Tracking NLM RO1 Outcomes: An Evaluation with Scopus

Project Leader

Suzy Roy, NLM Associate Fellow

Project Sponsor

Dr. Valerie Florance, Associate Director of Extramural Programs

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Abstract

OBJECTIVE: The National Library of Medicine (NLM) has been awarding research grants since the Medical Library Assistance Act (MLAA) was enacted in 1965. Currently, the NLM awards a number of types of grants, one of which is the RO1 research project grant. The RO1 mechanism is the premier grant awarded for biomedical research by the institutes at the National Institutes of Health. The purpose of this project was to begin an in-depth evaluation of the outcomes and impacts of R01 grants funded by the NLM.

METHODS: All RO1s awarded by the NLM between FY1988 to FY2011 were identified using the NIH RePORTER tool. PubMed and Scopus were used to determine activity measures (publication counts and lag-time) and impact measures (citation analysis) of the grants.

RESULTS: From FY1988 to FY2011 the NLM awarded 348 RO1 grants, of which 81 were awarded to support the publication of a book and 173 to support research in biomedical informatics. The book grants produced 113 publications and the research grants produced 2610 publications. Overall, NLM-funded grants have produced an average of 7.82 publications with a range of 0 to 233 publications per grant. The lag-time of RO1 award to year of first book publication was 7 years, whereas lag-time of first article publication was 1.54 years. Finally, an analysis of the 2666 RO1 produced articles revealed a total of 150,705 article citations. 73% of the publications that have resulted from NLM-funding have been cited at least 1 time.

CONCLUSIONS: Overall these data provide a picture of the outputs and influence of NLM funded research. The findings can be replicated in other resources such as Web of Science and Google Scholar, and to begin to assess the longer-term impact of NLM support. Furthermore, these data show different publishing patterns for subfields within biomedical informatics, thereby allowing for future tracking of trends in research and scientific publishing.

Introduction

Current U.S. federal government initiatives include an emphasis on an effective, efficient and accountable government. This push for a more open and transparent government has increased the awareness of knowing where taxpayer money is going. As such, agencies have begun to develop outcome-oriented evaluation methodologies to meet the mandates and they have set a priority on beginning to track and measure the reach, influence and success of funded projects (1, 2).

One way to meet these initiatives and mandates quantitatively is to use evaluative bibliometrics. Bibliometrics is a method to research the science of science, or to evaluate the productivity of scientific research. Essentially, bibliometrics uses mathematics and statistical methods to analyze and measure the impact of a scientific article based on references made to it by others. Bibliometrics was first proposed by Eugene Garfield, the pioneer of the field of citation analysis, to develop an indexing system for scientific literature (3). Early endeavors in citation analysis led to the development of "impact factor," a measure based on citations to published research articles and journals that could serve as an indicator of importance in the field. The impact factor has been used to argue that the more citations a researcher has, the more important his/her findings are, and that publications in a high-impact journal are more valued than articles published in low impact journals. Citation analysis has been extensively used to quantitatively evaluate the work of researchers for promotion and tenure (4).

Recently, bibliometric evaluation has gained momentum in science policy and management (1, 2). Indicators used for policy and management include productivity measurements of outputs and volume, research impact including citation analysis and research and science collaboration patterns (1, 2, 5-7). These productivity measures typically utilize citation analysis, where citations from published works are counted and used to measure the "impact", "influence", or "quality" of the research (4, 8, 9). For example, one academic institution recently investigated whether their institutional research support program (which awarded start-up funding to new investigators) increased the likelihood of future external funding awards and/or scholarly publications. The study showed that funded faculty members benefited from the support anecdotally, but no differences were found in the number of later external grants awarded or the number of articles published (11). In other investigations, the number of publications, and the citation counts of those publications were used to determine if the amount of funding equated to higher number of outputs. In one report, 34 countries were compared but the data had such variation that no price per paper could be estimated (10). Whereas, other research found that higher input (i.e. funding amount) produced higher outputs and impact (7).

In addition to institutional investigations, research on the outcomes of federally funded research has also been published. In particular, studies of the impact of government funding on research using funding acknowledgements and total research outputs, comparisons of the amount of funding with the amount of outputs, and the citation counts of research publications, have been evaluated (1, 7, 11). In one study, researchers showed that funding acknowledgements could be used to evaluate funding agency performance (11). These data provide support that publications

acknowledge funding, which is beneficial to government agencies trying to track outputs and impacts. In another study, a governmental agency in India, SERC (Science and Engineering Research Council), showed an increase in activity and research outputs with increased levels of funding. That is, using citation analysis, the governmental agency showed their higher funded research produced more outcomes and had more citations than their lower funded research (7). More recently, the publications from grants funded by the National Institutes of Health (NIH) were evaluated. In the study, publications from grants awarded by NIH institutes from 1980 to 2009 produced a high number of publications. The study showed that over 75,000 (or approximately 45%) of all published papers in biomedical research in the United States, have NIH funding sponsorship (1). These types of data begin to show how methodologically the outcomes of funding can be tracked and evaluated.

Ways to track outputs (i.e. publications) have become a popular topic in bibliometric science. Until very recently, Web of Science was the only tool that was used to track and obtain citation counts; however in 2004, Scopus and Google Scholar were developed to track and count citations. Since then all three resources have been extensively reviewed (8, 12-17). When comparing the content of PubMed, Scopus, Web of Science and Google Scholar, Scopus has been found to offer the most coverage for citation counts and PubMed was optimal for biomedical publication retrieval (15, 16). Interestingly, Web of Science was not found to cover as many resources as Scopus, and although there was some overlap in journal coverage, it was not found to be complete (18). Google Scholar was found to be inconsistent with coverage and lack quality control of indexed citations, however coverage includes more than just peer-reviewed journals (e.g., citations from books, dissertations, Web sites, patents and more) (12, 13, 15). Web sites, software tools, databases and patents are all additional outputs of research that are not yet systematically tracked, but need to also be considered in describing and measuring outputs and impacts of research. All in all, the resources appear to have different pros and cons for use in bibliometric evaluation. Knowing the scope and coverage of the resource may dictate which resource(s) to use for an evaluation study.

This report presents an initial evaluation of research grant outcomes funded by the National Library of Medicine ® (NLM). NIH Research Project Grants (RO1) are the premier grant mechanism awarded by NIH institutes and the NLM awards RO1 grants to researchers investigating novel research in informatics and biomedicine. Here, the outcomes and impact of NLM-funded RO1 grants are evaluated. Specifically, we evaluated the outputs and impact of grants by measuring activity (i.e., counts of publications) and impact (citation counts).

Methods

Extramural research project grants comprises almost half of NIH's total budget each fiscal year (FY), and the RO1 grant mechanism comprises approximately 60% of the extramural grant budget. At the NLM, RO1 funding comprises approximately 50% of NLM's extramural grant awards each FY. This report evaluates new NLM RO1 grants awarded from FY1988 to FY2011 using RePORTER (http://projectreporter.nih.gov/reporter.cfm), PubMed (http://www.ncbi.nlm.nih.gov/pubmed/) and Scopus (http://www.scopus.com/home.url).

RO1 Grant Descriptive Statistics

The dataset of new NLM-funded RO1 grants from FY1988 to FY2011 was generated from NIH's RePORT, using the RePORTER tool. The search parameters used were:

- Agency/Institute/Center: NLM
- Award Type: New
- Activity Code: RO1 Equivalents
- Fiscal Year (FY): checked each year to be included

Default settings were used for all of the remaining search options. Each FY was searched individually so that all RO1 data could be exported into an Excel spreadsheet. The search for RO1 grants in RePORTER occurred on November 22, 2011. After all RO1 grant data were collected, the number of grants awarded were calculated for each FY.

To complete an in-depth analysis of NLM project awards, grants were grouped by the type of research based on the scientific field and type of project proposed (categorizing of grants was provided by the Director of Extramural Programs). See Table 1 for the categories and description. These groups were used in subsequent analyses to determine differences between types of projects in measures such as outputs, lag-time and citation impacts.

Category	Description of Category
Book	RO1s awarded to individuals for scholarly pursuit in research and/or writing, with the outcome expected as the publication of a book.
Basic Science	RO1s awarded for basic science research, such as information retrieval, or knowledge representation, or human computer interaction.
Bioinformatics	RO1s awarded for bioinformatics research, such as computational biology, 'omics' sciences, genome-wide area studies or translational biology.
Clinical-informatics	RO1s awarded for clinical-informatics research, such as health decision support or clinical trials research informatics or enhancements to the electronic medical record.
Tool	RO1s awarded for research leading to the creation or improvement of a knowledge resource or software component relevant to clinical care or biomedical research.

Table 1. Description of groups used to categorize RO1 grants for data analysis.

RO1 Grant Publications

To investigate the outcomes of the NLM-funded RO1 grants, the number of publications resulting from each grant was determined. All 348 RO1s were manually searched by grant number in MEDLINE/PubMed using the string: LM###### [Grant Number]. All searches occurred during the week of November 28, 2011 to December 2, 2011.

For RO1s awarded for book writing, in addition to the PubMed search, the Principle Investigators' name was searched on Amazon.com, Books In Print and Google Scholar. Because PubMed does not index book citations, it was important to verify if the book that was proposed in the grant proposal had come to fruition by using multiple resources for validation. All searches for book publications occurred throughout the month of December 2011.

The total number of publications for each grant was determined based upon PubMed and book searches. Grant publication data were collapsed into grant categories (i.e. books, basic science, bioinformatics, clinical-informatics or tool). Publications were also averaged across all years to find the average number of publications that resulted from an award. The number of RO1 grants that have not produced a publication was also determined. The grants that have not produced a publication were compared by year and topic.

RO1 Grant Publication Lag-time

The lag-time, or the length of time from the award of the grant to the time of first publication, was calculated for each RO1. Because of the time differences in publishing a book versus an article, the analyses to determine lag-time were done separately for books versus articles.

Using the data collected from the grant publication data from PubMed and searches on books (from Amazon, GoogleScholar and Books In Print), the date of the first publication was determined for each RO1. This date was then used to determine the number of years, post-grant award. The lag-time data were manually calculated for each publication for each grant based on the year of the initial grant award. Data were then collapsed across years (FY1988 – FY2011), and across project categories (basic, bioinformatics, book, clinical-informatics and tool). Because some RO1 grants that proposed a written book also contributed to the publication of an article, the article publications were included in the article lag-time analyses and the book publications were analyzed in a separate, similar analysis.

RO1 Grant Citation Analysis

Finally, to determine the impact of NLM-funded grants on the scientific community, a citation analysis of grant publications was completed using Scopus. Using each article PubMed unique identifier (PMID), and the advance search function on Scopus, each grant was searched independently. For each RO1, citation data for each publication were gathered using a batch export search string:

PMID (####) OR

Total citations, excluding self-citations, were gathered for each publication. Self-citations were excluded to decrease the potential of citation inflation. The number of citations for each category of RO1 grant (basic science, bioinformatics, clinical-informatics and tool) was calculated. Additionally, citation ranges were calculated to determine the percent of citations.

A citation analysis of the books from NLM grant funding was not completed with this report. Those data will be presented in a planned future report.

Statistical Analysis

Where appropriate, a student's t-test analysis was completed to statistically compare the means of groups. An alpha level of 0.05 was used in all statistical tests.

Results

RO1 Grant Descriptive Statistics

NML-funded RO1 grant information was collected and analyzed using RePORTER and PubMed/MEDLINE. From 1988 to 2011, the NLM awarded 348 new RO1 grants (see Appendix A). The number of new RO1 grants awarded per FY has ranged from a low of six in 1996 to a high of 33 in 2009[1] (see Figure 1). On average, NLM has funded 14-15 grants per FY. The number of NLM-funded grants appears to have increased over time. However, when the grants from the 1990s (1990-1999) and 2000s (2000-2009) were combined and compared (131 and 154 RO1 grants, respectively) no differences were seen when analyzed by a student's t-test, $t(18)= -0.767$, $p=0.45$. These data show that the number of NLM-funded RO1s has been consistent over time.

Next, grant proposals were grouped by categories (i.e. book research and writing, basic science, bioinformatics, clinical-informatics or creation of a tool). Figure 1 shows the number of RO1 grants for each category across FYs. RO1s for book research and writing were funded from FY1988 to FY2002, however following FY2002 these types of scholarly pursuits were supported instead by the G13 grant mechanism. As a result, the number of informatics awards has increased. Grant counts were grouped by combining bioinformatics and clinical-informatics. During the 1990s, of the 131 grants awarded, 40 grants were for informatics (30.53%); whereas, in the 2000s, of the 154 grants awarded, 101 were for informatics research (65.58%). This was a significant difference, suggesting a change in the type of research that was awarded RO1 grants by NLM over time, $t(38)= -3.329$, $p=0.0019$.

[1] In 2009, the American Recovery and Reinvestment Act (ARRA) legislation provided federal agencies with funding to help stimulate the US economy. The NLM awarded an additional 19 RO1s (to the 14 RO1s already awarded) in 2009 to stimulate the economy and support the advancement of scientific research. Further ARRA grant outcome analyses will be presented in a future report.

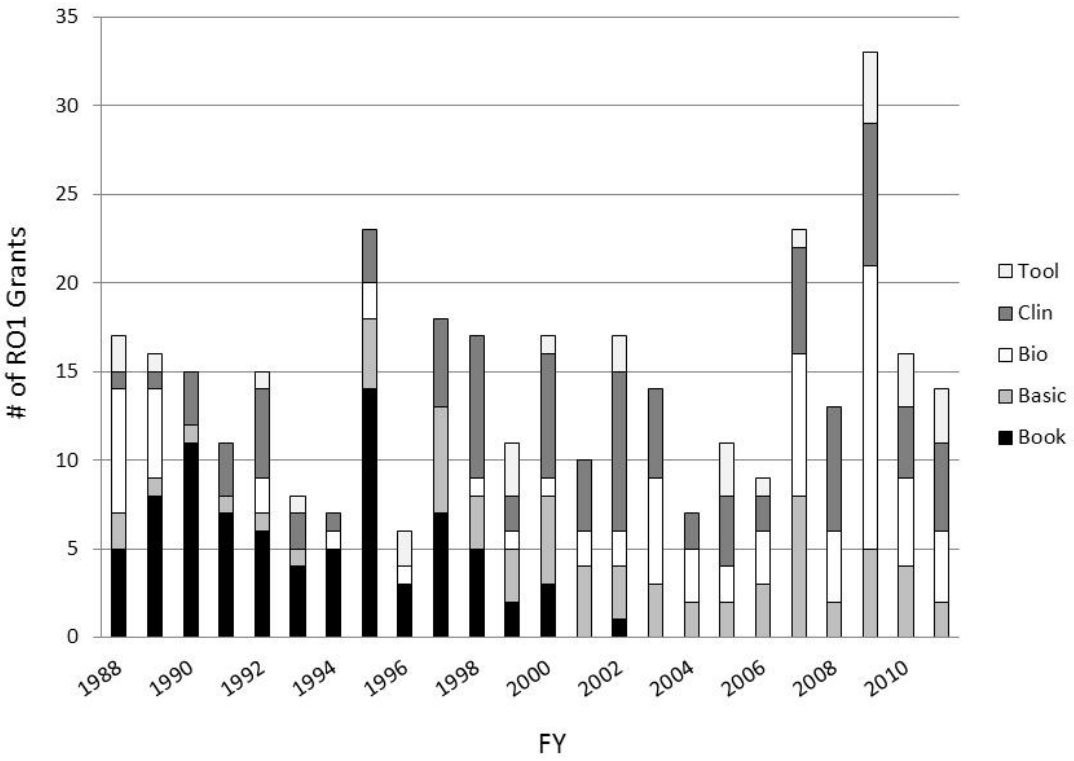

Figure 1. Distribution of the 348 NLM-funded RO1 grants, categorized by the type of research (book writing, basic science, bioinformatics, clinical-informatics or creation of tools) from FY1988 to FY2011.

RO1 Grant Publications

Next, the number of publications resulting from the 348 NLM-funded RO1 grants was determined (see Table 2). Figure 2 shows the total number of publications that have resulted from NLM-funding for each FY (1988 – 2011). A total of 2723 publications have resulted from NLM-funded RO1 grants, of which 57 were books and 2666 were articles from peer-reviewed journals. Overall, NLM RO1 grants produce an average of 7.82 publications. However, there is a range of 0 to 233 publications per grant. Most interesting was the finding that even though there was not a significant increase in the number of grants awarded over time, there appears to be an increased number of publications across time. During the 1990s NLM-funded RO1s produced 800 publications, whereas 1680 publications resulted from RO1s during the 2000s. This is a significant increase in publications, $t(18)= -2.489$, $p=0.022$.

The number of publications for each type of RO1 grant was determined by collapsing the number of publications by category (i.e. books, basic science, bioinformatics, clinical-informatics or tool). Figure 2 shows the number of publications for each category across FYs 1988-2010. Outputs from bioinformatics and clinical-informatics RO1 grants were combined and analyzed. During the 1990s, the 40 informatics grants produced 444 publications out of the

712 publications produced (contributing to 62.36% of the publications during the 1990s). During the 2000s, the 101 informatics grants produced 1303 publications out of the 1678 publications produced (contributing to 77.65% of the publications during the 2000s). This was a significant increase in informatics publication outputs, t(38)= -2.86, *p*=0.0067.

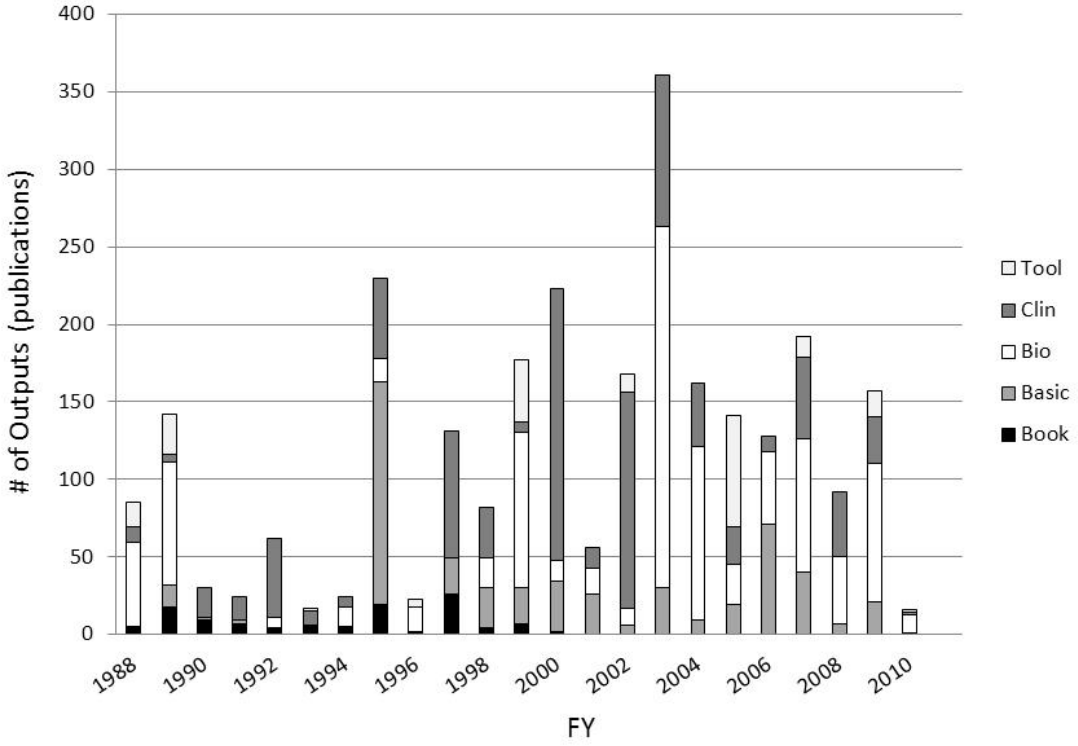

Figure 2. Number of outputs (i.e. books and article publications) for each type of RO1 grant (book writing, basic science, bioinformatics, clinical-informatics or tool development) for FY 1988 to FY 2011.

FY	# of Grants	# of publications	Avg publications
1988	17	85	5.00
1989	16	142	8.88
1990	15	30	2.00
1991	11	24	2.18
1992	15	62	4.13
1993	8	17	2.13
1994	7	24	3.43
1995	23	230	10.00
1996	6	23	3.83
1997	18	131	7.28
1998	17	82	4.82
1999	11	177	16.09
2000	17	223	13.12
2001	10	56	5.60
2002[2]	17	168	9.88
2003	14	361	25.79
2004	7	162	23.14
2005	11	141	12.82
2006	9	128	14.22
2007[3]	23	192	8.35
2008	13	92	7.08
2009	33	157	4.76
2010	16	16	1.00
2011	14	N/A	N/A

Table 2. Total number of grants, publications and the average number of publications for RO1s from FY1988 – FY2011.

Type of Grant	# of Grants	# of Pubs	Avg Pubs
Basic Science	66	497	7.53
Bioinformatics	76	993	13.07
Book	81	113	1.40
Clinical-informatics	97	915	9.43
Tool	28	205	7.32

Table 3. Displays the number of grants and publication and the average number of publications for each category of RO1 grant.

[2] In 2002, the last RO1 for book scholarship was awarded. Book research and writing is now awarded with the G13 grant mechanism.
[3] FY2007 through FY2011 may display lower numbers for publications because there are still active grants.

Although there was no significant change in the number of NLM grants funded over time, the number of publications has increased. Because the number of NLM grants funded can vary from year to year, it was necessary to normalize the number of publications by the number of grants awarded to analyze differences, or changes, over time (see Figure 3). Overall, grants that have produced publications (either published books or articles in peer-reviewed journals), publish on average 9.725 items per grant. Across years, the number of grants that have been awarded varies greatly. However, even when normalized by number of grants and number of grants that have published, there are differences in the number of outputs. RO1 grants that were awarded in FY 2003 and 2004 have the greatest number of outputs per grant (25.79 and 23.14 publications respectively).

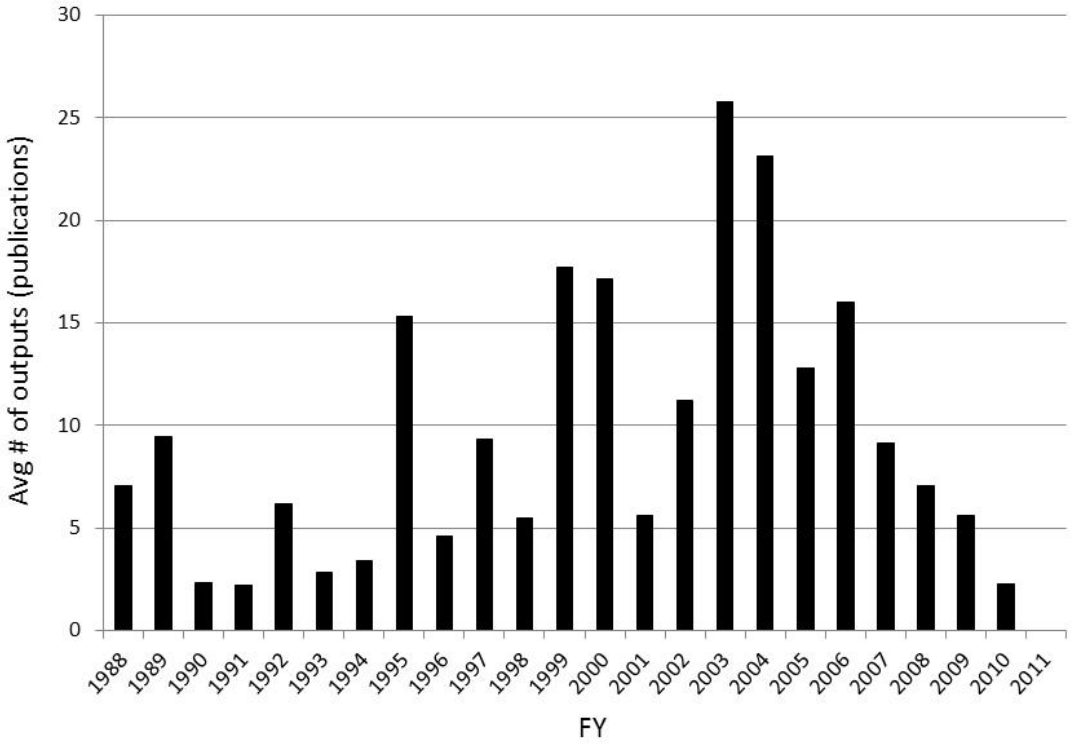

Figure 3. Average number of ouputs (i.e. book or article publications) normalized by those grants that have published across FY's 1988 - 2011.

Next, the number of grants that have not produced a publication was investigated (see Figure 4). As expected, a number of grants awarded in 2009-2010 have yet to produce a publication. However a number of older grants have yet to produce any publications. The lack of publications could be due to the fact that it may take longer for some types of work to produce publications, or it might suggest that publications might not be the deliverable of choice for the

type of research proposed. Nevertheless, to investigate the types of grants that have not produced publications, an in-depth analysis of the data was completed by collapsing across categories. It was found that a greater percentage of the RO1 grants given for creation of tools (n=10, 35.71%) have not yet published. Grants given to scholarly book research and writing (n=20, 24%), for basic science (n=13, 19.69%), bioinformatics (n=12, 15.79%), and for clinical-informatics (n=13, 13.4%) appear to produce publications to a greater extent than grants in the tool category. Only a small percentage of informatics (bio- and clinical-informatics) have not yet published (see Figure 5).

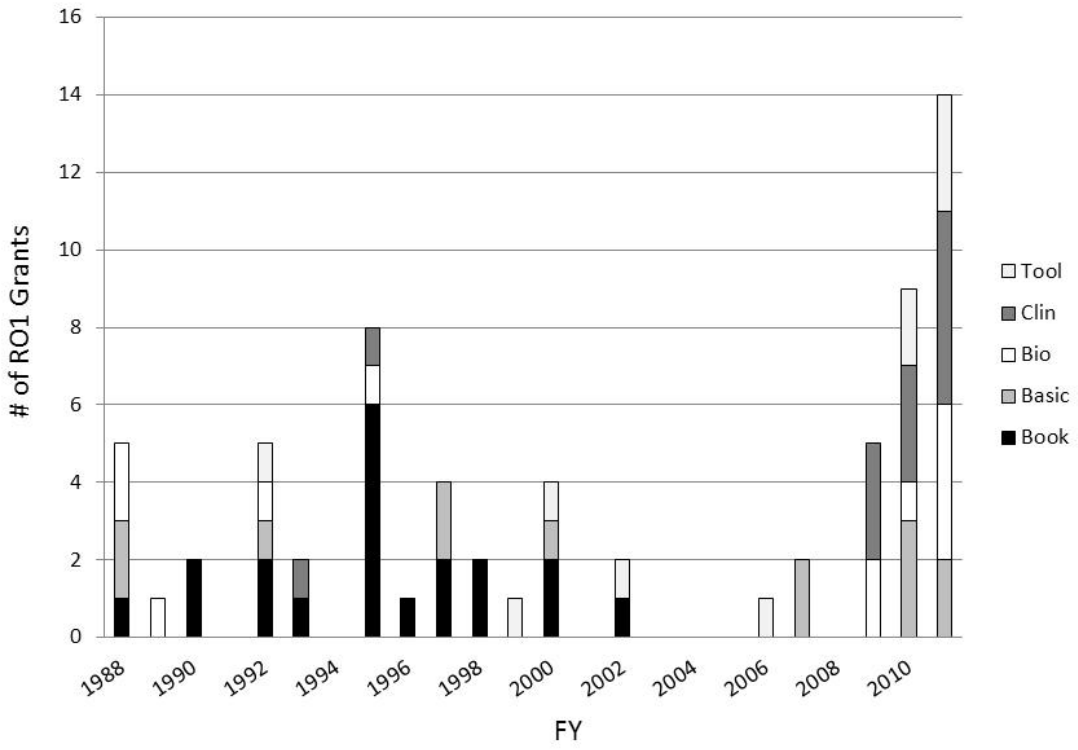

Figure 4. Number of RO1 grants that have not published, by type of research, from FY 1988 to FY 2011.

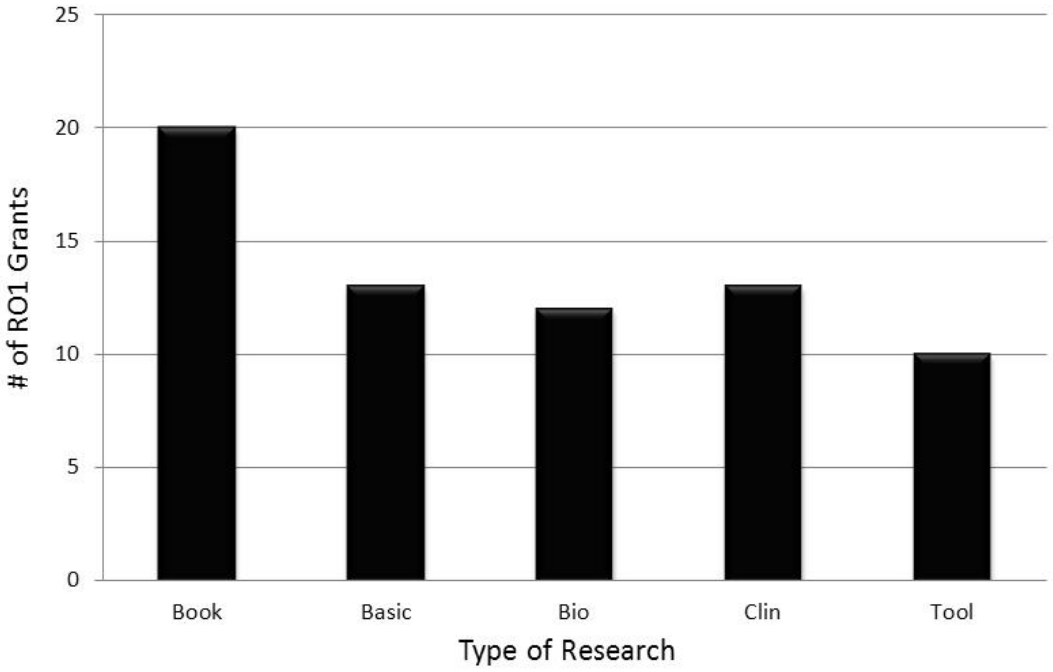

Figure 5. Number of RO1 grants that have not published, by type of research.

RO1 Grant Publication Lag-time

Because of the time differences that it takes to publish a book verses an article, the subsequent analyses to determine lag-time (or length of time from the time of grant award to first publication) separated published book and article data.

The 57 RO1 grants that have published a book were analyzed to determine the lag-time (see Figure 6). There was a low of 1 year (n=4) and a high of 19 years (n=2), from time of grant awarded (FY) to year of book publication. On average, the book lag-time of grant to publication was 7.0 years (Mdn=6 years, SD ±4.34 years). A total of 34 (59.65%) of the RO1 grants were able to produce a book publication within 6 years post award. However 15 (26.32%) of the grants published 10 years or later, post-grant award. Two grants (3.5%) took 19 years from award to time of book publication.

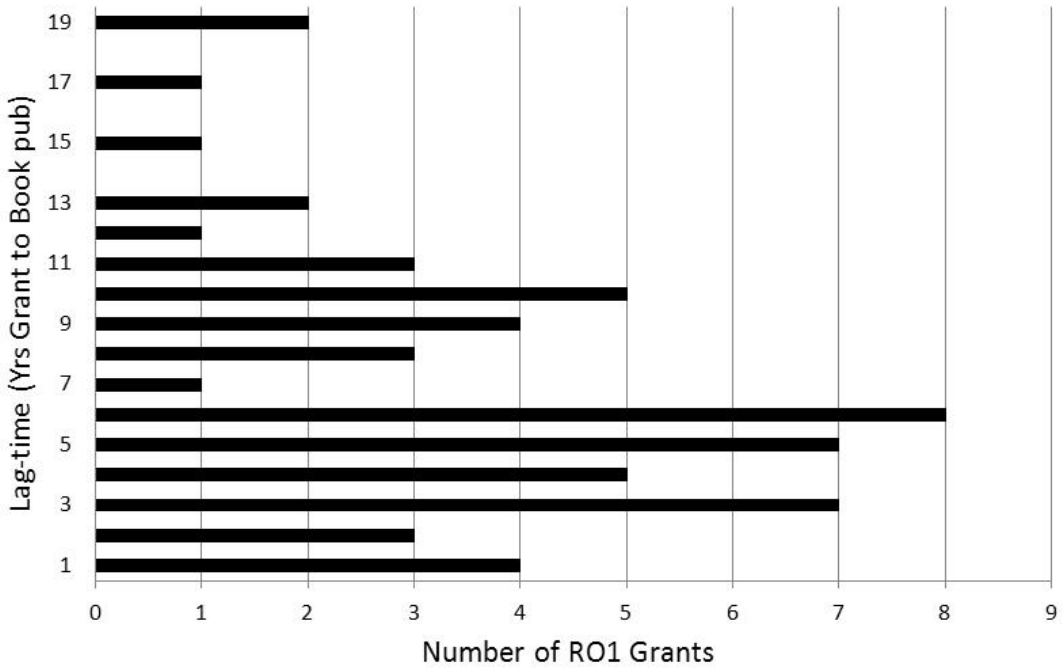

Figure 6. RO1 grant counts for book publication lag-time.

For RO1 grants that produced articles in peer-reviewed journals, there was an overall average lag-time of 1.54 years. On average, RO1 grants awarded to book scholarship (but also produced articles in peer-reviewed journals), had the greatest lag-time of 2.67 years from grant award to publication. The quickest turn-around of time of award to first publication is seen with grants given for tool production and bioinformatics research with an average lag-time of just over a year (see Table 4). To see changes in average lag-time across years, Figure 7 shows average lag-time for all RO1 grants, across FY. Although variable across years, there appears to be a trend towards a decrease in overall NLM-funded grant lag-time of time of award to first publication.

	Book	Basic	Bio	Clin	Tool
Average	2.67	1.69	1.14	1.63	1.06
High	10	7	9	10	5
Low	1	-1	-7	0	-2

Table 4. Average, high and low lag-time data (years between grant award to first publication) for book, basic science, bioinformatics, clinical informatics and tool articles publications.

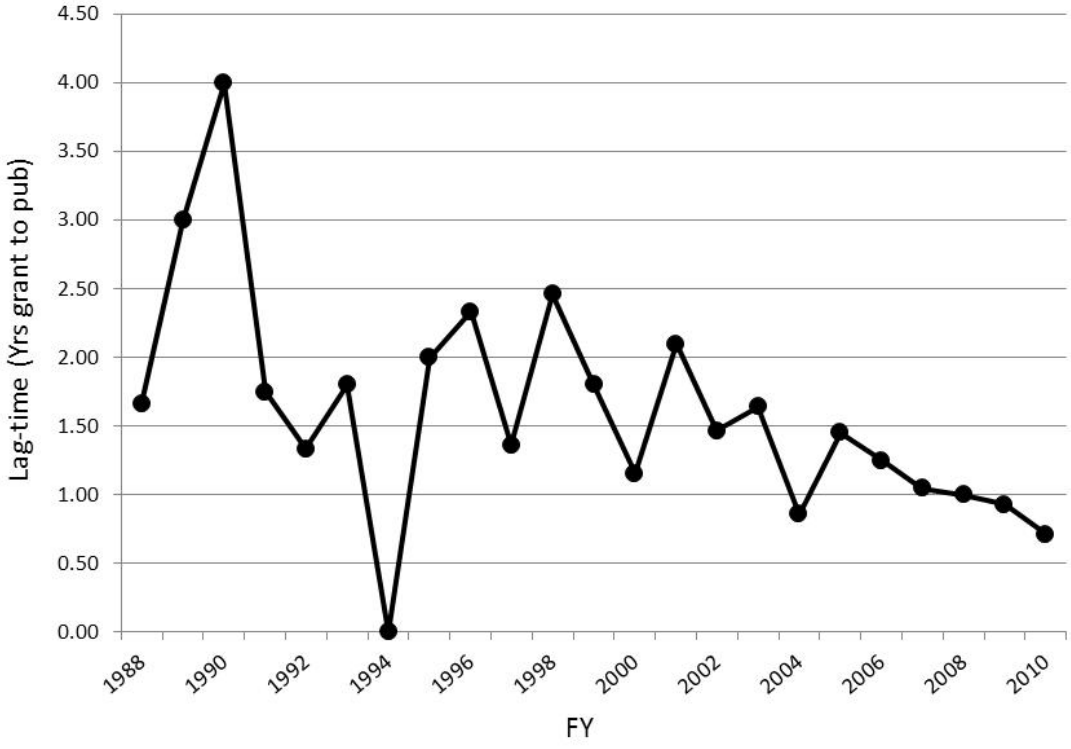

Figure 7. Average Lag-time for all RO1 grants to first publication (book or article).

RO1 Grant Citation Analysis

To investigate the impact of NLM-funded RO1 grants in the scientific field, an analysis of the number of publication that have cited RO1 outputs was completed (see Appendix A). Data from Scopus were collected and the total citations (excluding self-citations) were calculated for each publication from each grant.

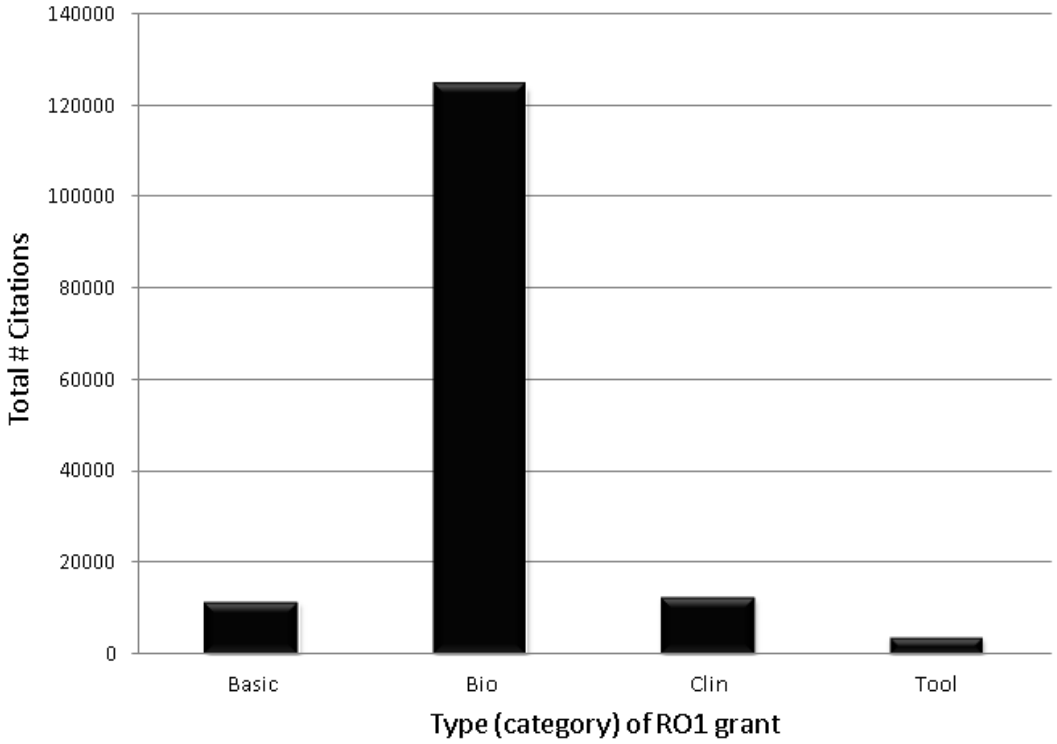

Figure 8. Total number of citations for each type of NLM-funded RO1 grant. The 497 basic science publications have been cited 11,126 times, the 993 bioinformatics publications have been cited 124,166 times, the 915 clinical-informatics publications have been cited 12,010 times and the 205 tool publications have been cited 3403 times.

A total of 150,705 articles have cited publications from NLM-funded RO1 grants. Overall, grants awarded to bioinformatics research have shown to potentially have the greatest impact, as measured by the number of total citations (see Figure 8). However citations of individual

outputs of the NLM-funded RO1 grants range from 0 to over 60,000 (see Appendix B for examples of 2 high-impact grants and the highly cited publications). Because of these large ranges in citations counts, the number of citations for each type of grant was calculated and grouped. Thus far, 21% of the publications resulting from NLM-funding had 1-20 citations, 24% had 21- 100 citations, and 17% had 101 – 500 citations (see Table 5). Most interesting was the finding that 11% of the articles resulting from NLM-funding were highly cited, or cited 500 or more times. Two grants in particular (both bioinformatic projects, funded in 1988 and 1989) have articles that have been cited over 29,992 times.

Citation Range	Number of Grants with publications within citation range					Percent of Citations
	Basic	Bio	Clin	Tool	Total	
0	20	18	22	12	72	27%
1 to 10	12	12	17	3	44	21%
11 to 20	5	5	3	0	13	
21 to 30	4	5	7	1	17	24%
31 to 40	1	4	5	4	14	
41 to 50	2	1	4	1	8	
51 to 100	10	5	10	2	27	
101 to 150	2	2	4	0	8	17%
151 to 200	2	0	7	1	11	
201 to 300	0	5	7	0	13	
301 to 400	1	2	2	0	5	
401 to 500	4	2	3	0	9	
500 to 1000	0	3	5	1	9	5%
1001 to 5000	3	8	1	1	13	5%
5000 to 10000	0	1	0	0	1	
10001 and up	0	2	0	0	2	1%

Table 5. Displays the number of grants that have publications within citation ranges. The final column shows the percent of RO1s that fall within the citation ranges.

Discussion

The purpose of this study was to begin to track and measure the outcomes and impact of 348 NLM-funded RO1 grants. In recent years, bioinformatics and clinical informatics have been the predominant research areas awarded RO1 funding from NLM.

As far as grant outcomes, the 348 RO1 grants have thus far produced 2723 book and article publications. There has been a positive trend of increased number of publications resulting from each grant over time. In the early era of NLM-funded RO1 grants, the average number of publications was less than 10 per grant. However, in recent years (since FY2002), the average number of publications was greater than 10 per grant. Of these, bioinformatics funded grants have produced the most number of outputs with an average of 13.07 publications per grant. These results are similar to those shown previously, where bioinformatics research has been shown to be publishing at an exponential rate (19).

The average lag-time for NLM RO1 grants was found to be 7 years for book publications and 1.54 years for article publications. Most interesting was the finding that lag-time appears to be decreasing over time (see Figure 7). These results might be due to the changes in types of research that are funded by the NLM. That is, scholarship for book research and writing used to be funded by the RO1 mechanism and these types of manuscripts take longer to publish. However, when taken with the data that shows the bioinformatics funded research is producing greater number of articles (19) we might be seeing a shift in the lag-time, and the number of grant deliverables. Although still too early to tell for RO1 grants awarded in the past 5 years (FY2007 through FY2011), the trend to produce a great number of publications, and quickly, appears to be holding true. It will be interesting to follow these trends in NLM-funded grants to see the changes in funding, projects and outputs over the next several years.

The activity measures and citation analysis of the grant publications begin to show the impact that NLM-funding has on the biomedical research community. These data suggest that NLM funding has had direct (2723 publications) and indirect (cited in 150,705 articles) influence in biomedical literature. These high numbers are not that surprising. Bioinformatics is a growing interdisciplinary field of science that utilizes information technology, computer science, mathematics and statistics to solve problems in biomedical and clinical sciences. Because of the interdisciplinary nature of the research, it is easy to recognize the widespread reach that informatics research might impact. NLM, compared to other NIH institutes, has a relatively small extramural budget. Even with the small budget, 83% of the publications from NLM grants have been cited showing the influence and impact of the research supported by NLM.

The longitudinal impact of NLM-funding of informatics research can be showcased with examples of two RO1 grants from FY1988 and FY1989 (LM004960 to Dr. Eugene Myers[4] and LM005110 to Dr. Webb Miller[5], respectively). These two bioinformatics RO1 grants produced a number of articles (7 and 66 respectively) published in peer-reviewed journals. What is most interesting is the tool that was developed from this funded research. These grants funded research that led to the development of BLAST (basic local alignment search tool), that has

revolutionized the way in which molecular and genomic biology research is done. BLAST is one of the most widely used genomic sequence tools to search and compare protein or nucleic sequences. These two grants produced articles that have been cited 29895 and 32653 times (see Appendix B for more information on these RO1s and highly cited articles). Although these highly cited articles are not the norm compared to other grants, these types of research and deliverables show the tremendous impact federally-funded research can have on the scientific community.

Limitations

Although the data of highly cited literature spark excitement and show the enormous impact that federal funding can have on research, citation analysis is often criticized. In citation analysis, it is assumed that all citations are equal. However, research articles can be referenced because it is being critiqued/criticized, the procedures or methods are utilized or because the study was used in the introduction or background or used in the discussion as rationale for various opinions on a

[4] Grant LM004960 to Dr. Eugene Myers entitled *Efficient software for the analysis of biosequences*.
[5] Grant LM005110 to Dr. Webb Colby Miller entitled *Algorithms for analyzing biosequence data*.

NLM-funded grants for tools development appear to have fewer publications. However, instead of publications in peer-reviewed journals, outputs could be other forms of deliverables such as tools, patents, web applications. This makes publication counts and citation analysis difficult to compare across different types of research fields and project types. Similarly, one can argue that clinical informatics research might have a greater impact (negative or positive) on health care (i.e., a novel, practical way to implement electronic health records to help physicians and patients). However, these types of data would be difficult, if not impossible, to record quantitatively. Therefore, these different forms of deliverables should not be forgotten. And even though ways to track these outputs have yet to be established, future work should begin to investigate ways in which to do so. Despite these limitations and difficulties in bibliometric evaluation, the methods employed in the current study are a good first start in tracking and evaluating the impact of NLM-funded grants.

Another aspect of the current study is to emphasize that this was an initial project. Scopus was the only resource utilized for citation analysis. However, Web of Science, Google Scholar and other resources such as Publish or Perish might be additional resources to utilize for complete coverage and validation. Scopus was used as the resource of choice because of the depth of coverage and ease of use. The current study had to be done within a particular timeframe, and as such, the ease of search and exporting of data from Scopus was a benefit. Compared to the other resources, Scopus covers the greatest number of journals that the NLM-funded research would publish in (e.g., biomedical, health science, clinical, genomic, informatics). However, not all resources are covered in Scopus. For example, books, chapters and grey literature are not indexed in Scopus. Also, for NLM-funded book RO1s Google Scholar would have been a better indicator of works that have cited the published book. Therefore, to get complete coverage and to check for validity of already gathered citation data, additional resources should be utilized.

Conclusions

All in all, this current report evaluates and begins to track the outcomes and trends of NLM-funded research. Utilizing RePORTER, PubMed and Scopus has proven to be a good start in showing the outcomes and impacts of RO1 grants. Quantifying the outputs of NLM-funded research is important due to the current federal initiative on an effective, efficient and accountable government. Importantly we have shown that these mandates can be met can be met by extramural programs of agencies by utilizing bibliometrics to track and evaluate grant outcomes. The statistical analysis of outputs and outcomes appears to be a good first step in fulfilling these mandates. Furthermore, the data gathered and analyzed in this current study suggests the methods employed were a good first step and that future work including additional resources will validate that the most of RO1 grants funded by NLM have good record of deliverables and many have shown to have great impact on the biomedical scientific field.

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Appendix A.

List of the 348 NLM-funded RO1 grants from FY1988 – FY2011.

Year	Type	Project Number	TOTAL PUBMED	Total Books	Yrs to 1st pub	Yrs to 1st Book	Scopus
1988	basic	1R01LM004617-01A1	0		NA		
1988	basic	1R01LM004635-01A1	0		NA		
1988	bio	1R01LM004971-01	15		1		1158
1988	bio	1R01LM004958-01	10		2		391
1988	bio	1R01LM004960-01	7		2		29992
1988	bio	1R01LM004957-01	1		3		9
1988	bio	1R01LM004969-01	21		3		1091
1988	bio	1R01LM004965-01	0		NA		
1988	bio	1R01LM004896-01	0		NA		
1988	Book	1R01LM004902-01	0	1	NA	5	
1988	Book	1R01LM005040-01	0	1	NA	6	
1988	Book	1R01LM004872-01	0	1	NA	11	
1988	Book	1R01LM004906-01	1	1	3	19	
1988	Book	1R01LM004855-01	0		NA	NA	
1988	clin	1R01LM004864-01	10		3		47
1988	tool	1R01LM004932-01	5		-2		41
1988	tool	1R01LM004843-01	11		0		38
1989	basic	1R01LM004925-01	14		2		173
1989	bio	1R01LM005044-01	10		1		44
1989	bio	1R01LM005110-01	66		1		66556
1989	bio	1R01LM005102-01	2		2		232
1989	bio	1R01LM005094-01	1		9		10
1989	bio	1R01LM005118-01	0		NA		
1989	Book	1R01LM005005-01	6	1	1	6	
1989	Book	1R01LM004949-01	0	1	NA	7	
1989	Book	1R01LM005013-01	2	1	2	9	
1989	Book	1R01LM004901-01A1	1	1	3	10	
1989	Book	1R01LM004686-01A1	0	1	NA	10	
1989	Book	1R01LM004980-01	1	1	1	12	
1989	Book	1R01LM005068-01	1		3		
1989	Book	1R01LM004996-01	1		10		
1989	clin	1R01LM005104-01	5		2		27
1989	tool	1R01LM004836-01	26		2		1753

1990	basic	1R01LM005007-01A1	2		6		63
1990	Book	1R01LM005144-01	0	1	NA	1	
1990	Book	1R01LM005139-01	0	1	NA	3	
1990	Book	1R01LM004938-01	0	1	NA	3	
1990	Book	1R01LM005166-01	0	1	NA	4	
1990	Book	1R01LM005067-01A1	0	1	NA	10	
1990	Book	1R01LM005141-01	0	1	NA	10	
1990	Book	1R01LM005175-01	0	1	NA	11	
1990	Book	1R01LM005150-01	0	1	NA	11	
1990	Book	1R01LM005066-01	0	1	NA	17	
1990	Book	1R01LM005140-01	0		NA	NA	
1990	BOOK	1R01LM004933-01	0		NA		N/A
1990	clin	1R01LM005125-01	9		1		174
1990	clin	1R01LM005200-01	9		3		46
1990	clin	1R01LM005189-01	1		6		2
1991	basic	1R01LM005217-01	2		3		2
1991	Book	1R01LM005310-01	0	1	NA	2	
1991	Book	1R01LM005326-01	0	1	NA	4	
1991	Book	1R01LM005279-01	0	1	NA	5	
1991	Book	1R01LM005339-01	0	1	NA	5	
1991	Book	1R01LM005281-01	0	1	NA	6	
1991	Book	1R01LM005320-01	0	1	NA	9	
1991	Book	1R01LM005334-01	0	1	NA	13	
1991	clin	1R01LM005299-01	7		1		96
1991	clin	1R01LM005202-01A1	1		1		2
1991	clin	1R01LM005323-01	7		2		60
1992	basic	1R01LM005384-01	0		NA		
1992	bio	1R01LM005513-01	7		1		32
1992	bio	1R01LM005429-01	0		NA		
1992	Book	1R01LM005409-01	0	1	NA	3	
1992	Book	1R01LM005407-01	0	1	NA	9	
1992	Book	1R01LM005444-01	0	1	NA	10	
1992	Book	1R01LM005381-01	0	1	NA	19	
1992	Book	1R01LM005487-01	0		NA	NA	
1992	Book	1R01LM005445-01	0		NA	NA	
1992	clin	1R01LM005481-01	4		1		165
1992	clin	1R01LM005416-01	13		1		168
1992	clin	1R01LM005401-01	21		1		404
1992	clin	1R01LM005530-01	9		1		100
1992	clin	1R01LM005508-01	4		3		36

1992	tool	1R01LM005515-01	0		NA		
1993	basic	1R01LM005527-01	1		1		1422
1993	Book	1R01LM005491-01	0	1	NA	2	
1993	Book	1R01LM005563-01	1	1	3	6	
1993	Book	1R01LM005479-01	0	1	NA	6	
1993	book	1R01LM005466-01	1		1		
1993	clin	1R01LM005630-01	9		3		299
1993	clin	1R01LM005428-01	0		NA		
1993	too	1R01LM005296-01A1	2		1		40
1994	bio	1R01LM005716-01	13		0		767
1994	Book	1R01LM005538-01	0	1	NA	1	
1994	Book	1R01LM005467-01	0	1	NA	3	
1994	Book	1R01LM005803-01	0	1	NA	5	
1994	Book	1R01LM005470-01A1	0	1	NA	6	
1994	Book	1R01LM005433-01	0	1	NA	13	
1994	clin	1R01LM005324-01A1	6		0		189
1995	basic	1R01LM005639-01A1	140		-1		4388
1995	basic	1R01LM005607-01A1	2		2		46
1995	basic	1R01LM005944-01	1		3		26
1995	basic	1R01LM005907-01	1		3		0
1995	bio	1R01LM005773-01A1	15		1		1379
1995	bio	1R01LM005732-01	0		NA		
1995	Book	1R01LM005753-01	0	1	NA	2	
1995	Book	1R01LM005903-01	0	1	NA	3	
1995	Book	1R01LM005361-01A3	0	1	NA	4	
1995	Book	1R01LM005949-01	0	1	NA	5	
1995	Book	1R01LM005675-01A1	1	1	5	8	
1995	Book	1R01LM005678-01	0	1	NA	8	
1995	Book	1R01LM005700-01	0	1	NA	11	
1995	Book	1R01LM005921-01	0	1	NA	15	
1995	Book	1R01LM005649-01	1		4	NA	
1995	Book	1R01LM005624-01	0		NA	NA	
1995	Book	1R01LM005906-01	0		NA	NA	
1995	Book	1R01LM005933-01	0		NA	NA	
1995	Book	1R01LM005545-01A2	9		1		
1995	book	1R01LM005674-01A1	0		NA		
1995	clin	1R01LM005708-01	46		0		693
1995	clin	1R01LM005764-01	6		2		38
1995	clin	1R01LM005698-01	0		NA		
1996	bio	1R01LM006244-01	16		1		1483

1996	Book	1R01LM006005-01	0	1	NA	5	
1996	Book	1R01LM005993-01	0	1	NA	9	
1996	Book	1R01LM005917-01A2	0		NA		
1996	tool	1R01LM005982-01	2		1		74
1996	tool	1R01LM006243-01	3		5		37
1997	basic	1R01LM006325-01	1		0		17
1997	basic	1R01LM006316-01	15		1		76
1997	basic	1R01LM006488-01	4		3		18
1997	basic	1R01LM006311-01A1	3		3		87
1997	basic	1R01LM006236-01A1	0		NA		
1997	basic	1R01LM006326-01A1	0		NA		
1997	Book	1R01LM006528-01	0	1	NA	3	
1997	Book	1R01LM006304-01	0	1	NA	4	
1997	Book	1R01LM006262-01	2	1	2	5	
1997	Book	1R01LM005934-01A1	0	1	NA	6	
1997	Book	1R01LM005983-01A1	0		NA	NA	
1997	book	1R01LM006270-01	20		0		
1997	book	1R01LM006265-01	0		NA		
1997	clin	1R01LM006226-01A1	19		0		502
1997	clin	1R01LM006274-01A1	36		1		898
1997	clin	1R01LM006539-01	9		1		126
1997	clin	1R01LM006249-01A2	17		2		91
1997	clin	1R01LM005997-01A2	1		2		0
1998	basic	1R01LM006538-01	23		0		459
1998	basic	1R01LM006638-01	2		2		66
1998	basic	1R01LM006543-01A1	1		5		70
1998	bio	1R01LM006747-01	19		1		1461
1998	Book	1R01LM006567-01	1	1	3	3	
1998	Book	1R01LM006566-01	0	1	NA	6	
1998	Book	1R01LM006574-01	0	1	NA	8	
1998	Book	1R01LM006662-01	0		NA	NA	
1998	Book	1R01LM006590-01A1	0		NA	NA	
1998	clin	1R01LM006726-01	4		0		73
1998	clin	1R01LM006587-01	8		0		494
1998	clin	1R01LM006696-01	5		1		10
1998	clin	1R01LM006591-01	1		1		1
1998	clin	1R01LM006682-01	7		1		15
1998	clin	1R01LM006593-01	4		2		7
1998	clin	1R01LM006321-01A1	1		6		30
1998	clin	1R01LM006533-01A1	3		10		10

1999	basic	1R01LM006822-01	19		0		354
1999	basic	1R01LM006759-01	2		2		105
1999	basic	1R01LM006649-01A1	2		2		112
1999	bio	1R01LM006845-01	100		0		6629
1999	book	1R01LM006617-01A1	2	1	1	1	
1999	Book	1R01LM006653-01A1	3	1	4	4	
1999	clin	1R01LM006967-01	4		3		6
1999	clin	1R01LM006856-01	3		4		101
1999	tool	1R01LM006594-01	28		1		649
1999	tool	1R01LM006780-01	12		1		187
1999	tool	1R01LM006708-01	0		NA		
2000	basic	1R01LM006858-01	15		-1		1538
2000	basic	1R01LM006909-01	1		1		21
2000	basic	1R01LM007050-01	12		2		191
2000	basic	1R01LM006911-01	4		3		6
2000	basic	1R01LM006627-01A1	0		NA		
2000	bio	1R01LM006916-01	14		0		2633
2000	Book	1R01LM006893-01	2		1	NA	
2000	Book	1R01LM006966-01	0		NA	NA	
2000	Book	1R01LM006859-01	0		NA	NA	
2000	clin	1R01LM006843-01	15		0		175
2000	clin	1R01LM006942-01	59		1		1323
2000	clin	1R01LM006806-01A1	28		1		130
2000	clin	1R01LM006910-01	51		1		595
2000	clin	1R01LM006659-01A1	6		1		119
2000	clin	1R01LM006756-01	5		1		10
2000	clin	1R01LM006866-01	11		4		360
2000	tool	1R01LM006761-01A1	0		NA		
2001	basic	1R01LM007061-01	3		2		8
2001	basic	1R01LM007292-01	21		2		473
2001	basic	1R01LM006919-01A1	1		4		58
2001	basic	1R01LM006849-01A2	1		4		0
2001	bio	1R01LM006789-01A2	11		1		99
2001	bio	1R01LM007174-01	6		2		183
2001	clin	1R01LM006955-01A1	5		0		17
2001	clin	1R01LM007179-01	3		1		285
2001	clin	1R01LM007203-01	3		2		73
2001	clin	1R01LM006920-01A1	2		3		29
2002	basic	1R01LM007319-01A1	2		1		2
2002	basic	1R01LM007685-01	1		2		1

2002	basic	1R01LM007167-01	3		3		4
2002	bio	1R01LM007609-01	6		1		393
2002	bio	1R01LM007218-01A1	5		2		84
2002	book	1R01LM007081-01A1	0		NA	NA	
2002	clin	1R01LM007593-01	38		0		176
2002	clin	1R01LM006918-01A1	18		0		83
2002	clin	1R01LM007222-01	27		0		202
2002	clin	1R01LM007453-01	6		1		28
2002	clin	1R01LM007268-01A1	17		1		51
2002	clin	1R01LM007199-01	17		1		249
2002	clin	1R01LM007273-01	5		2		49
2002	clin	1R01LM007606-01	1		3		7
2002	clin	1R01LM007595-01	10		4		33
2002	tool	1R01LM007455-01A1	12		1		66
2002	tool	1R01LM007591-01	0		NA		
2003	basic	1R01LM007891-01	7		0		40
2003	basic	1R01LM007948-01	19		1		406
2003	basic	1R01LM007849-01	4		2		43
2003	bio	1R01LM007329-01A1	40		0		977
2003	bio	1R01LM007688-01A1	99		1		3905
2003	bio	1R01LM007659-01	53		1		448
2003	bio	1R01LM007938-01	21		1		1151
2003	bio	1R01LM008106-01	19		2		281
2003	bio	1R01LM007878-01A1	1		4		28
2003	clin	1R01LM007677-01	32		0		397
2003	clin	1R01LM007861-01A1	41		0		999
2003	clin	1R01LM008142-01	21		1		280
2003	clin	1R01LM008192-01	3		3		4
2003	clin	1R01LM008154-01	1		7		0
2004	basic	1R01LM007709-01A1	8		2		21
2004	basic	1R01LM008143-01A1	1		7		0
2004	bio	1R01LM008111-01A1	52		-7		440
2004	bio	1R01LM007994-01A1	57		1		820
2004	bio	1R01LM008000-01A1	3		1		3
2004	clin	1R01LM007995-01	21		1		206
2004	clin	1R01LM007894-01A1	20		1		188
2005	basic	1R01LM008323-01A1	1		0		2
2005	basic	1R01LM008713-01A1	18		1		62
2005	bio	1R01LM009027-01	18		1		226
2005	bio	1R01LM008626-01A1	8		2		58

2005	clin	1R01LM008374-01	5		0		4
2005	clin	1R01LM008443-01A1	16		1		461
2005	clin	1R01LM007663-01A2	1		2		0
2005	clin	1R01LM008255-01A1	2		5		8
2005	tool	1R01LM008247-01	1		2		3
2005	tool	1R01LM008635-01	43		1		198
2005	tool	1R01LM008696-01	28		1		251
2006	basic	1R01LM009012-01A1	34		0		450
2006	basic	1R01LM009254-01	23		1		94
2006	basic	1R01LM008445-01A2	14		1		11
2006	bio	1R01LM008991-01	41		0		94
2006	bio	1R01LM008796-01	3		0		16
2006	bio	1R01LM008795-01	3		2		13
2006	clin	1R01LM008799-01A1	8		2		26
2006	clin	1R01LM009256-01	2		4		1
2006	tool	1R01LM009018-01	0		NA		
2007	basic	1R01LM009427-01	7		1		13
2007	basic	1R01LM009501-01	3		1		9
2007	basic	1R01LM009758-01	9		1		82
2007	basic	1R01LM009375-01A1	1		1		51
2007	basic	1R01LM008912-01A1	4		1		1
2007	basic	1R01LM009362-01	16		1		29
2007	basic	1R01LM009121-01A1	0		NA		
2007	basic	1R01LM009765-01	0		NA		NA
2007	bio	1R01LM009722-01	19		-1		125
2007	bio	1R01LM009338-01	9		0		38
2007	bio	1R01LM009153-01A1	9		0		27
2007	bio	1R01LM009331-01	11		1		22
2007	bio	1R01LM009239-01A1	18		1		12
2007	bio	1R01LM009219-01A1	5		1		15
2007	bio	1R01LM009657-01	12		2		117
2007	bio	1R01LM009651-01	3		3		39
2007	clin	1R01LM009520-01	18		0		52
2007	clin	1R01LM009836-01A1	16		0		66
2007	clin	1R01LM009143-01A2	8		1		0
2007	clin	1R01LM009157-01A1	4		2		1
2007	clin	1R01LM009516-01A1	3		3		0
2007	clin	1R01LM008923-01A1	4		3		33
2007	tool	1R01LM009161-01A1	13		0		39
2008	basic	1R01LM009725-01A1	6		1		12

2008	basic	1R01LM009538-01A1	1		3		0
2008	bio	1R01LM009719-01A1	27		0		260
2008	bio	1R01LM009519-01A1	2		0		2
2008	bio	1R01LM009731-01	6		1		1
2008	bio	1R01LM009494-01A1	8		1		30
2008	clin	1R01LM009500-01A2	11		0		48
2008	clin	1R01LM009965-01	6		0		30
2008	clin	1R01LM009533-01A1	7		1		28
2008	clin	1R01LM009623-01A2	2		1		0
2008	clin	1R01LM009723-01A1	1		1		0
2008	clin	1R01LM009591-01A1	4		2		6
2008	clin	1R01LM009132-01A2	11		2		11
2009	basic	1R01LM010119-01	5		0		4
2009	basic	1R01LM009886-01A1	11		0		9
2009	basic	1R01LM009956-01A1	1		1		0
2009	basic	1R01LM010207-01	2		2		1
2009	basic	1R01LM010132-01	2		2		0
2009	bio	1R01LM010009-01	14		0		35
2009	bio	1R01LM010098-01	16		0		242
2009	bio	1R01LM010185-01	16		0		26
2009	bio	1R01LM010125-01	3		1		1
2009	bio	1R01LM009959-01A1	2		1		2
2009	bio	1R01LM010144-01	3		1		11
2009	bio	1R01LM010129-01	5		1		0
2009	bio	1R01LM010140-01	8		1		58
2009	bio	1R01LM010040-01	12		1		6
2009	bio	1R01LM010120-01	2		1		5
2009	bio	1R01LM009985-01A1	3		2		2
2009	bio	1R01LM010130-01	1		2		0
2009	bio	1R01LM010138-01	1		3		0
2009	bio	1R01LM010100-01	0		NA		
2009	bio	1R01LM009505-01A1	0		NA		
2009	cio	1R01LM010020-01	3		2		2
2009	clin	1R01LM010016-01	8		0		33
2009	clin	1R01LM009879-01A1	2		0		2
2009	clin	1R01LM010213-01	13		0		214
2009	clin	1R01LM009966-01A1	3		0		8
2009	clin	1R01LM010019-01A1	4		1		0
2009	clin	1R01LM010031-01	0		NA		
2009	clin	1R01LM010027-01	0		NA		

2009	clin	1R01LM009897-01A1	0		NA		
2009	tool	1R01LM009607-01A2	6		0		0
2009	tool	1R01LM009989-01A1	6		1		23
2009	tool	1R01LM009961-01	4		1		3
2009	tool	1R01LM009522-01A1	1		2		
2010	basic	1R01LM010811-01	1		1		0
2010	basic	1R01LM010813-01	0		NA		
2010	basic	1R01LM009812-01A2	0		NA		
2010	basic	1R01LM010817-01	0		NA		
2010	bio	1R01LM010101-01A1	4		0		0
2010	bio	1R01LM010033-01A1	6		0		0
2010	bio	1R01LM010235-01A1	1		1		0
2010	bio	1R01LM010834-01	1		1		2
2010	bio	1R01LM010212-01A1	0		NA		
2010	clin	1R01LM010815-01	1		1		0
2010	clin	1R01LM010090-01A1	0		NA		
2010	clin	1R01LM010679-01	0		NA		
2010	clin	1R01LM010681-01	0		NA		
2010	tool	1R01LM010812-01	2		1		1
2010	tool	1R01LM010828-01	0		NA		
2010	tool	1R01LM010142-01A1	0		NA		
2011	basic	1R01LM010022-01A2	0				
2011	basic	1R01LM010673-01A1	0				
2011	bio	1R01LM010685-01A1	0		NA		
2011	bio	1R01LM010950-01	0				
2011	bio	1R01LM011155-01	0				
2011	bio	1R01LM010730-01A1	0				
2011	clin	1R01LM010921-01A1	0		NA		
2011	clin	1R01LM010964-01	0		NA		
2011	clin	1R01LM010981-01A1	0				
2011	clin	1R01LM010923-01	0				
2011	clin	1R01LM011124-01	0				
2011	tool	1R01LM010942-01	0				
2011	tool	1R01LM011028-01	0				
2011	tool	1R01LM011119-01	0				

Appendix B.

Examples of two high-impact NLM-funded RO1 grants.

FY1988

Grant: **LM004960** – Efficient software for the analysis of biosequences

PI: Dr. Eugene Myers

This RO1 grant produced 7 articles from 1990 to 1997.

One publication in particular has thus far had 29895 citations:

Altschul, S.F., Gish, W., Miller, W., Myers, E.W., and Lipman, D.J. (1990). Basic local alignment search tool. *Journal of Molecular Biology*, 215(3): 403-10.

FY1989

Grant: **LM005110** – Algorithms for analyzing biosequence data

PI: Dr. Webb Colby Miller

This RO1 grant produced 66 articles from 1990 to 2004.

Two publications have resulted in a high number of citations. One is the same as listed above (Drs Miller and Myers are co-authors on the BLAST publication).

And this additional article had 32653 citations:

Altschul, S.F., Madden, T.L., Schaffer, A.A., Zhang, J., Zhang, Z., Miller, W., and Lipman, D.J. (1997). Gapped BLAST and PSI-BLAST: a new generation of protein database search programs. *Nucleic Acids Research*, 25(17):3389-402.