants awarded in the 1990s portion of the sample which accrued no publications as assessed in this study provided funding for historical research with output expected in monographic form. As well, there may be difference among research groups in the practices of funding acknowledgement. This study relied on the identification within the publication of the supporting research grant number. While some researchers may only include the grant number with papers that directly result from research undertaken with that grant, others might request that any publication making use of a computer application developed with the support of the grant, for example, acknowledge the grant (2009 conversation with V Florance; unreferenced).

Second, the question of whether the research publications produced with NLM’s grant funding are cited was considered. A count of the number of citations to an article can provide an indication of the impact of that research, as a citation is assumed to show that a researcher has found a particular article useful in his or her own research. Results of this study indicate that these publications are being cited, at a rate of approximately 25 citations per article. However, the range in terms of number of citations is wide, from zero to 221, and may be influenced again by the particular focus of a research study as well as the number of researchers working in that field. In the sample studied, bioinformatics papers tended to be cited more heavily on average than clinical informatics papers. This may be impacted by the journal in which publications appear and the limits in coverage of the databases used for citation analysis. For example, several of the clinical informatics papers in this sample were published in the *American Medical Informatics Association (AMIA) Annual Symposium Proceedings*, a source that is not well covered in either Web of Science or Scopus.

Of further interest was the fact that bioinformatics research resulted in both larger average numbers of publications per grant and citations per publication. This might seem to suggest a connection between the productivity of a grant and its impact, but it should be noted that the grant receiving the largest number of citations per article also produced the fewest number of articles.

Finally, an evaluation of the extent of coverage of the three citation indexes, Web of Science, Scopus, and Google Scholar, was undertaken to guide the decision of which index or indexes to use in a citation analysis of informatics research. The results of this research coincided with previous findings [3; 10] indicating significant overlap between Web of Science and Scopus, with Scopus having more unique citations than Web of Science. As well, results showing a larger number of citations retrieved in Scopus and Google Scholar compared to Web of Science for recent research [11; 12; 13] were supported. Citations for the majority of articles were located in all three databases considered, but in general, Google Scholar retrieved the most citations, while Web of Science found the fewest. Differences in index coverage were noted between clinical informatics and bioinformatics research, with Scopus performing better in the area of clinical informatics, and Web of Science better in bioinformatics. Google Scholar outperformed both of the other two databases across both types of informatics.

Despite its superiority in terms of numbers of citations and variety of resources retrieved, the disadvantages of Google Scholar should be acknowledged. In conducting this study, it was noted that analyzing citation results from Google Scholar required more time and effort than those from the other two databases. Google Scholar results often contained duplicate citations, citations to materials of questionable significance, and citations to materials that could not be easily accessed or described. For example, citations sometimes contained broken links or links to Web sites in foreign languages. This posed difficulty in determining whether or not a citation was unique.

Overall, impressions from this research were that Scopus and Google Scholar might be more useful than Web of Science when assessing the impact of informatics research. Coverage of Scopus is broader than that of Web of Science in terms of recent publications, and an evaluation of the type proposed would focus on recent research. The use of Scopus provides more access to publications in conference proceedings, such as the *AMIA Annual Symposium Proceedings*, and in open access journals, such as *PLoS One*, that did not appear to be as well covered by Web of Science. Although the extent of Google’s coverage is not known, it seemed as though Google Scholar increased access even further to provide additional conference proceedings and other resources, such as dissertations, technical reports, and book chapters, as well as the most recent published literature. A number of ahead-of-print journal articles posted online as recently as July and August 2009 were retrieved through Google Scholar, but not using the other two databases. However, each of the three databases did provide access to unique resources and so would have value in a full citation study.

## Limitations

Several limitations of this study exist that may affect the generalizability of the research findings. As a pilot study exploring the potential for bibliometric analysis, this study relied on a small, purposively selected sample to evaluate the appropriateness of citation analysis generally and the citation indexes specifically. The results of this small-scale study may not be representative of the entire population of NLM-funded R01 grants and may not be upheld by future research with a larger, randomly selected sample. It should be noted as well that the small sample used for citation analysis had an average productivity higher than that of the total sample of research grants; this may have affected the estimations of impact. Searches to identify publications for this study were conducted solely in PubMed and using only one search parameter. It is likely that additional publications could be located using other databases or search engines or less restrictive search strategies, and the citation patterns for non-PubMed articles may differ. Finally, data was collected and decisions made regarding the uniqueness of citations by a single individual and based on the results lists of citation indexes, often without viewing the citing resources themselves.

# Recommendations

This project demonstrated that bibliometric techniques could be used on research in the areas of biomedical informatics and bioinformatics as one means of quantifying productivity and impact. A methodology for conducting a study using these tools was developed and described by applying the procedures identified on a small scale. The results of this pilot test indicated that bibliometric analysis, and specifically citation analysis, might provide useful information to supplement that currently used in decision-making related to research grant funding.

Each of the databases available for citation analysis had its own strengths and unique resources and so could be valuable in a full-scale evaluation of NLM-funded research. However, Google Scholar tended to outperform the other two databases in terms of the number and range of citations provided. While the most comprehensive analysis would make use of all three citation indexes, if only a single database could be used, Google Scholar might be the best option for assessing informatics research. This strategy would require time to sort through the list of citations retrieved to determine whether they are appropriately scholarly and unique; if this time was not available, Scopus might offer a compromise between coverage and ease of use. In this study, Scopus was searched simply by PMID and retrieved over 60% of all citations found with little further investigation of potential duplicates needed. If the type of informatics is identifiable, Google Scholar searches should be supplemented first by Scopus for clinical informatics research and by Web of Science for bioinformatics research.

A bibliometric analysis employing the methodology described above could be undertaken with a larger sample of NLM-funded research to determine whether the results of this study hold. Future research could also expand on publication and citation counts to evaluate other factors relating to publications. The data collected for this study could be used to estimate rates of self-citation as opposed to citation by other researchers or to evaluate the trend in citations to a publication over time. The data could be supplemented with additional information about the journals in which the citations appeared to determine if the prestige of the journal or the subject area in which the original article was published affects its citation rate. Finally, other bibliometric measures, such as the h-index or journal impact factor, or additional elements, such as software development or patent applications, could be explored to determine whether they might offer further useful information for research evaluation.

# Acknowledgements

The author would like to thank Valerie Florance of Extramural Programs for her interest in exploring this area, her guidance in designing this study, and her flexibility in allowing the transformation of the study over the last few months. As well, Pam Sieving at the NIH Library was particularly helpful, in sharing her experience with citation analysis and always keeping her eyes open for resources for the project, as was Mark Siegal of EP, in explaining how to search PubMed for publications supported by NLM grants. Finally, the support of NLM, the Associate Fellowship Program, and the other associates as this project developed was, as always, greatly appreciated.

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# Appendices

## Appendix 1. Publication Counts for NLM-funded R01 research grants, FY1995-2009

| **Fiscal Year of Grant Funding** | **Grant Number** | **Number of Publications** |
| --- | --- | --- |
| **1995** | 1R01LM005545-01A2 | 9 |
|  | 1R01LM005361-01A3 | 0 |
|  | 1R01LM005624-01 | 0 |
|  | 1R01LM005649-01 | 1 |
|  | 1R01LM005732-01 | 0 |
|  | 1R01LM005700-01 | 0 |
|  | 1R01LM005906-01 | 0 |
|  | 1R01LM005773-01A1 | 15 |
|  | 1R01LM005675-01A1 | 1 |
|  | 1R01LM005698-01 | 0 |
|  | 1R01LM005933-01 | 0 |
|  | 1R01LM005678-01 | 0 |
|  | 1R01LM005949-01 | 0 |
|  | 1R01LM005708-01 | 46 |
|  | 1R01LM005903-01 | 0 |
|  | 1R01LM005753-01 | 0 |
|  | 1R01LM005921-01 | 0 |
|  | 1R01LM005944-01 | 1 |
|  | 1R01LM005607-01A1 | 2 |
|  | 1R01LM005907-01 | 1 |
|  | 1R01LM005674-01A1 | 0 |
|  | 1R01LM005639-01A1 | 109 |
|  | 1R01LM005764-01 | 6 |
| **1996** | 1R01LM006244-01 | 16 |
|  | 1R01LM006243-01 | 3 |
|  | 1R01LM005917-01A2 | 0 |
|  | 1R01LM006005-01 | 0 |
|  | 1R01LM005982-01 | 2 |
|  | 1R01LM005993-01 | 0 |
| **1997** | 1R01LM006262-01 | 2 |
|  | 1R01LM006249-01A2 | 11 |
|  | 1R01LM006316-01 | 15 |
|  | 1R01LM006304-01 | 0 |
|  | 1R01LM006274-01A1 | 36 |
|  | 1R01LM006236-01A1 | 0 |
|  | 1R01LM006488-01 | 4 |
|  | 1R01LM006325-01 | 1 |
|  | 1R01LM006539-01 | 9 |
|  | 1R01LM006311-01A1 | 3 |
|  | 1R01LM006270-01 | 20 |
|  | 1R01LM005934-01A1 | 0 |
|  | 1R01LM006326-01A1 | 0 |
|  | 1R01LM005997-01A2 | 1 |
|  | 1R01LM005983-01A1 | 0 |
|  | 1R01LM006226-01A1 | 19 |
|  | 1R01LM006528-01 | 0 |
|  | 1R01LM006265-01 | 0 |
| **1998** | 1R01LM006543-01A1 | 1 |
|  | 1R01LM006696-01 | 3 |
|  | 1R01LM006726-01 | 4 |
|  | 1R01LM006591-01 | 1 |
|  | 1R01LM006567-01 | 1 |
|  | 1R01LM006533-01A1 | 1 |
|  | 1R01LM006574-01 | 0 |
|  | 1R01LM006587-01 | 8 |
|  | 1R01LM006593-01 | 3 |
|  | 1R01LM006638-01 | 2 |
|  | 1R01LM006682-01 | 7 |
|  | 1R01LM006747-01 | 19 |
|  | 1R01LM006538-01 | 23 |
|  | 1R01LM006662-01 | 0 |
|  | 1R01LM006566-01 | 0 |
|  | 1R01LM006321-01A1 | 1 |
|  | 1R01LM006590-01A1 | 0 |
| **1999** | 1R01LM006653-01A1 | 3 |
|  | 1R01LM006759-01 | 2 |
|  | 1R01LM006856-01 | 3 |
|  | 1R01LM006967-01 | 4 |
|  | 1R01LM006649-01A1 | 2 |
|  | 1R01LM006617-01A1 | 2 |
|  | 1R01LM006822-01 | 19 |
|  | 1R01LM006845-01 | 71 |
|  | 1R01LM006708-01 | 0 |
|  | 1R01LM006594-01 | 28 |
|  | 1R01LM006780-01 | 10 |
| **2000** | 1R01LM006942-01 | 35 |
|  | 1R01LM007050-01 | 9 |
|  | 1R01LM006916-01 | 14 |
|  | 1R01LM006858-01 | 15 |
|  | 1R01LM006806-01A1 | 28 |
|  | 1R01LM006866-01 | 9 |
|  | 1R01LM006910-01 | 39 |
|  | 1R01LM006627-01A1 | 0 |
|  | 1R01LM006761-01A1 | 0 |
|  | 1R01LM006843-01 | 13 |
|  | 1R01LM006966-01 | 0 |
|  | 1R01LM006659-01A1 | 6 |
|  | 1R01LM006756-01 | 5 |
|  | 1R01LM006909-01 | 1 |
|  | 1R01LM006893-01 | 2 |
|  | 1R01LM006911-01 | 3 |
|  | 1R01LM006859-01 | 0 |
| **2001** | 1R01LM007203-01 | 3 |
|  | 1R01LM006955-01A1 | 5 |
|  | 1R01LM007061-01 | 3 |
|  | 1R01LM006919-01A1 | 1 |
|  | 1R01LM007179-01 | 3 |
|  | 1R01LM006849-01A2 | 1 |
|  | 1R01LM007174-01 | 4 |
|  | 1R01LM006920-01A1 | 2 |
|  | 1R01LM006789-01A2 | 8 |
|  | 1R01LM007292-01 | 17 |
| **2002** | 1R01LM007319-01A1 | 2 |
|  | 1R01LM007593-01 | 35 |
|  | 1R01LM007591-01 | 0 |
|  | 1R01LM007609-01 | 6 |
|  | 1R01LM006918-01A1 | 17 |
|  | 1R01LM007455-01A1 | 10 |
|  | 1R01LM007453-01 | 5 |
|  | 1R01LM007606-01 | 1 |
|  | 1R01LM007268-01A1 | 16 |
|  | 1R01LM007081-01A1 | 0 |
|  | 1R01LM007167-01 | 3 |
|  | 1R01LM007685-01 | 1 |
|  | 1R01LM007199-01 | 11 |
|  | 1R01LM007218-01A1 | 5 |
|  | 1R01LM007595-01 | 10 |
|  | 1R01LM007273-01 | 4 |
|  | 1R01LM007222-01 | 20 |
| **2003** | 1R01LM007948-01 | 12 |
|  | 1R01LM007878-01A1 | 1 |
|  | 1R01LM007891-01 | 4 |
|  | 1R01LM007688-01A1 | 61 |
|  | 1R01LM007659-01 | 44 |
|  | 1R01LM007849-01 | 4 |
|  | 1R01LM008192-01 | 3 |
|  | 1R01LM007677-01 | 27 |
|  | 1R01LM008154-01 | 0 |
|  | 1R01LM008142-01 | 12 |
|  | 1R01LM007329-01A1 | 36 |
|  | 1R01LM007938-01 | 21 |
|  | 1R01LM008106-01 | 17 |
|  | 1R01LM007861-01A1 | 41 |
| **2004** | 1R01LM007994-01A1 | 27 |
|  | 1R01LM008000-01A1 | 3 |
|  | 1R01LM008111-01A1 | 25 |
|  | 1R01LM007709-01A1 | 7 |
|  | 1R01LM007995-01 | 14 |
|  | 1R01LM007894-01A1 | 19 |
|  | 1R01LM008143-01A1 | 0 |
| **2005** | 1R01LM008247-01 | 1 |
|  | 1R01LM008443-01A1 | 9 |
|  | 1R01LM008374-01 | 4 |
|  | 1R01LM008635-01 | 29 |
|  | 1R01LM008713-01A1 | 10 |
|  | 1R01LM009027-01 | 11 |
|  | 1R01LM008323-01A1 | 1 |
|  | 1R01LM008255-01A1 | 0 |
|  | 1R01LM007663-01A2 | 1 |
|  | 1R01LM008626-01A1 | 3 |
|  | 1R01LM008696-01 | 19 |
| **2006** | 1R01LM009254-01 | 11 |
|  | 1R01LM008991-01 | 17 |
|  | 1R01LM008799-01A1 | 4 |
|  | 1R01LM009012-01A1 | 11 |
|  | 1R01LM008445-01A2 | 9 |
|  | 1R01LM009256-01 | 0 |
|  | 1R01LM008795-01 | 1 |
|  | 1R01LM008796-01 | 3 |
|  | 1R01LM009018-01 | 0 |
| **2007** | 1R01LM009657-01 | 2 |
|  | 1R01LM009331-01 | 2 |
|  | 1R01LM009427-01 | 0 |
|  | 1R01LM009501-01 | 1 |
|  | 1R01LM009121-01A1 | 0 |
|  | 1R01LM009157-01A1 | 0 |
|  | 1R01LM009516-01A1 | 0 |
|  | 1R01LM009338-01 | 2 |
|  | 1R01LM009239-01A1 | 1 |
|  | 1R01LM009758-01 | 5 |
|  | 1R01LM009651-01 | 0 |
|  | 1R01LM008923-01A1 | 0 |
|  | 1R01LM009375-01A1 | 1 |
|  | 1R01LM009153-01A1 | 2 |
|  | 1R01LM009722-01 | 3 |
|  | 1R01LM009219-01A1 | 2 |
|  | 1R01LM009520-01 | 5 |
|  | 1RL1LM009833-01 | 0 |
|  | 1R01LM008912-01A1 | 1 |
|  | 1R01LM009765-01 | 0 |
|  | 1R01LM009143-01A2 | 0 |
|  | 1R01LM009161-01A1 | 4 |
|  | 1R01LM009362-01 | 4 |
|  | 1R01LM009836-01A1 | 2 |
| **2008** | 1R01LM009731-01 | 0 |
|  | 1R01LM009719-01A1 | 0 |
|  | 1R01LM009533-01A1 | 1 |
|  | 1R01LM009500-01A2 | 0 |
|  | 1R01LM009519-01A1 | 2 |
|  | 1R01LM009538-01A1 | 0 |
|  | 1R01LM009494-01A1 | 1 |
|  | 1R01LM009623-01A2 | 0 |
|  | 1R01LM009965-01 | 0 |
|  | 1R01LM009591-01A1 | 0 |
|  | 1R01LM009725-01A1 | 0 |
|  | 1R01LM009723-01A1 | 0 |
|  | 1R01LM009132-01A2 | 0 |
| **2009** | 1R01LM010031-01 | 0 |
|  | 1R01LM010020-01 | 0 |
|  | 1R01LM009607-01A2 | 0 |
|  | 1R01LM010016-01 | 0 |
|  | 1R01LM010009-01 | 0 |
|  | 1R01LM010119-0109 | 0 |
|  | 1R01LM010138-0109 | 0 |
|  | 1R01LM010125-0109 | 0 |
|  | 1R01LM010129-0109 | 0 |
|  | 1R01LM010140-0109 | 0 |
|  | 1R01LM009879-01A1 | 0 |
|  | 1R01LM010040-01 | 0 |
|  | 1R01LM010132-0109 | 0 |
|  | 1R01LM009897-01A1 | 0 |
|  | 1R01LM009961-01 | 0 |
|  | 1R01LM010130-0109 | 0 |
|  | 1R01LM010120-0109 | 0 |
|  | 1R01LM009886-01A1 | 0 |

## Appendix 2. Citation Counts for NLM Grant-Funded Publications

| **Grant Number** | **Article PMID** | **Number of Citations in Web of Science** | **Number of Citations in Scopus** | **Number of Citations in Google Scholar** | **Total Number of Citations** |
| --- | --- | --- | --- | --- | --- |
| **1R01LM006866-01** | 18083460 | 0 | 1 | 1 | **2** |
|  | 17213490 | 0 | 0 | 0 | **0** |
|  | 17213044 | 2 | 2 | 1 | **2** |
|  | 17082841 | 9 | 9 | 11 | **12** |
|  | 16404468 | 6 | 7 | 10 | **12** |
|  | 16773925 | 2 | 2 | 4 | **4** |
|  | 15894554 | 63 | 78 | 96 | **116** |
|  | 15619601 | 46 | 49 | 63 | **63** |
|  | 15073027 | 65 | 78 | 70 | **101** |
| **1R01LM007179-01** | 17460122 | 4 | 3 | 7 | **7** |
|  | 15561792 | 42 | 47 | 79 | **84** |
|  | 11909789 | 93 | 152 | 191 | **221** |
| **1R01LM006789-01A2** | 18004788 | 1 | 2 | 2 | **2** |
|  | 17387739 | 4 | 4 | 3 | **4** |
|  | 15557265 | 12 | 12 | 14 | **15** |
|  | 14696195 | 17 | 18 | 21 | **24** |
|  | 14983063 | 3 | 3 | 4 | **4** |
|  | 14573856 | 17 | 19 | 17 | **23** |
|  | 12211006 | 8 | 8 | 6 | **8** |
|  | 12112672 | 14 | 14 | 19 | **21** |
| **1R01LM007222-01** | 19275981 | 0 | 0 | 0 | **0** |
|  | 18999150 | N/A | N/A | 0 | **0** |
|  | 18436906 | 0 | 0 | 0 | **0** |
|  | 18436895 | 0 | 1 | 3 | **3** |
|  | 18308983 | 0 | 0 | 0 | **0** |
|  | 18693956 | N/A | 0 | 1 | **1** |
|  | 18693870 | N/A | 0 | 2 | **2** |
|  | 17478414 | 6 | 6 | 8 | **9** |
|  | 17478413 | 1 | 3 | 4 | **4** |
|  | 17911889 | 0 | 2 | 4 | **4** |
|  | 17238431 | N/A | 0 | 0 | **0** |
|  | 16221948 | 10 | 15 | 27 | **30** |
|  | 16221944 | 7 | 13 | 24 | **26** |
|  | 16779162 | N/A | 3 | 15 | **15** |
|  | 15471753 | 4 | 4 | 13 | **13** |
|  | 14764616 | 0 | 3 | 5 | **5** |
|  | 15036078 | 13 | 15 | 25 | **29** |
|  | 15361030 | 0 | 0 | 0 | **0** |
|  | 14728328 | N/A | 1 | 2 | **2** |
|  | 12425240 | 11 | 15 | 37 | **40** |
| **1R01LM007938-01** | 18341692 | 6 | 6 | 9 | **11** |
|  | 18070356 | 6 | 15 | 26 | **29** |
|  | 17885136 | 62 | 62 | 72 | **90** |
|  | 17642473 | 1 | 1 | 1 | **1** |
|  | 17517127 | 9 | 10 | 14 | **15** |
|  | 17553249 | 37 | 39 | 40 | **57** |
|  | 17237039 | 36 | 40 | 56 | **59** |
|  | 17324286 | 6 | N/A | 7 | **7** |
|  | 17218520 | 107 | 92 | 111 | **141** |
|  | 17313685 | 24 | 22 | 24 | **28** |
|  | 17274839 | 22 | 25 | 32 | **34** |
|  | 16933976 | 105 | 37 | 105 | **135** |
|  | 16766564 | N/A | 0 | 0 | **0** |
|  | 16925843 | N/A | 9 | 13 | **13** |
|  | 16076884 | 27 | 27 | 38 | **43** |
|  | 15691859 | 9 | 13 | 14 | **15** |
|  | 15667658 | 3 | N/A | 7 | **7** |
|  | 15774024 | 41 | 41 | 43 | **51** |
|  | 15613242 | 5 | N/A | 8 | **9** |
|  | 15247098 | 26 | 30 | 47 | **49** |
|  | 15383210 | 23 | 26 | 36 | **38** |
| **1R01LM008374-01** | 18694149 | N/A | 0 | 0 | **0** |
|  | 18693850 | N/A | 0 | 0 | **0** |
|  | 16779142 | N/A | 2 | 2 | **3** |
|  | 16779022 | N/A | 0 | 0 | **0** |
| **1R01LM009520-01** | 19015285 | N/A | 0 | 0 | **0** |
|  | 19387512 | 1 | 0 | 1 | **2** |
|  | 18999118 | N/A | N/A | 0 | **0** |
|  | 17600771 | 2 | 3 | 4 | **4** |
|  | 17787066 | N/A | 2 | 5 | **5** |

1. The grant associated with 109 publications (number 1R01LM005639-01A1) was issued to Arthur Toga in 1995 and used to produce a piece of computer software. It is believed that the grant number was included in publications using this software and that there are not 109 publications about the software (2009 conversation with V Florance; unreferenced). [↑](#footnote-ref-1)
2. The publication attracting 221 citations was produced with grant number 1R01LM007179-01 issued to John Ely in 2001. The citation information for the publication is: Ely JW, Osheroff JA, Ebell MH, Chambliss ML, Vinson DC, Stevermer JJ, Pifer EA. Obstacles to answering doctors' questions about patient care with evidence: qualitative study. BMJ. 2002 Mar 23; 324(7339): 710. [↑](#footnote-ref-2)