Academic Emergency Medicine
Official Journal of the Society for Academic Emergency Medicine

SPECIAL CONTRIBUTION

Using Publication Metrics to Highlight Academic Productivity and Research Impact

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Abstract

This article provides a broad overview of widely available measures of academic productivity and impact using publication data and highlights uses of these metrics for various purposes. Metrics based on publication data include measures such as number of publications, number of citations, the journal impact factor score, and the h-index, as well as emerging metrics based on document-level metrics. Publication metrics can be used for a variety of purposes for tenure and promotion, grant applications and renewal reports, benchmarking, recruiting efforts, and administrative purposes for departmental or university performance reports. The authors also highlight practical applications of measuring and reporting academic productivity and impact to emphasize and promote individual investigators, grant applications, or department output.

ACADEMIC EMERGENCY MEDICINE 2014;21:1160–1172

The objective of this article is to provide an overview of scientific publishing and traditional and emerging publication metrics used for measuring and reporting scholarly productivity and impact by academic clinicians, departments, institutions, or research groups. Understanding these metrics and reporting trends will be increasingly critical for academic clinicians, department leaders, academic review committees, funding agencies, and journal editors in light of the focus toward reporting of productivity and impact to demonstrate diffusion of knowledge, synthesis into clinical applications, and improved public health outcomes.

THE DEVELOPMENT OF SCIENTIFIC PUBLISHING AND BIBLIOMETRICS

The traditional responsibilities for academic clinicians include providing bedside patient care (which for most clinicians generate the greatest amount of revenue), educating new generations of medical students and resident physicians, academic service, and original research. When evaluating academic clinicians for appointment and promotion, some academic review committees may place a higher value on research productivity than upon clinicians' other responsibilities. Consequently, the mantra of academic medicine for decades has been to "publish or perish." This expression embodies a philosophy that traces a logical path between research endeavors and scientific expertise to subsequent peer-reviewed publications and external funding of research efforts. This "publish or perish" philosophy was likely first noted by Logan Wilson in his 1942 review of American academic life: "Situational imperatives dictate a 'publish or perish' credo within the ranks."[1] Over time, awarding tenure and/or academic promotion has been linked to the number of publications and to how frequently those publications are cited. The pressure to publish in tandem with fulfilling teaching and professional obligations has become an ongoing challenge for academic clinicians. Tracking of

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Received March 11, 2014; revisions received May 7 and June 4, 2014; accepted June 5, 2014.

Portions of this manuscript were presented as a Didactic Session (DS074) at the Society for Academic Emergency Medicine (SAEM) Annual Meeting, Atlanta, GA, May 2013.

The authors have no financial relationships or conflicts of interest to disclose. Dr. Cone, the editor-in-chief of this journal, and Dr. Carpenter, an associate editor for this journal, had no role in the peer-review process or publication decision for this paper.

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ISSN 1069-6563
PII ISSN 1069-6563583

doi: 10.1111/acem.12482

this academic output has become more complex for academic review committees and department leaders.

A substantial increase of U. S. governmental funding for health research following World War II led to more opportunities for researchers. Since then there has been a continually expanding number of scientific journals and published manuscripts, which has challenged academic clinicians' ability to identify medical research findings most pertinent to their practice.[2,3] The proliferation of journals and articles led to development of automated bibliographic tools to index scientific publication data. Eugene Garfield, in his seminal work from 1955, suggested a citation index based on mechanical means to manage and catalog the literature of science.[4] Perhaps the earliest computerized bibliographic database was the Medical Literature Analysis and Retrieval System (MEDLARS), the precursor to MEDLINE/PubMed, introduced by the National Library of Medicine in 1964, soon followed by the *Science Citation Index*.[5,6] Since then a number of other bibliographic databases have been produced, with each capturing various publication data elements and offering a myriad of tools.

Bibliometrics is a term that was coined by Alan Pritchard in 1969 to describe the quantification of discrete data publication elements of the processes of written communication.[7] One seminal work related to bibliometrics is that of Francis Narin's *Evaluative Bibliometrics: The Use of Publication and Citation Analysis in the Evaluation of Scientific Activity*, published in 1976. It outlines many bibliometric measures still in use for evaluation of productivity and impact.[8]

Today, bibliometrics refers to quantitative analyses of publication data using document-, author-, or source-(e.g., journal-) level data elements to uncover characteristics, patterns, and relationships to demonstrate individual investigator or research team productivity, quality, or impact. Most academic clinicians seek to publish their research findings as often as possible in journals widely perceived to be of high quality. However, most academic clinicians also publish in journals less likely to reject their manuscripts. Thus, a simple tally of the number of publications authored or coauthored by an academic clinician is arguably a poor method to assess research productivity.[9,10] With rewards typically accruing to investigators with the longest curricula vitae, academic clinicians may become tempted to bolster their apparent research output by double publishing, self-plagiarism, and reporting on the minimal publishable unit, all of which increases the complexity of the peer review process while reducing the per manuscript yield for busy bedside clinicians who are overwhelmed with information.[11] These challenges led evaluation experts to develop and introduce a series of publication metrics over the past few decades upon which funders and academic review committees increasingly rely to differentiate academic clinicians in an increasingly competitive funding milieu.

Some academic work products are formally published as peer-reviewed journal articles or textbooks and indexed by bibliographic databases or catalogs; others are video files or position/clinical guidance documents disseminated by professional societies or institutions. Most academic work products contain a unique identifier number such as a Digital Object Identifier (DOI), a PubMed reference number (PMID), an accession number, or other unique identifier number. For this article, the initial focus will be on traditional ways that publication data (based on peer-reviewed journal articles) from bibliographic databases are used to demonstrate research productivity and impact. This is followed by an overview of newer methods to measure research productivity and impact and a discussion of new trends in reporting of productivity and impact.

When a peer-reviewed journal article is indexed by a bibliographic database such as MEDLINE/PubMed, a record for the work is created to allow users to search for, discover, and retrieve the work. Publication records are created by various entities and can be modified or supplemented by bibliographic database vendors. Refer to MEDLINE/PubMed Data Element (Field) Descriptions (http://www.nlm.nih.gov/bsd/mms/medlineelements.html) for examples of publication data elements. A publication record contains discrete elements (i.e., metadata) to describe the characteristics and content of a work, from its creation to dissemination, and for select databases, subsequent reach, and impact. Publication data elements as noted for a publication vary among bibliographic databases and may be more robust for specific publication types such as peer-reviewed journal articles or subject disciplines such as biomedical sciences. Most bibliographic databases allow for searching and capture of the publication data, with others offering tools to generate graphs and citation maps as well as the ability to export the data for further analysis.

Publication data metrics capture a wide range of activities based on research and scholarly activities, and some serve as a useful means of demonstrating not only the productivity of an academic clinician but also the impact or influence of his or her published works. Historically, impact or influence from a published work was acknowledgement of the publication in the form of a citation in a subsequent publication. The usefulness of quantitative analyses of publication data to uncover characteristics, patterns, and relationships to demonstrate productivity or impact has been described in a variety of academic and scientific environments. Examples include highly cited articles for a research group and the size and composition of the research group, publication types, the h-index, and journals to which an academic clinician contributes, to name a few.[12–15]

Publication data can be used to illuminate many stories to provide a meaningful narrative of scholarly productivity and impact, as noted in Table 1. These narratives can be used for a variety of purposes such as tenure/promotion, grant applications and renewal reports, benchmarking, recruiting efforts, and for administrative purposes such as departmental or university performance reports.[16–18]

PUBLICATION METRICS BASED ON PRODUCTIVITY

Number of Publications

The most elementary metric related to publication data is simply the number of publications by an author or group of authors. This metric, based on the document-level unit

Table 1
What Stories Can Publication Data Tell?

Authorship and collaboration patterns
Coauthorship characteristics
Citation patterns
Grant acknowledgment networks
Qualification to undertake research project
Justification for grant renewal
Qualification for tenure and promotion
Performance and impact for a group
Cross-disciplinary research efforts
Research foci trends represented by journals and articles
Career development and trajectory
Breadth of influence of published works
Subject foci trends over time
Research areas of expertise and strength

of analysis, can be further refined to denote publication types such as peer-reviewed journal articles, books or book chapters, dissertations, trade publications, and conference abstracts, among others. One metric related to the peer-reviewed journal article is the number of research articles versus review articles. Original research articles present original findings based on research, whereas review articles serve as a comprehensive summary of what is known on a specific subject. In addition, articles that are meta-analyses can be used to highlight unique research efforts. Specific details about an author's publication timeline are also informative. For example, the time from research funding to publication of the first peer-reviewed journal article describing the findings of that funded research project provides funders with an early indicator of researcher efficiency and productivity. Another example is the number of publications within a specific time frame based on career trajectory, such as before starting residency training. These productivity time frames can be used by funding agencies to distinguish between investigators in awarding or renewing grants.[19] One study using radiology residency candidates found that multiple publications by candidates was predictive of future publication performance and National Institutes of Health funding.[20]

Author Status

A publication metric based on the author-level unit of analysis is the author status on a publication—sole author, first author, or last author. A century ago 98% of *New England Journal of Medicine* articles were credited to a single author, but by 2000 less than 5% were single-authored, a trend observed across journals.[21] The 1993 GUSTO report had 972 coauthors, which mathematically represents two words of the manuscript attributable to each coauthor.[21] The International Committee of Medical Journal Editors defines criteria justifying authorship, but many authors are unfamiliar with these standards.[22] Some authors frequently overrate their contributions to a manuscript, and undeserved authorship is a common problem that undermines the value and meaning of any metric that relies on publication counts alone.[23] Nonetheless, authorship is a recognized necessity for career advancement, tenure/promotion, and obtaining grant funding.[24] It is accepted practice in academia that authors who are first or last authors to a publication are recognized or assumed as having contributed the bulk of the work toward the publication.[25,26] Publications with multiple authors can be indicative of collaborative activity, which can be used to demonstrate productivity. For example, what are the affiliations of the authors? Do the collaborations represent inter- or intrainstitutional collaborations?

Publication Sources

Most academic clinicians seek to publish in peer-reviewed journals. One publication metric is the number of peer-reviewed journals in which an academic clinician has published. Journals that reflect varied areas of specialty are indicative of diversity and depth of publication efforts and can be used to create a compelling narrative of interdisciplinary and even translational research efforts. Conversely, an author who publishes exclusively or nearly exclusively in a subspecialty journal may be seen to have created the "narrow and deep niche" that academia and traditional funding sources typically covet. We advise authors to follow the recommended publication practices for their areas of specialty, as publishing in diverse journals may preclude establishing a well-defined niche. Table 2 provides additional examples of descriptors of publication data.

PUBLICATION METRICS BASED ON IMPACT

Journal Impact Factor Score

For the past 30 years, academia has quantified the influence or impact of an author based on the journal impact factor score of journals for the author's publications. Publishing in "high-impact" journals is integral to tenure or promotion.[27] Perhaps the most commonly used metric related to the source level (i.e., journal unit) of analysis is the *Journal Citation Reports* (JCR) Journal Impact Factor score. The JCR Impact Factor score was developed in the 1960s by Eugene Garfield and Irving Sher as a journal selection tool for inclusion in the *Science Citation Index*, the precursor to the Thomson Reuters *Web of Science* database, and later used as an acquisitions tool by libraries.[4,28] The JCR Impact Factor score is calculated by dividing the number of citations to a journal in the JCR year by the total number of articles published by that journal in the two previous years. A JCR Impact Factor score of 1.0 means that, on average, articles published 1 or 2 years ago have been cited one time. For varied reasons, the JCR Impact Factor score evolved as a proxy, albeit unintentionally, for assessing the impact or influence of published works of an author.[29] One reason for this practice was that the JCR Impact Factor score was an easy-to-find metric in the days before the contemporary, more sophisticated databases existed to more closely track publication citations at the individual level, rather than at the journal level.

Despite its appeal, the JCR Impact Factor score is subject to numerous flaws.[30] One major flaw is that the JCR Impact Factor score does not reveal any insight as to a specific publication or author. On the contrary, it is a unit of analysis based on the journal as a whole and not to any individual author-based performance or impact.[28] In addition, the JCR Impact Factor score is limited to journals indexed by the Thomson Reuters

Table 2
Descriptors of Publication Data

Unit of Analysis	Description
Publications	Number of publications authored.
Types of publications	Number of *all* publications types authored.
Peer-reviewed publications	Number of peer-reviewed publications. Peer-reviewed publications are considered as an indicator of quality.
Research vs. review publications	Number of research vs. review publications.
Animal vs. human research publications	Number of animal vs. human research publications.
Average number of publications per year	Average number of publications per year generated by an author.
Publications at specific career stages	The number of publications at specific career milestones may be indicative of future success. Milestones include entering graduate school or medical school; joining a lab as a post-doc; or starting a residency, internship, or training program.
Author as sole author	Number of publications in which the author is the sole author.
Author as first or second or last author	Number of publications in which the author is the first, second, or last author. First, second, and last authors are generally considered to be those that contributed the bulk of the work.
Coauthors	Coauthors can provide insightful information as to authorship patterns. Is there change in coauthorship collaborations over time? Does the number of coauthors increase over a specific time period? Is there a change in research direction or foci? Is there evidence of interdisciplinary efforts? Which coauthors are frequent collaborators? What collaboration patterns can be demonstrated? Do coauthors represent similar career status as the author? Do coauthors represent various stages of career status such as junior investigator, mentor/mentee, principal investigator, faculty, etc.?
Coauthor institutional affiliations	Institutional affiliations of coauthors may serve as a means of demonstrating collaborative efforts. Categories of institutional affiliations to consider are cross-sector, community, industry, university, government, domestic, international, or inter- vs. intrainstitution. When preparing a report consider noting the unique institutional affiliations and the type of institution as well as countries represented by the affiliations. What types of institutions do the coauthors represent? Is there evidence of cross-pollination with coauthors from a different sector or different country?
Coauthor departmental affiliations and specialties	Various coauthor departmental affiliations and specialties represented by coauthors may serve as evidence of collaborative and interdisciplinary effort. Also to consider are specialties such as basic science vs. clinical, inter- vs. intradepartment, inter- vs. intraspecialty, or career status. When preparing a report consider the specialties or areas of study represented by coauthors as well as career status. Are coauthors within the department or area of study of the author? Research direction or foci? Same discipline?
Medical subject headings (MeSH) terms or author keywords	What MeSH terms or author keywords are represented in publications? Use of MeSH terms or author keywords can demonstrate strength in a specific area of specialty or can demonstrate evidence of interdisciplinary research efforts. Have the terms or keywords changed over time?
Grant award acknowledgments	How many grant awards are acknowledged in support of a publication? What types of funding are represented? Many publications are generated with the support of grant funding. Grant funding support is usually noted in the acknowledgment section of a publication. Consider the various types of funding: private, industry, federal, or state. Compare grant award acknowledgment patterns over a period of time to assess increase in and integration of funding sources and change in research direction or foci.
Journal titles represented by publications	What journal titles are represented by the publications? Are there a number of titles represented by the publications or are they limited to select few titles that are indicative of a specialized niche? Do journal titles reflect diversity and/or interdisciplinary effort? Some databases categorize journals by a specific category. Do the journals represent different categories?
Total citation count	Number of times an author's publications have been cited. Citation rates will vary among databases that provide publication and citation data.
Citations per publication	Number of citations per publication. How many citations has each publication garnered?
Citations: publication types	Number of *all* publication types that are cited and number of citations.
Citations: reviews	Number of reviews that cite a publication. Review articles are a significant indicator of impact as they represent a review of key publications on a particular topic and include the current understanding of a topic and discussion of recent advances and future directions.
Citations: textbooks or textbook chapters	Number of textbooks or textbook chapters that cite a publication. Generally speaking, textbooks are representative of the seminal knowledge of a subject.
Citation rate vs. uncited rate	Number of citations for a group of publications compared to publications that remain uncited.
Self-citation vs. non–self-citation rate	Number of self-citations to publications compared to non–self-cited publications.
Grant acknowledgments represented in citing publications	How many grant awards are acknowledged in support of a citing publication? Grant funding support is usually noted in the acknowledgment section of a publication. What types of funding are represented? Consider the various types of funding: private, industry, federal, and state. Do the funded projects represent diversity of subject foci or interdisciplinary efforts? Are the funded projects outside the research direction of the cited publication?

Table 2
(Continued)

Unit of Analysis	Description
Journal titles represented in citing publications	What journal titles are represented by the citations to the publications? Are there a number of titles represented by the publications or are they limited to a select few titles? Do journal titles reflect diversity and/or interdisciplinary effort? Some databases categorize journals by a specific category. Do the journals represent different categories?
Institutions represented in citing publications	How many institutions were noted in the author affiliations of the citations? Institutional affiliations of authors of citing publications may serve as a means of demonstrating influence or impact of a publication. Categories of institutional affiliations to consider are cross-sector, community, industry, university, government, domestic, international, or inter- vs. intrainstitution. When preparing a report consider noting the unique institutional affiliations and the types of institution as well as countries represented by the affiliations of the citing authors.
Languages represented in citing publications	How many languages are represented by citing publications? Some citing publications are authored using a language different from the publication.
Second-generation citations	Number of second-generation citations for all publications. Second-generation citations are citations to the original citing publications for a publication. How many second-generation citations are there for a specific publication?

Web of Science database. Individual journal rankings depend on how many times the articles included in that journal are cited in other journals indexed by *Web of Science*, a small subset of all journals published, and currently including approximately 10,800 journals. According to Ulrich's *Global Serials Directory*,[31] there are approximately 73,130 active, academic English-language journals in publication as of December 2013, so *Web of Science* indexes about 15% of existing journals. Other idiosyncrasies affect the interpretation of the JCR Impact Factor score. For example, citation practices vary among disciplines and clinical specialties.[32] Additionally, the JCR Impact Factor score encompasses citations from the previous 2 years, whereas the full impact of an individual publication is often measured over decades. Another issue is that journals and journal authors can manipulate the JCR Impact Factor by intentional self-citations and by encouraging peer reviewers to suggest other citations to add to a submitted manuscript's references list from that same journal in the prior 2 years.[32–35] There are other ways to "game the system," as noted by editors of *PLoS Medicine*.[6] Finally, the JCR Impact Factor score is not static and often trends upward[36] for prolific journals.[4]

Thomson Reuters fully acknowledges that while the JCR Journal Impact Factor score is a valuable metric and tool for the selection of journals for coverage in its *Web of Science* database, it is subject to misapplication. As a means of quality control, Thomson Reuters reviews journal citations on an annual basis for evidence of questionable citation activity. One specific example of questionable citation activity is the editorial published in the Swiss journal *Folia Phoniatrica et Logopaedica* in 2007.[37] The editorial purposely cited all articles published in the journal from 2005 to 2006, which led to an increase in the JCR Journal Impact factor score in 2008. Consequently, *Folia Phoniatrica et Logopaedica* was not included in Journal Citation Reports for 2008 and 2009.[38] For the 2013 JCR Journal Impact Factor scores, 37 journals were suppressed from the listing and will be reevaluated in 2 years.[39]

Although the JCR Impact Factor score has been a leading indicator of publication impact for decades, the landscape is changing.[30,40] In an attempt to raise awareness of misuses of the JCR Impact Factor, The San Francisco Declaration on Research Assessment (DORA, archived at http://am.ascb.org/dora/) recently issued a set of recommendations urging funding bodies, publishers, and institutions to avoid use of the JCR Impact Factor score as a means of assessing research impact or scientific quality. The Australian National Health and Medical Research Council has done likewise since 2010. DORA also stressed the use of other metrics, to shift the focus onto the scientific content of an article rather than the publication metrics of a journal. Among other metrics suggested by DORA are article-level metrics, influence of a work on policy and practice, and the h-index.

CITATIONS

Citation analysis is a traditional method of assessing research impact by determining how often subsequent publications cite a specific publication. It is a tool for gauging the specialty and geographic reach and rate of uptake of a publication's influence in the literature by tracking the advancement of knowledge with the inherent assumption that significant publications will demonstrate a high citation count.[41]

Citations can be analyzed as a unit of analysis applied to the body of published works by an author or based on a single publication. The number of citations can be extrapolated further to include the characteristics of the citing publications. Some examples include: Who are the authors? Which affiliations or countries are noted by the authors? What languages are represented in the citing publications? What grant acknowledgement networks are noted? Do the citing publications represent new subject foci? (See Table 2 for further descriptors of publication data metrics based on citations.)

Despite usefulness as an indicator for impact of publications by an author, citations should be used with caution, because they are subject to idiosyncrasies that can skew citation counts. First, older publications have more time to accrue citations than newer publications, and invariably yield higher citation counts than more

recent publications.[42] Second, early reports of scientific findings, which at the time they are reported are at odds with the broadly held beliefs or expectations of the scientific community, are often not cited until years have passed. This phenomenon is known as the "Mendel effect" or "Sleeping Beauties."[43,44] In contrast, some works are highly cited soon after their publication to support statements or provide data-based sources for quantitative estimates, only to be found later to be examples of research based on misinformed science. This exemplifies a distinction that raw citation counts cannot illuminate.

One obvious issue with citation counts as a measure of impact is that they can be manipulated by deliberate self-citation or reciprocal citations by colleagues.[45,46] One study analyzing articles from the journal *Science* found a strong relationship between the number of citations of a manuscript and the number of references contained in that publication. In other words, the more references a publication has, the more citations the publication is likely to receive.[47] Study design also affects citations, with one study demonstrating that meta-analyses are cited more frequently than all other designs.[48] Data sharing can also be a factor for citations, as noted in a study of cancer microarray clinical trial publications that found that data sharing led to a higher citation count.[49] Mentorship, industry funding, and mixed-gender authorship composition may also lead to higher citations.[50–52]

Perhaps even more significant is that the raw number of citations of a manuscript may not reveal evidence of tangible or meaningful impact to clinicians, patients, or policy-makers, such as incorporation of scientific advances into clinical guidelines or practice-changing clinical relevance that translate into bedside implementation and improved patient outcomes. Ideally, the end users (health care providers and patients) desire manuscripts that have "clinical relevance." Clinical relevance can be difficult to quantify. Recently clinical educators and researchers explored half of this clinical relevance paradigm by seeking input from a sampling of practicing emergency physicians using a scale to assess the impact of contemporary publications on bedside practice.[53] Further research is required to discover why select publications garner a higher citation rate than others and if any metric accurately portrays clinical applicability, penetration, or synthesis with contemporary practice (for further citation caveats, please refer to Table 3).

Table 3
Citation Caveats

No single resource is available for locating all citations to a publication.
Citations from a particular resource reflect only those publications that are indexed by the resource used for citation data—potentially a small pool of journal literature.
Citations for books and book chapters, conference abstracts, and gray literature are rudimentary.
Author self-citations and reciprocal citing by colleagues often inflate citation counts.
Citations do not reveal evidence of research impact such as synthesis into clinical applications or public health outcomes.
Citations are not indicative of meaningful health outcomes.
High citation counts do not equate to quality of research or greater influence.
Multiple versions of the same publication may affect citation counts.

GOING BEYOND CITATION COUNTS

The necessity of examining each cited publication has been explained in the preceding section. Another important motivation for moving beyond simple citation counts is that elements related to citation data can yield valuable information to supplement an impact narrative for reporting purposes. This requires careful review of each citing publication to discern various data points. Who is citing the publication? Where are they from? What are their affiliations? What types of affiliations do they represent? In what language is the citing publication? What states or countries are represented by the affiliations? Why are they citing the publication? Discussion of the author affiliations alone can establish a compelling narrative of international influence.

One metric related to citation data is to review the grant funding acknowledgements noted in the citing publications. This can provide valuable information for reporting of impact of publications. For example, if the grant projects and funding sources noted in the citing publications reflect subject foci areas beyond the cited publication, this may be indicative of interdisciplinary or even transdisciplinary influence. The type of citing publications may also be useful. For example, review articles are considered to be reflective of the most current and impactful work in a field. The language of the citing publications is another way of reporting impact from publications. A list of the different languages of citing publications can be used to show influence on a national and international scale. The subject context of the citing publications can also be used to demonstrate influence in one's field and beyond. Why did authors from other disciplines or areas of clinical specialty cite a publication?

The h-index

The h-index is a relatively new metric that is increasingly being used by academia as a benchmark for performance of an author and even by funding agencies and for comparing academic institutions.[54] The h-index, developed by Hirsch,[55] is derived from a formula using publications and citations to provide "an estimate of the importance, significance, and broad impact of a scientist's cumulative research contributions." One computes the h-index by noting the maximum number of one's publications that have been referenced at least "X" times. If one has 10 manuscripts that have each been cited 10 times, that individual's h-index is 10. Whether that individual has 10 total manuscripts or 1000 manuscripts, the h-index will not move to 11 until at least 11 of the manuscripts have been cited at least 11 times. As with the JCR Impact Factor score, the h-index is an easy-to-find number, as many databases include the h-index for authors, including *Google Scholar*, a freely available resource. Despite its appeal as a single metric that includes both publications

and citations, there are some caveats to its use and application. One of the major caveats is that the h-index varies among bibliographic databases.[56] In other words, the same author will have a different h-index depending on which database one uses to define its h-index. Accordingly, Hirsch[55] cautioned about the possible misuse of the h-index, especially for key purposes such as granting or denying of tenure (see Table 4 for additional h-index caveats).

Other Indices

As a means of normalizing the h-index for younger authors, Hirsch[55] proposed the m-value, which adjusts for time by correcting for the number of years since an author's first publication. According to Hirsch, the m-value is an "indicator of the successfulness of a scientist," and the parameter m should provide a useful yardstick to compare scientists of different seniority. The m-index can be seen as an indicator for "scientific quality," with the advantage (compared to the h-index) that it is corrected for age.[55]

Multiple investigators continue to seek a more definitive index of academic productivity.[57] The h′-index is a mathematical adjustment of the h-index as is the segmented regression model of high visibility publications.[58] The e-index complements the h-index for excess citations, whereas the hi-5! is the h-index over a 5-year period.[59,60] The hc-index adjusts for the age of the publication, while weighting authorship value by author position and the journal Impact Factor.[61] The Carbon_h factor also integrates a scientist's research age into the h-index.[62] The Profit index (p-index) estimates contributions of coauthors relative to the work of individual authors.[63] The Absolute index (Ab-index) takes into account the impact of research findings while weighting the physical and intellectual contributions of the researcher.[64] The rate of change of the Ab-index per year is the Productivity (Pr) index.[64] The Bh-index only assesses the h-index of articles in h-core journals.[65] Finally, one particularly interesting index is the v-index, which includes the proportion of time devoted to research to normalize for clinical academicians who may devote only 40% to 50% of their time to research.[66]

Table 4
h-index Caveats

The h-index is a metric for evaluating the cumulative impact of an author's career publications; it measures quantity with quality by comparing publications to citations. It is, however, not intended for a specific time frame.
The h-index calculation does not discern among publication types. For example, meta-analyses and review articles are more likely to be cited than research articles and meeting abstracts.
Author name variants and multiple versions of the same work in some resources pose challenges with calculating the h-index.
Different publication practices among disciplines may affect the h-index.
Several resources (Scopus, Web of Science, and Google Scholar) offer tools that automatically calculate the h-index for authors, allowing for a metric that is easily available. However, the h-index for each resource will vary greatly, even if the same set of publications is being compared.
Self-citations or gratuitous citations among colleagues can skew the h-index.
The h-index disregards author ranking and coauthor characteristics on publications.
Young authors are at a disadvantage.
The h-index does not provide the context of the citations; why is the work being cited?
The h-index does not serve as a predictor of future scholarly performance or impact.

EMERGING MEASURES OF PUBLICATION IMPACT

Document-level Metrics

With the advent of new digital technologies, sophisticated publisher platforms, and widespread use of social media applications, an emerging set of metrics has allowed for measuring usage of a publication, including the public or social engagement at the document-level (also referred to as article-level) unit of analysis. Document-level metrics other than citations represent data points of a work (journal articles, books, slides, software, conference papers, data sets, figures, etc.) that can be captured to determine how a work is read online, downloaded, shared among others, commented upon, recommended, viewed, and saved in online reference managers.[67,68]

Examples of new document-level metrics include:

- Online downloads of a work;
- Online views of a work;
- Bookmarks to a work from online reference managers such as Mendeley;
- Mentions of a work in social network sites such as Twitter or Facebook;
- Discussions of a work in blogs or by mass media technologies;
- Favorites/recommendations of a work in platforms for sharing of works such as in Slideshare, Figshare, or YouTube;
- Comments/annotations for a work noted in online commenting platforms such as PubMed Commons.

These metrics can provide evidence of nascent influence of a work, serve as complementary measures of impact to citations, and can allow authors to highlight multiple examples of scholarly output, outside of the peer-reviewed journal article. Document-level metrics are available from various sources and platforms such as publishers, software applications, and databases.

Public Library of Science (PLoS) publishers (http://www.plos.org/), the first to offer document-level metrics in 2009, provide the most highly developed publisher platform for document-level metrics.[67] Figure 1 illustrates examples of PLoS metrics. Other publishers and repositories that also offer document-level metrics include ScienceDirect (http://www.sciencedirect.com/), PubMed Central (http://www.ncbi.nlm.nih.gov/pmc/), and BioMed Central (http://www.biomedcentral.com/).

Platforms that allow authors to share their works and offer metrics for usage include ResearchGate (http://www.researchgate.net/), Academia.edu (http://www.academia.edu/), Google Scholar (http://scholar.google.com/), Slideshare (http://www.slideshare.net/), and Figshare (http://figshare.com/).

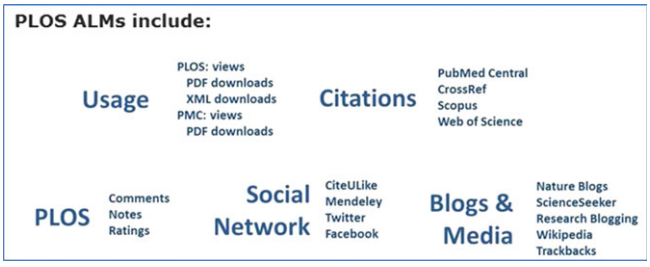


Figure 1. Example of PLoS metrics. Image courtesy of Public Library of Science (PLoS): http://article-level-metrics.plos.org/alm-info/.

MEDLINE/PubMed recently released a beta version of PubMed Commons (http://www.ncbi.nlm.nih.gov/pubmedcommons/) that enables authors of works indexed by MEDLINE/PubMed to share publicly posted comments about works in MEDLINE/PubMed. Comments can be tabulated by authors to the work and used for reporting or departmental purposes.

Software applications (free and subscription-based) are available for authors to use for capture of document-level metrics for their works: Altmetric (http://www.altmetric.com/), Impact Story (http://impactstory.org/), and Plum Analytics (http://www.plumanalytics.com/).

CAN TRADITIONAL PUBLICATION METRICS AND DOCUMENT-LEVEL METRICS COEXIST?

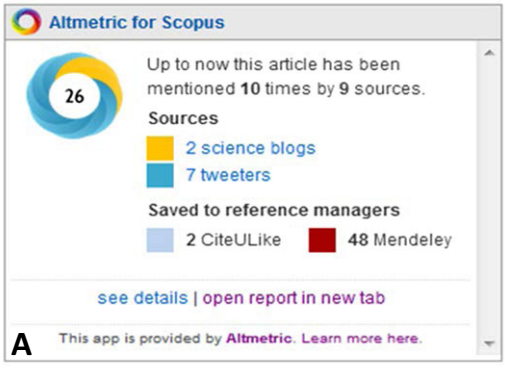
These new document-level metrics, however transient, rudimentary, and anonymous in nature, may serve as an early indicator of the impact of a work. Document-level metrics represent early-stage social or public engagement indicators of how and by whom a work is being shared, used, commented on, and disseminated further. Who is reading the new work? Who is tweeting about the new work? Where are they tweeting from? Is the work being commented on in a blog posting? By whom? A scientist or a policy-maker or a layperson? Are users bookmarking the work in Mendeley? Is the work the topic of an article in the press? Is a user viewing slides in Slideshare? Is a user viewing figures in Figshare? For newer publications, document-level metrics may be a strong source of data to supplement traditional publication metrics, especially if the publication has not yet garnered citations.

However, these metrics based on social attention or social or public engagement can also be a marker of strong disagreement, research error, or frank misconduct. The publication of a landmark mammography clinical trial with 25 years of follow-up that disputed the benefits of routine mammography to screen for breast cancer in unselected populations generated a visceral negative reception in the nonmedical mass media in 2014. Immediate and impressive medical research defense of the mass media portrayal was evident as noted by the Altmetric bookmarklet report for the publication.[69] As another example, publication of the IST3 stroke-thrombolysis trial in 2013 generated a significant volume of dissenting social chatter as noted by its Altmetric bookmarklet.[70]

HOW CAN I USE PUBLICATION METRICS FOR FUNDING OR ACADEMIC PURPOSES?

Many bibliographic databases provide tools that allow for publication data analysis, with some offering tools for authors to track citations to their publications and citation maps for authors to download for reporting purposes. Two major bibliographic databases in the biomedical field, Elsevier *Scopus* and Thomson Reuters *Web of Science*, offer tools for capture of publication data including citations, as well as graphs or charts to download. The *Scopus* database also allows for integration of applications such as the Altmetric bookmarklet. The Altmetric bookmarklet allows authors to view online activity for an article such as blogs, tweets, and saves in online reference managers, among others (see Figures 2A and 2B for an example of the Altmetric bookmarklet report for a publication of one of the coauthors [CRC]).

Thomson Reuters *Web of Science* offers creation of second-generation citation maps. Second-generation maps are illustrations that display the direct citations to a work (first-generation citations), plus the works that cite the direct citations (second-generation citations), color coded by language. This allows users to trace advancement in knowledge over time, forward and backward (see Figure 3 for an example of a forward second-generation citation map for the example study from Figure 2). The nodes are colored and labeled by the country affiliation of corresponding author of the citing works. There are 11 different



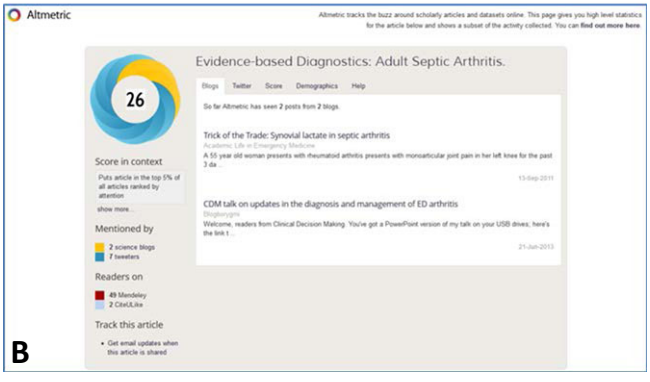


Figure 2. Example of the Altmetric report for Carpenter CR, et al. Evidence-based diagnostics: adult septic arthritis. *Acad Emerg Med* 2011;18:781–96. Images courtesy of Elsevier *Scopus*.

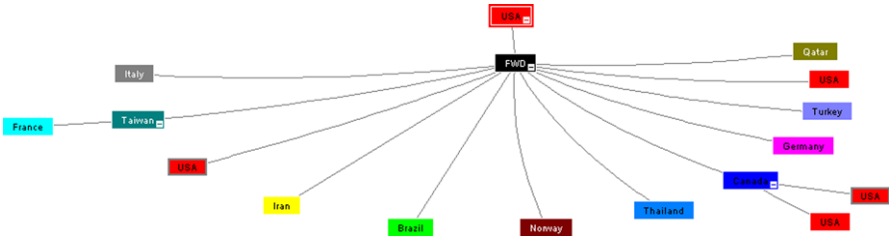


Figure 3. Second-generation map from *Web of Science*. Image courtesy of Thomson Reuters *Web of Science*.

countries represented by the original (first-generation) 12 citing works and two countries (U.S. and France) representing the three citations to the first-generation citations.

When using publication data for any purpose, it is essential to go beyond the numbers to create a narrative that provides contextual background as to productivity and impact. Crafting a narrative based on publication data depends on the intended purpose. Some metrics based on productivity and impact are more useful for tenure purposes; others are more appropriate for demonstrating in a grant application that one is the best qualified investigator to be funded for a research study. Justification of grant renewal requires a narrative based on impact to demonstrate that that research resulted in meaningful outcomes and tangible effects. Reports that contain numerical values may be more suited for institutional administrative reporting purposes. Finally, some metrics do not suffice, and to demonstrate meaningful health outcomes, one must go beyond the numbers to tell a story.[71] Discovery of an author's most compelling and impactful work may only be evident through use of measures beyond publication data. Academic clinicians affiliated with academic institutions are encouraged to contact their libraries for assistance with publication reports for productivity and/or impact. Most academic libraries have staff who are designated experts on specific databases and can run reports, perform analysis, and in some instances, create network maps using social network analysis tools.[72,73] Narratives should be tailored appropriately for their intended purposes. What follows here are specific examples that academic clinicians can use for tenure/promotion or grant funding purposes.

Example for Tenure and/or Promotion

Since 2002, Dr. ABC has published 48 peer-reviewed manuscripts with 92 unique coauthors, representing 86 institutions, including two authorship groups from eight countries. Dr. ABC is first author on 21 manuscripts and sole author of five works. The manuscripts have been published in 28 journals representing 15 research areas including hematology, pathology, emergency medicine, cardiovascular cardiology, and toxicology. Since 2008, Dr. ABC's manuscripts noted 18 different funding agencies in the acknowledgement sections. To date, Dr. ABC's manuscripts have been cited over 1,000 times by 698 other manuscripts by authors from 18 countries in five languages. Each one of Dr. ABC's manuscripts has at least five citations.

Example for Demonstrating Qualification to Undertake Research for a Grant Proposal

The publications most relevant to the proposal fall under Research Area A (based on document-level subject content) in the Thomson Reuters *Web of Science* database. Over the past 5 years, ABC publications (all types and all languages) were indexed by *Web of Science*. Of the ABC publications, only X pertain to research area A. Of these X publications (X articles, X reviews, and X proceedings papers), X are authored by the grant applicant. Clearly, there is a gap in the literature per research area A, with the grant applicant being among the most qualified investigators to research and report further on research area A. Only X number of authors share the same number of publications, all of whom are coauthors of the grant applicant from different institutions.

Example for Justification of Grant Renewal Funding

Since Dr. XYZ's grant was funded 3 years ago, three peer-reviewed journal articles reporting on preliminary findings have been published in the past 2 years. These three articles have been cited a total of 32 times by subsequent publications, with a second-generation citation count of 15, with authors from six countries, and published in three languages. In addition, one of the articles was reviewed by six *Faculty1000 Prime* reviewers as recommended readings and assigned the following categories: "Technical Advance," "New Finding," and "Interesting Hypothesis." The three articles by Dr. XYZ have been saved by 33 readers on Mendeley, tweeted three times, mentioned in 12 blog postings, and saved in four Facebook accounts.

Example of a Faculty Project Page

Publication metrics can be used to highlight a faculty research page, as in the case with a coauthor's (CRC) project page (see Figure 4).

FUTURE OF PUBLICATION METRICS: WHAT DOES THE FUTURE HOLD?

With the advent of new document-level metrics, in tandem with the recent DORA initiative, academic clinicians can access a new array of metrics to assess and quantify scholarly productivity and impact, from a traditionally academic perspective as well as a social perspective. The narrative is more expansive and focuses on the scientific content of the document itself and not its "container" (i.e., journal). Despite the advantages that new document-level metrics afford authors, they are still

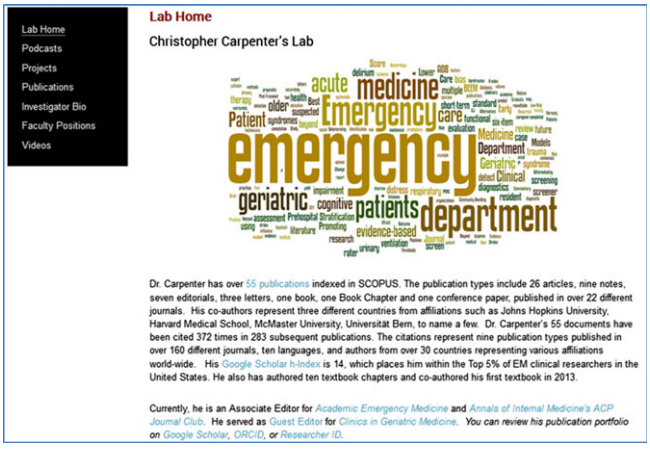


Figure 4. Example of the project page for author Christopher R. Carpenter. URL: http://emed.wustl.edu/carpenter_christopher/LabHome.aspx.

in their infancy. Much work is required to develop common vocabularies and classifications to ensure harmonized assessment.[67]

Meanwhile, it is critical that academic clinicians use the same variation of his or her name consistently throughout his or her academic and research career and take steps to ensure that all research outputs and activities are properly attributed. Maintaining a robust and public profile throughout one's academic career is part of responsible conduct of research and is essential for discovery and promotion of research outputs and activities.

What follows are recommendations for academic clinicians to follow to ensure their research outputs and activities are properly attributed to them and to track the dissemination and reach of their research efforts.

- Register for an ORCID iD (http://orcid.org/) and complete a profile. ORCID provides a universal, nonproprietary solution by linking publications and research activities to an author/investigator. ORCID is linked among other identifier systems such as the Elsevier *Scopus* Author ID and the Thomson Reuters ResearcherID, publishers such as Nature and Public Library of Science (PLoS), and funding agencies such as the Wellcome Trust and included in the new federal biosketch tool, Science Experts Network Curriculum Vitae, SciENcv (http://rbm.nih.gov/profile_project.htm). Registering for an ORCID identifier helps to promote discoverability among multiple information platforms and workflows and establishes a unique presence for researchers and scholars, regardless of name variants or affiliation history.
- Use a consistent format for noting of a name, institutional affiliation, and departmental information. Check to see if there is an official style guide at your institution. See the Style Guide for Washington University in St. Louis for an example.[74]
- Create an author profile on Google Scholar (http://scholar.google.com/) and other author profile platforms such as ResearcherID (http://www.researcherid.com/) and LinkedIn (https://www.linkedin.com/).
- Check your name in Elsevier *Scopus*. If your institution does not subscribe to *Scopus*, use the free *Scopus* Author Lookup Tool (http://www.scopus.com/search/form/authorFreeLookup.url). Authors can check their name variants and submit requests to merge or correct name variants.
- Create alerts in bibliographic databases and in Google Scholar to be notified when your works are cited by others.
- Download the Altmetric bookmarklet (http://www.altmetric.com/bookmarklet.php) to keep track of document-level metrics for peer-reviewed journal articles.
- Persuade the publishers of journals you use frequently for publication to implement software to capture document-level metrics for peer-reviewed journal articles, modeling the PLoS platform.
- Contact your academic library for assistance with use of bibliographic databases and how to run reports and create search alerts for publications. Librarians can also check for name variants and help reconcile author name variants in bibliographic databases.

BEYOND TRADITIONAL PUBLICATION METRICS

Traditional measures to quantify productivity based on "counts" (number of publications, number of citations, etc.) are insufficiently robust to meet the increasing demands of accountability and value. The digital revolution has enabled the creation of sophisticated databases and software tools that provide insights regarding research productivity and impact, which until recently were impossible to obtain. However, increased competition for biomedical research funding, along with a growing emphasis by funding agencies and institutions to demonstrate meaningful and transparent outcomes, has led to pressure to use metrics that more concretely quantify the impact of research on knowledge diffusion, synthesis into clinical applications, and public health outcomes. Therefore, it will become increasingly important to "go beyond the numbers" to evaluate and/or justify funding requests or requests for promotion and/or tenure and report on performance. Creating a narrative that provides contextual background to illustrate productivity and academic impact is far more meaningful than raw bibliometric data. Tailoring the academic productivity narrative for the intended purpose is one key to meaningful communication with stakeholders and successful dissemination of academic output. Medical librarians offer substantial expertise in navigating the ever expanding array of resources that exist to paint this academic productivity narrative.

While publication metrics can provide compelling narratives, no single metric is sufficient for measuring performance, quality, or impact by an author. Publication data is but a single chapter in an author's academic and research story. Publication data alone does not provide a full narrative of an author's impact or influence, nor is it necessarily predictive of meaningful health outcomes that may have resulted from an author's research. Other sources include awarded grants, honors and awards, patents, intellectual property, outreach efforts, teaching activities, professional organization efforts, journal editorship, advisory board

activities, mentoring efforts, and community engagement activities, to name a few.

In today's competitive academic milieu, it is critical that authors proactively "curate" themselves. Curate is based on the Latin word *cura*, loosely translated as "care." Authors need to establish their presence on author profile platforms, use contemporary strategies to enhance discoverability, consider multiple avenues of dissemination, reach beyond numbers to tell a story, and efficiently track research outputs and activities.

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