BMJ Open is committed to open peer review. As part of this commitment we make the peer review history of every article we publish publicly available.

When an article is published we post the peer reviewers' comments and the authors' responses online. We also post the versions of the paper that were used during peer review. These are the versions that the peer review comments apply to.

The versions of the paper that follow are the versions that were submitted during the peer review process. They are not the versions of record or the final published versions. They should not be cited or distributed as the published version of this manuscript.

BMJ Open is an open access journal and the full, final, typeset and author-corrected version of record of the manuscript is available on our site with no access controls, subscription charges or pay-per-view fees (http://bmjopen.bmj.com).

If you have any questions on BMJ Open's open peer review process please email editorial.bmjopen@bmj.com

BMJ Open

The Comprehensive Researcher Achievement Model (CRAM): a framework for measuring researcher achievement, impact and influence derived from a systematic literature review of metrics and models

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-025320
Article Type:	Research
Date Submitted by the Author:	10-Jul-2018
Complete List of Authors:	Braithwaite, Jeffrey; Macquarie University, Australian Institute of Health Innovation Herkes, Jessica; Macquarie University, Australian Institute of Health Innovation Churruca, Kate; Macquarie University, Australian Institute of Health Innovation; Macquarie University Long , Janet; Australian Institute of Health Innovation, Centre for Healthcare Resilience and Implementation Science Pomare, Chiara; Macquarie University Faculty of Medicine and Health Sciences, Australian Institute of Health Innovation Boyling, Claire; Macquarie University Faculty of Medicine and Health Sciences, Australian Institute of Health Innovation Bierbaum, Mia; Macquarie University, Australian Institute of Health Innovation Clay-Williams, Robyn; Macquarie University, Australian Institute of Health Innovation Rapport, Frances ; Macquarie University, Australian Institute of Health Innovation Shih, Patti; Macquarie University, Australian Institute of Health Innovation Hogden, Anne; Macquarie University, Australian Institute of Health Innovation Ellis, Louise A.; Macquarie University, Institute of Health Innovation Ludlow, Kristiana; Macquarie University, Australian Institute of Health Innovation Austin, Elizabeth; Macquarie University Faculty of Medicine and Health Sciences, Australian Institute of Health Innovation Seah, Rebecca; Macquarie University Faculty of Medicine and Health Sciences, Australian Institute of Health Innovation McPherson, Elise; Macquarie University, Australian Institute of Health Innovation Hibbert, Peter; Macquarie University Faculty of Medicine and Health Sciences, Faculty of Medicine and Health Sciences; University of South Australia Division of Health Sciences, Westbrook, Johanna; Macquarie University Faculty of Medicine and Health Sciences, Australian Institute of Health Innovation

Keywords:	Researcher assessment, Research metrics, h-index, Journal impact factor, Comprehensive Researcher Achievement Model (CRAM), Citations

The Comprehensive Researcher Achievement Model (CRAM): a framework for measuring researcher achievement, impact and influence derived from a systematic literature review of metrics and models

Authors

Professor Jeffrey Braithwaite (JB)*[1], BA, MIR (Hons), MBA, DipLR, PhD, FIML, FCHSM, FFPHRCP (UK), FACSS, Hon FRACMA, FAHMS

Ms Jessica Herkes (JH) [1], BSc (Adv), MRes

Dr Kate Churruca (KC) [1], BA (Hons) Psych, PhD

Dr Janet C Long (JCL) [1], BSc (Hons), MN (Ed), CertOpthNurs, PhD, FISQua

Ms Chiara Pomare (CP) [1], BPsych (Hons), MRes

Ms Claire Boyling (CB) [1], BHSc (Health Promotion)

Ms Mia Bierbaum (MB) [1], BSc (Biomedical), B.Ed, Grad Dip TESOL, MPH

Dr Robyn Clay-Williams (RC-W) [1], BEng, PhD

Professor Frances Rapport (FR) [1], BA (Hons), Cert Ed, FRSA, MPhil, PhD

Dr Patti Shih (PS) [1], BA(Hons), M.Pub.Pol., PhD

Dr Anne Hogden (AH) [1], BA (Hons), B SpPath, PhD, FISQua

Dr Louise A Ellis (LAE) [1], BPsych (Hons), PhD

Ms Kristiana Ludlow (KL) [1], BPsych (Hons), MRes

Dr Elizabeth Austin (EA) [1], BA (Hons) Psych, PhD

Ms Rebecca Seah (RS) [1], BSc Psychology (Hons I) Bcomm

Ms Elise McPherson (EM) [1], BA, BSc(Hons)

Mr Peter Hibbert (PH)[1], B.App.Sc (Physio), Grad.Dip. Comp, Grad.Dip. Econ, FAAQHC

Professor Johanna I Westbrook (JIW) [1], BAppSc, GradDipAppEpid, MHA, PhD

[1]Australian Institute of Health Innovation, Macquarie University, Sydney, Australia

***Corresponding Author**

Level 6, 75 Talavera Rd

Macquarie University, North Ryde

New South Wales, Australia, 2109

Word count: 4528 exl. Abstract, tables, figures, references and acknowledgements

ABSTRACT

Introduction

Effective researcher assessment is key to decisions about funding allocations, promotion and tenure. In the age of ubiquitous data availability, however, weighing the achievements, impact and track record of researchers is a challenge. Despite increased interest in this issue, there is a lack of clarity about what information to include and how.

Objective

We aimed to identify what is known about methods for assessing researcher achievements, drawing on this to propose a new composite assessment model.

Methods

A set of inclusion criteria was applied to information gathered through a systematic search of Web of Science Core Collection, MEDLINE, and BIOSIS Citation Index review for literature published between 2007 and 2017. The research followed the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) framework.

Results

Four hundred and seventy-eight articles were included in the final review. Established approaches, which had been developed prior to our inclusion period (e.g., citations and outputs, h-index, journal impact factor), remained dominant in the literature and in practice. There was a profusion of new bibliometric methods and models in the last 10 years including: measures based on PageRank algorithms or "altmetric" data, those purporting to improve upon existing methods to apply peer judgement, and novel techniques to assign values to publication quantity and quality. Each assessment method tended to prioritize certain aspects of achievement—academic productivity, quality of research, impact or popularity—over others.

Conclusions

Judging researchers' achievement is complex. All metrics and models focus on an element or elements, at the expense of others. Because of these issues, a new composite design, the Comprehensive Researcher Achievement Model (CRAM) is presented, which limits disadvantages with any one metric and supersedes past anachronistic models. The CRAM contains a blend of measures and is modifiable to a range of applications.

Keywords: Researcher assessment; Research metrics; h-index; Journal impact factor; citations; outputs; Comprehensive Researcher Achievement Model (CRAM)

Article Summary

Strengths and limitations of this study

- A large dataset of over 478 articles, containing many ideas for assessing researcher performance, was analyzed
- A new model combining multiple factors to assess researcher performance is now available
- Its strengths include combining quantitative and qualitative components in the one model
- The CRAM model, despite being evidence-oriented, is a generic one and now needs to be applied in the field

INTRODUCTION

Judging researchers' achievements and impact continues to be an important means of allocating scarce research funds and assessing candidates for promotion or tenure. It has historically been carried out through some form of expert peer judgement, including numbers and quality of outputs, and in more recent decades, citations to them. This approach requires judgements regarding the weight which should be assigned to the number of publications, their quality, where they were published, and their downstream influence or impact. There are significant questions about the extent to which human judgement based on these criteria is an effective mechanism for making these complex assessments in a consistent and unbiased way.[1-3] Criticisms of peer assessment, even when underpinned by relatively impartial productivity data, include the propensity for bias, inconsistency among reviewers, nepotism, group-think and subjectivity.[4-7]

To compensate for these limitations, approaches have been proposed that rely less on subjective judgement and more on objective indicators.[3, 8-10] Indicators of achievement focus on one or a combination of four aspects: quantity of researcher outputs (*productivity*); value of outputs (*quality*); outcomes of research outputs (*impact*); and relations between publications or authors and the wider world (*influence*).[11-15] Online publishing of journal articles has provided the opportunity to easily track citations and user interactions (e.g., number of article downloads) and thus has provided a new set of indices against which individual researchers, journals and articles can be compared and the relative worth of contributions assessed and valued.[14] These relatively new metrics have been collectively termed *bibliometrics*[16] when based on citations and numbers of publications, or *altmetrics*[17] when calculated by alternative online measures of impact such as number of downloads or social media mentions.[16]

The most established metrics for inferring researcher achievement are the h-index and the Journal Impact Factor (JIF). The JIF measures the average number of citations of an article in the journal over the previous year, and hence is a good indication of journal quality but is increasingly regarded as a primitive measure of quality for individual researchers.[18] The h-index, proposed by Hirsch in 2005,[19] attempts to portray a researcher's productivity and impact in one data point. The h-index is defined as the number (h) of articles published by a researcher that have received a citation count of at least h. Use of the h-index has become widespread, reflected in its inclusion in author profiles on online databases such as Google Scholar and Scopus.

Also influenced by the advent of online databases, there has been a proliferation of other assessment models and metrics,[16] many of which purport to improve upon existing approaches.[20, 21] These include methods that assess the impact of articles measured by: downloads or online views received; practice change related to specific research: take-up by the scientific community; or mentions in social media.

Against the backdrop of growth in metrics and models for assessing researchers' achievements, there is a lack of guidance on the relative strengths and limitations of these different approaches. Understanding them is of fundamental importance to funding bodies that drive the future of research, tenure and promotion committees, and more broadly for providing insights into how we recognize and value the work of medical science and scientists. This review identifies approaches to assessing researchers' achievements published in the academic literature over the last 10 years, considering their relative strengths and limitations.

METHOD

Search Strategy

Web of Science databases (including Web of Science Core Collection, MEDLINE, and BIOSIS Citation Index) were searched using terms related to researcher achievement (*researcher excellence, track record, researcher funding, researcher perform*, relative to opportunity, researcher potential, research* career pathway, academic career pathway, funding system, funding body, researcher impact, scientific* productivity, academic productivity, top researcher, researcher ranking, grant application, researcher output, h*index, i*index, impact factor, individual researcher*) and approaches to its assessment (*model, framework, assess*, evaluat*, *metric*, measur*, criteri*, citation*, unconscious bias, rank**) with "*" used as an unlimited truncation to capture variation in search terms. These two searches were combined (using "*and*") and results were downloaded into EndNote, the reference management software.

Study Selection

After removing duplicate references in EndNote,[22] articles were allocated amongst pairs of reviewers (MB-JCL, CP-CB, KL-JH, KC-LAE) for screening against inclusion criteria. Following established procedures,[23, 24] each pair was randomly assigned 5% of their allocation to review concurrently against inclusion criteria, with inter-rater reliability assessed using Cohen's Kappa (κ). The κ statistic was calculated for pairs of researchers, with agreement ranging from moderate to almost perfect (0.4848-0.9039).[25] Following the abstract and title screen, selected articles underwent full text review. Reasons for exclusion were recorded.

Inclusion Criteria

The following inclusion criteria were operationalized: (1) English language, (2) published in the last 10 years (2007-2017), (3) full text for the article was available, and (4) the article discussed an approach to the assessment of an individual researcher's achievements (at the researcher or singular output-level). The research followed the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) framework.[26] Empirical and non-empirical articles were included, because many articles proposing new approaches to assessment, or discussing the limitations of existing ones, are not level one evidence or research-based.

Data Extraction

Data from the included articles were extracted, including: the country of article origin, the characteristics of the models or metrics discussed, the perspective the article presented on the metric or model (positive, negative, indeterminable) including any potential benefits or limitations of the assessment model (and if these were perceived or based on some form of evidence). A custom data extraction sheet was developed in Microsoft Excel, trialed among members of the research team and subsequently refined. This information was synthesized for each model and metric identified through narrative techniques. The publication details and classification of each paper are contained in **Appendix 1**.

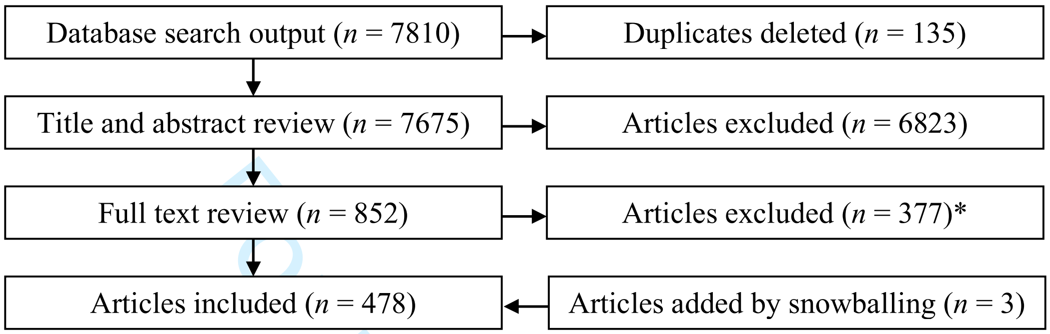
Appraisal of the Literature

Due to the prevalence of non-empirical articles in this field (e.g., editorial contributions, commentaries), it was determined that a risk of bias tool such as the Quality Assessment Tool could not be applied.[27] Rather, assessors were trained in multiple meetings (October 24, October 30, November 13, 2017) to critically assess the quality of articles. Given the nature of the topic (in relation to the publication process) the type of models and metrics identified (i.e., more metrics that use publication metrics) may influence the cumulative evidence and subsequently create a risk of bias. In addition, three researchers (JH, EM, CB) reviewed every included article, to extract documented conflicts of interests of authors.

RESULTS

The final dataset consisted of 478 academic articles. The data screening process is presented in **Figure 1**.

Figure 1. Data screening and extraction process for academic articles



***Reasons for exclusion are noted below**

Reason for exclusion at the full text level	Number of articles excluded
Not in English language	**47**
Full text not available	**62**
Does not discuss assessment of an individual researcher	**268**
Total	**377**

Of the 478 included papers (see **Appendix 1** for a summary), 295 (61.7%) had an empirical component, which ranged from interventional studies that assessed researcher achievement as an outcome measure (e.g., a study measuring the outcomes of a training program),[28] as a predictor[29-31] (e.g., a study that demonstrated the association between number of citations early in one's career and later career productivity), or reported a descriptive analysis of a new metric.[32, 33] One hundred and sixty-six (34.7%) papers were not empirical, including editorial/opinion contributions that discussed the assessment of research achievement, or proposed models for assessing researcher achievement. Seventeen papers (3.6%) were reviews that considered one or more elements of assessing researcher achievements. The quality of these contributions ranged in terms of the risk of bias in the viewpoint expressed. Only for 19 papers (4.0%) did the authors declare a potential conflict of interest.

Across the study period, 78 articles (16.3%) involved authors purporting to propose new models or metrics. Most articles described or cited pre-existing metrics and largely discussed their perceived strengths and limitations. **Figure 2** shows the proportion of positive or negative discussions of five of the most common approaches to assessing an individual's research achievement (altmetrics, peer-review, h-index, simple counts, and JIF). The approach with most support was altmetrics (51.0% of articles mentioning altmetrics). The JIF was discussed with mostly negative sentiments in relevant articles (69.4%).

Figure 2. Percentages of positive and negative discussion regarding selected commonly used metrics for assessing individual researchers (n=478 articles)

[Insert Figure 2 here]

Citation-Based Metrics

Publication and Citation Counts

One hundred and fifty-three papers (32.0%) discussed the use of publication and citation counts for purposes of assessing researcher achievement, with papers describing them as a simple "traditional but somewhat crude measure",[34] as well as the building blocks for other metrics.[35] A researcher's number of publications, commonly termed an n-index,[36] was suggested by some to indicate researcher productivity,[14] rather than quality or influence of these papers.[37] On the other hand, the literature suggested that numbers of citations indicated the influence of an individual publication or at researcher-level, as an author's cumulative number received across their body of work or mean citations per article.[38] Some studies found support for the validity of citation counts and publications in that they were correlated with other indications of a researcher's achievement, such as awards and grant funding,[39, 40] and predictive of long term success in a field.[41] For example, one paper argued that having larger numbers of publications and being highly cited early in one's career predicted later high quality research.[42]

A number of limitations of using citation or publication counts was observed. For example, Minasny et al. (2013) highlighted discrepancies between publications and citations counts in different databases because of their differential structures and inputs.[43] Other authors[38, 44, 45] noted that citation patterns vary by discipline, which they suggested can make them inappropriate for comparing researchers from different fields. Average citations per publication were reported as highly sensitive to change or could be skewed if, for example, a researcher has one heavily-cited article.[46, 47] A further disadvantage is the lag-effect of citations,[48, 49] and that in most models citations and publications count equally for all co-authors, despite potential differential contributions.[50] Some also questioned the extent to which citations actually indicated quality or impact, noting that a paper may influence clinical practice more than academic thinking.[51] Indeed, a paper may be highly cited because it is useful (e.g., a review), controversial, or even by chance, making citations a limited indication of quality or impact.[40, 50, 52] In addition to limitations, numerous authors made the point that focusing on citation and publication counts can have unintended, negative consequences for the assessment of researcher achievement, potentially leading to gaming and manipulation, including self-citations and gratuitous authorship.[53, 54]

Singular Output-Level Approaches

Forty-one papers (8.6%) discussed models and metrics at the singular output or article-level that could be used to infer researcher achievement. The components of achievement they reported assessing were typically quality or impact.[55, 56] For example, some papers reported attempts to examine the quality of a single article by assessing its content.[57, 58] Among the metrics identified in the literature, the immediacy index (II) focused on impact by measuring the average number of cites an article received in the year it was published.[59] Similarly, Finch suggested adapting the Source Normalized Impact per Publication (SNIP; a metric used for journal-level calculations across different fields of research) to an article-level.[21]

Many of the article-level metrics identified could also be upscaled to produce researcher-level indications of achievement. For example, the sCientific currENcy Tokens (CENTs), proposed by Szymanski et al. (2012), involved giving a “cent” for each new non-self-citation a publication received; CENTs are then used as the basis for the researcher-level i-index, which follows a similar approach as the h-index, but removes self-citations.[60] The TAPSIF (Temporally-Averaged Paper-Specific Impact Factor) calculates an article’s average number of citations per year combined with bonus cites for the publishing journal’s prestige, and can be aggregated to measure the overall relevance of a researcher (Temporally Averaged Author-Specific Impact Factor; TAASIF).[61]

Journal impact factor

The JIF, commonly recognized as a journal-level measure of quality,[59, 62-64] was discussed in 211 (44.1%) of the papers reviewed in relation to assessing singular outputs or individual researchers. A number of papers described the JIF being used informally to assess an individual's research achievement at the singular output-level, and formally in countries such as France and China.[65] It implies article quality because it is typically a more competitive process to publish in journals with high impact factors.[66] Indeed, the JIF was found to be the best predictor of a paper's propensity to receive citations.[67]

The JIF has a range of limitations when used to indicate journal quality,[68] including that it is disproportionally affected by highly cited, outlier articles,[41, 69] and is susceptible to "gaming" by editors.[17, 70] Other criticisms focused on using the JIF to assess individual articles or the researchers who author them.[71] Some critics claimed that using the JIF to measure an individual's achievement encourages researchers to publish in higher-impact but less-appropriate journals for their field—which ultimately means their article may not be read by relevant researchers.[72, 73] Furthermore, the popularity of a journal was argued to be a poor indication of the quality of any one article, with the citation distributions for calculating JIF found to be heavily skewed (i.e., a small subset of papers receive the bulk of the citations while some may receive none).[18] Ultimately, many commentators argued that the JIF is an inappropriate metric to assess individual researchers because it is an aggregate metric of a journal's publication, and expresses nothing about any individual paper.[21, 49, 50, 74] However, Bornmann et al. (2017) suggested one case in which it would be appropriate to use JIF for assessing individual researchers: in relation to their recently published papers that had not had the opportunity to accumulate citations.[75]

Researcher-Level Approaches

h-index

The h-index was among the most commonly discussed metrics in the literature (254 [53.1%] of the papers reviewed); in many of these papers, it was described by authors as more sophisticated than citation and publication counts, but still straightforward, logical and intuitive.[76-78] Authors noted its combination of productivity (h publications) and impact indicators (h citations) as being more reliable[79, 80] and stable than average citations per publications[41] because it is not skewed by the influence of one popular article.[81] One study found that the h-index correlated with other metrics more difficult to obtain.[78] It also showed convergent validity with peer-reviewed assessments[82] and was found to be a good predictor of future achievement.[41]

However because of the lag-effect with citations and publications, the h-index increases with a researcher's years of activity in the field, and cannot decrease, even if productivity later declines.[83] Hence, numerous authors suggested it was inappropriate for comparing researchers at different career stages,[84] or those early in their career.[70] The h-index was also noted as being susceptible to many of the critiques leveled against citation counts, including potential for gaming, and inability to reflect differential contributions by co-authors.[85] Because disciplines differ in citation patterns[86] some studies noted variations in author h-indices between different methodologies[87] and within medical subspecialities.[88] Some therefore argued that the h-index should not be used as the sole measure of a researcher's achievement.[88]

h-index variants

A number of modified versions of the h-index were identified; these purported to draw on its basic strengths of balancing productivity with impact while redressing perceived limitations. For example, the g-index measures global citation performance,[89] and was defined similarly to the h-index but with more weight given to highly cited articles by assuming the top g articles have received at least g^2 citations.[90] Azer and Azer (2016) argued it was a more useful measure of researcher productivity.[91] Another variant of the h-index identified, the m-quotient, was suggested to minimize the potential to favor senior academics by accounting for the time passed since a researcher has begun publishing papers.[92, 93] Other h-index variations reported in the articles reviewed attempted to account for author contributions, such as the h-maj index, which includes only articles in which the researcher played a core role (based on author order); and the weighted h-index, which assigns credit points according to author order.[89, 94]

Recurring Issues with Citation-Based Metrics

The literature review results suggested that no one citation-based metric was ideal for all purposes. All of the common metrics examined focused on one aspect of an individual's achievement, and thus failed to account for other aspects of achievement. The limitations with some of the frequently used citation-based metrics are listed in **Box 1**.

1. Challenges with reconciling differences in citation patterns across varying fields of study
2. Time-dependency issues stemming from differences in career length of researchers
3. Prioritizing impact over merit, or quality over quantity, or vice versa
4. The lag-effect of citations
5. Gaming and the ability of self-citation to distort metrics
6. Failure to account for author order
7. Contributions from publications are viewed as equal when they may not be
8. Perpetuate "publish or perish" culture
9. Potential to stifle innovation in favor of what is popular

325 **Box 1. Common limitations in the use of citation-based metrics**

326 **Non-Citation Based Approaches**

327 ***altmetrics***

328 In contradistinction with the metrics discussed above, fifty-four papers (11.3%) discussed
329 altmetrics (or "alternative metrics"), which included a wide range of techniques to measure
330 non-traditional, non-citation based usage of articles.[17] Altmetric measures included the
331 number of online article views,[95] bookmarks,[96] downloads,[41] PageRank
332 algorithms[97] and attention by mainstream news,[65] in books[98] and social media, for
333 example, in blogs, commentaries, online topic reviews or tweets.[99, 100] These metrics
334 typically measure the "web visibility" of an output.[101]

335 A strength of altmetrics lies in providing a measure of impact promptly after
336 publication.[70, 102, 103] Moreover, altmetrics allows tracking of the downloads of multiple
337 sources (e.g., students, the general public, clinicians, as well as academics) and multiple types
338 of format (e.g., reports and policy documents),[104] which are useful in gauging a broader
339 indication of impact or influence, compared to more traditional metrics that solely or largely
340 measure acknowledgement by experts in the field through citations.[17]

341 Disadvantages noted in the articles reviewed included that altmetrics calculations
342 have been established by commercial enterprises such as *Altmetrics LLC (London, UK)* and
343 other competitors,[105] and there may be fees levied for their use. The application of these
344 metrics has also not been standardized.[98] Furthermore, it has been argued that, because
345 altmetrics are cumulative and typically at the article-level, they provide more an indication of
346 impact or even popularity,[106] instead of quality or productivity.[107] Hence, one study

suggested no correlation between attention on Twitter and expert analysis of an article's originality, significance or rigour.[108] Another showed that Tweets predict citations.[109] Overall, further work needs to assess the value of altmetric scores in terms of their association with other traditional indicators of achievement.[110] Notwithstanding this, there were increasing calls to consider altmetrics alongside more conventional metrics in assessing researchers and their work.[111]

Past Funding

A past record of being funded by national agencies was identified as a common measurement of individual academic achievement in a number of papers, and has been argued to be a reliable method that is consistent across medical research.[112-114] For example, the NIH's (National Institute of Health's) RePORT (Research Portfolio Online Reporting Tools) system encourages public accountability for funding by providing online access to reports, data and NIH-funded research projects.[112, 115]

New Metrics and Models identified

The review also identified and assessed new metrics and models that were proposed during the review period, many of which had not gained widespread acceptance or use. While there was considerable heterogeneity and varying degrees of complexity among the 78 new approaches identified, there were also many areas of overlap in their methods and purposes. For example, some papers reported on metrics that used a PageRank algorithm,[116, 117] a form of network analysis based on structural characteristics of publications (e.g., co-authorship or citation patterns).[14] Metrics based on PageRank purported to measure both the direct and indirect impact of a publication or researcher. Other approaches considered the relative contributions of authors to a paper in calculating productivity.[118] Numerous metrics and models that built upon existing approaches were also reported.[119] For example, some developed composite metrics that included a publication's JIF alongside an author contribution measure[120] or other existing metrics.[121] However, each of these approaches reported limitations, in addition to their strengths or improvements upon other methods. For example, in focusing on productivity, a metric necessarily often neglected impact.[122] **Appendix 2** provides a summary of these new or re-fashioned metrics and models, with details of their basis and purpose.

DISCUSSION

This systematic review identified a large number of diverse metrics and models for assessing an individual's research achievement that have been developed in the last 10 years (2007-2017), as evidenced in **Appendix 2.** At the same time, other approaches that pre-dated our study time period were also discussed frequently in the literature reviewed, including the h-index and JIF. All metrics and models proposed had their relative strengths, based on the components of achievement they focused on, and their sophistication or transparency.

Strengths and limitations

The review also identified and assessed new metrics and Over the past few decades, peer-review has been increasingly criticized for reliance on subjectivity and propensity for bias,[7] and there have been arguments that the use of specific metrics may be a more objective and fair approach for assessing individual research achievement. However, this review has highlighted that even seemingly objective measures have a range of shortcomings. For example, there are inadequacies in comparing researchers at different career stages, and across disciplines with different citation patterns.[86] Furthermore, the use of citation-based metrics can lead to gaming and potential ethical misconduct by contributing to a "publish or perish" culture in which researchers are under pressure to maintain or improve their publication records.[123, 124] New methods and adjustments to existing metrics have been proposed to explicitly address some of these limitations; for example, normalizing metrics with "exchange rates" to remove discipline-specific variation in citation patterns, thereby making metric scores more comparable for researchers working in disparate fields.[125, 126] Normalization techniques have also been used to assess researchers' metrics with greater recognition of their relative opportunity and career longevity.[127]

Other criticisms of traditional approaches center less on how they calculated achievement, and more on what they understood or assumed about its constituent elements. In this review, the measurement of impact or knowledge gain was often exclusively tied to citations.[128] Some articles proposed novel approaches to using citations as a measure of impact, such as giving greater weight to citations from papers that were themselves highly cited[129] or that come from outside the field in which the paper was published.[130] However, even other potential means of considering scientific contributions and achievement, such as mentoring, were still ultimately tied to citations because mentoring was measured by the publication output of mentees.[131]

A focus only on citations was widely thought to disadvantage certain types of researchers. For example, researchers who aim to publish with a focus on influencing practice may target “lower-impact”, more specialized or regional journals that are not necessarily highly cited, where their papers will be read by the appropriate audience and findings implemented.[51] In this regard, categorizing the type of journal in which an article has been published, in terms of its focus (e.g., industry, clinical, regional/national), may go some way toward recognizing those publications that have a clear knowledge translation intention.[123] There were only a few other approaches identified that captured broader conceptualizations of knowledge gain, such as practical impact or wealth generation for the economy, and these too were often simplistic, such as including patents and their citations[132] or altmetric data.[98] While altmetrics hold potential in this regard, their use has not been standardized,[98] and they come with their own limitations, with suggestions that they reflect popularity more so than real world impact.[106] Other methodologies have been proposed for assessing knowledge translation, but these can often be labor intensive.[133] For example, Sutherland et al. (2011)[134] suggested that assessing individual research outputs in light of specific policy objectives, through peer-review based scoring, may be a strategy, but this is typically not feasible in situations such as grant funding allocation, where there are time-constraints and large applicant pools to assess.

In terms of how one can make sense of the validity of many of these emerging approaches for assessing an individual’s research achievements, metrics should demonstrate their legitimacy empirically, as well as having a theoretical basis for their use and clearly differentiating what aspects of quality, achievement or impact they purport to examine.[55, 67] If the recent, well-publicized[135-137] San Francisco Declaration on Research Assessment (DORA)[138] is anything to go by, internationally there is a move away from the assessment of individual researchers using the JIF and the journal in which the research has been published.

Figure 3. The Comprehensive Researcher Achievement Model (CRAM)

[Insert Figure 3 Here]

There is momentum, instead, for assessment of researcher achievements on the basis of a wider mix of measures, hence our proposed Comprehensive Researcher Achievement

Model (CRAM) (**Figure 3**). On the left-hand side of this model is the researcher to be assessed, and key characteristics that influence the assessment. Among these factors, some (i.e., field or discipline, co-authorship, career longevity) can be controlled for depending on the metric, while other components, such as gaming or the research topic (i.e., whether it is "trendy" or innovative) are less amenable to control or even prediction. Online databases, which track citations and downloads and measure other forms of impact, hold much potential and will likely be increasingly used in the future to assess both individual researchers and their outputs. Hence, assessment components (past funding, articles, citations, patents, downloads, and some media traction) included in our model are those primarily accessible online.

The findings of this review suggest assessment components should be used with care, and with recognition of how they can be influenced by other factors, and what aspects of achievement they reflect (i.e., productivity, quality, impact, influence). No metric or model singularly captures all aspects of achievement, and hence use of a range, such as the examples in our model, is advisable. Finally, this model recognizes that the configuration and weighting of assessment methods will depend on the assessors and their purpose, the resources available for the assessment process, and access to assessment components. However, these results must be interpreted in light of our focus only on academic literature in the review; this may have led to a more publication concentrated model.

CONCLUSION

There is no ideal model or metric by which to assess individual researcher achievement. We have proposed a generic model, designed to minimize risk of the use of any one or a smaller number of metrics, but it is not proposed as an ultimate solution. The mix of assessment components and metrics will depend on the purpose. Greater transparency in approaches used to assess achievement including their evidence-base is required.[37] Any model used to assess achievement for purposes such as promotion or funding allocation should include some quantitative components, based on robust data, and be able to be rapidly updated, presented with confidence intervals, and normalized.[37] The assessment process should be difficult to manipulate, and explicit about the components of achievement being measured. As such, no current metric suitably fulfills all these criteria. The best strategy to assess an individual's research achievement is likely to involve the use of multiple approaches[139] in order to dilute the influence and potential disadvantages of any one metric, while providing more rounded picture of a researcher's achievement;[85, 140] this is what the CRAM aims to contribute.

All-in-all, achievement in terms of impact and knowledge gain is broader than the number of articles published or their citation rates, and yet most metrics have no means of factoring in these broader issues. Altmetrics hold promise in complementing citation-based metrics and assessing more diverse notions of impact, but usage of this type of tool requires further standardization.[98] Finally, despite the limitations of peer-review, the role of expert judgement should not be discounted.[41] Metrics are perhaps best applied as a complement or check on the peer-review process, rather than the sole means of assessment of an individual's research achievements.[141]

489 **Acknowledgements**

490 None.

491

492 **Competing Interests**

493 The authors have declared that no competing interests exist.

494

495 **Funding**

496 This work was funded by the Australian National Health and Medical Research Council
497 (NHMRC) for work related to an assessment of its peer review processes being conducted by
498 the Council. Staff of the Australian Institute of Health Innovation undertook this systematic
499 review for Council as part of that assessment. Other than specifying what they would like to
500 see from a literature review, NHMRC had no role in the conduct of the systematic review, or
501 the decision to publish.

502

503 **Data sharing statement**

504 All data has been made available as Appendices.

505

506 **Author Contributions**

507 JB conceptualized and drafted the manuscript, revised it critically for important intellectual
508 content, and led the study.

509 JH, KC and JCL made substantial contributions to the design, analysis and revision of the
510 work and critically reviewed the manuscript for important intellectual content.

511 CP, CB, MB, RC-W, FR, PS, AH, LAE, KL, EA, RS and EM carried out the initial
512 investigation, sourced and analyzed the data and revised the manuscript for important
513 intellectual content.

514 PH and JIW critically commented on the manuscript, contributed to the revision and editing
515 of the final manuscript and reviewed the work for important intellectual content.

516 All authors approved the final manuscript as submitted and agree to be accountable for all
517 aspects of the work.

REFERENCES

1. Ibrahim N, Chaibi AH, Ben Ahmed M. New scientometric indicator for the qualitative evaluation of scientific production. *New Libr World*. 2015;116(11-12):661-76.
2. Aixela FJ, Rovira-Esteva S. Publishing and impact criteria, and their bearing on translation studies: in search of comparability. *Perspectives-Studies in Translatology*. 2015;23(2):265-83.
3. Belter CW. Bibliometric indicators: opportunities and limits. *J Med Libr Assoc*. 2015;103(4):219-21.
4. Frixione E, Ruiz-Zamarripa L, Hernandez G. Assessing individual intellectual output in scientific research: Mexico's national system for evaluating scholars performance in the humanities and the behavioral sciences. *PLOS One*. 2016;11(5): doi: 10.1371/journal.pone.0155732.
5. Marzolla M. Assessing evaluation procedures for individual researchers: the case of the Italian national scientific qualification. *J Informetr*. 2016;10(2):408-38.
6. Marsh HW, Jayasinghe UW, Bond NW. Improving the peer-review process for grant applications-reliability, validity, bias, and generalizability. *Am Psychol*. 2008;63(3):160-8.
7. Kaatz A, Magua W, Zimmerman DR, Carnes M. A quantitative linguistic analysis of national institutes of health R01 application critiques from investigators at one institution. *Acad Med*. 2015;90(1):69-75.
8. Aoun SG, Bendok BR, Rahme RJ, Dacey RG, Jr., Batjer HH. Standardizing the evaluation of scientific and academic performance in neurosurgery-critical review of the "h" index and its variants. *World Neurosurg*. 2013;80(5):E85-E90.
9. Hicks D, Wouters P, Waltman L, de Rijcke S, Rafols I. Bibliometrics: the Leiden Manifesto for research metrics. *Nature*. 2015;520(7548):429-31.
10. King J. A review of bibliometric and other science indicators and their role in research evaluation. *J Inf Sci*. 1987;13(5):261-76.
11. Abramo G, Cicero T, D'Angelo CA. A sensitivity analysis of researchers' productivity rankings to the time of citation observation. *J Informetr*. 2012;6(2):192-201.
12. Arimoto A. Declining symptom of academic productivity in the Japanese research university sector. *High Educ*. 2015;70(2):155-72.
13. Carey RM. Quantifying scientific merit is it time to transform the impact factor? *Circ Res*. 2016;119(12):1273-5.

14. Durieux V, Gevenois PA. Bibliometric indicators: quality measurements of scientific publication. *Radiology*. 2010;255(2):342-51.

15. Selvarajoo K. Measuring merit: take the risk. *Science*. 2015;347(6218):139-40.

16. Wildgaard L, Schneider JW, Larsen B. A review of the characteristics of 108 author-level bibliometric indicators. *Scientometrics*. 2014;101(1):125-58.

17. Maximin S, Green D. The science and art of measuring the impact of an article. *Radiographics*. 2014;34(1):116-8.

18. Callaway E. Publishing elite turns against impact factor. *Nature*. 2016;535(7611):210-1.

19. Hirsch JE. An index to quantify an individual's scientific research output. *Proc Natl Acad Sci USA*. 2005;102(46):16569-72.

20. Bollen J, Crandall D, Junk D, Ding Y, Boerner K. An efficient system to fund science: from proposal review to peer-to-peer distributions. *Scientometrics*. 2017;110(1):521-8.

21. Finch A. Can we do better than existing author citation metrics? *Bioessays*. 2010;32(9):744-7.

22. EndNote. Clarivate Analytics; 2017.

23. Schlosser RW. Appraising the quality of systematic reviews. *Focus: Technical Briefs*. 2007;17:1-8.

24. Braithwaite J, Herkes J, Ludlow K, Testa L, Lamprell G. Association between organisational and workplace cultures, and patient outcomes: systematic review. *BMJ Open*. 2017;7(11):e017708.

25. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33(1):159-74.

26. Shamseer L, Moher D, Clarke M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. *BMJ*. 2015;2(349):g7647.

27. Hawker S, Payne S, Kerr C, Hardey M, Powell J. Appraising the evidence: reviewing disparate data systematically. *Qual Health Res*. 2002;12(9):1284-99.

28. Thorngate W, Chowdhury W. By the numbers: track record, flawed reviews, journal space, and the fate of talented authors. In: Kaminski B, Koloch G, editors. Advances in Social Simulation: Proceedings of the 9th Conference of the European Social Simulation Association. Advances in Intelligent Systems and Computing. 229. Heidelberg, Germany: Springer Berlin; 2014. p. 177-88.

29. Sood A, Therattil PJ, Chung S, Lee ES. Impact of subspecialty fellowship training on research productivity among academic plastic surgery faculty in the United States. *Eplasty*. 2015;15:e50.

30. Mutz R, Bornmann L, Daniel H-D. Testing for the fairness and predictive validity of research funding decisions: a multilevel multiple imputation for missing data approach using ex-ante and ex-post peer evaluation data from the Austrian science fund. *J Assoc Inf Sci Technol*. 2015;66(11):2321-39.

31. Rezek I, McDonald RJ, Kallmes DF. Pre-residency publication rate strongly predicts future academic radiology potential. *Acad Radiol*. 2012;19(5):632-4.

32. Knudson D. Kinesiology faculty citations across academic rank. *Quest*. 2015;67(4):346-51.

33. Wang D, Song C, Barabasi A-L. Quantifying long-term scientific impact. *Science*. 2013;342(6154):127-32.

34. Efron N, Brennan NA. Citation analysis of Australia-trained optometrists. *Clin Exp Optom*. 2011;94(6):600-5.

35. Perlin MS, Santos AAP, Imasato T, Borenstein D, Da Silva S. The Brazilian scientific output published in journals: a study based on a large CV database. *J Informetr*. 2017;11(1):18-31.

36. Stallings J, Vance E, Yang J, et al. Determining scientific impact using a collaboration index. *Proc Natl Acad Sci USA*. 2013;110(24):9680-5.

37. Kreiman G, Maunsell JHR. Nine criteria for a measure of scientific output. *Front Comput Neurosci*. 2011;5(48): doi: 10.3389/fncom.2011.00048.

38. Mingers J. Measuring the research contribution of management academics using the Hirsch-index. *J Oper Res Soc*. 2009;60(9):1143-53.

39. Halvorson MA, Finlay AK, Cronkite RC, et al. Ten-year publication trajectories of health services research career development award recipients: collaboration, awardee characteristics, and productivity correlates. *Eval Health Prof*. 2016;39(1):49-64.

40. Stroebe W. The graying of academia: will it reduce scientific productivity? *Am Psychol*. 2010;65(7):660-73.

41. Agarwal A, Durairajanayagam D, Tatagari S, et al. Bibliometrics: tracking research impact by selecting the appropriate metrics. *Asian J Androl*. 2016;18(2):296-309.

42. Jacob JH, Lehrl S, Henkel AW. Early recognition of high quality researchers of the German psychiatry by worldwide accessible bibliometric indicators. *Scientometrics*. 2007;73(2):117-30.

43. Minasny B, Hartemink AE, McBratney A, Jang H-J. Citations and the h-index of soil researchers and journals in the Web of Science, Scopus, and Google Scholar. *Peerj*. 2013;1: doi: 10.7717/peerj.183.

44. Gorraiz J, Gumpenberger C. Going beyond citations: SERUM - a new tool provided by a network of libraries. *Liber Quarterly*. 2010;20(1):80-93.

45. van Eck NJ, Waltman L, van Raan AFJ, Klautz RJM, Peul WC. Citation analysis may severely underestimate the impact of clinical research as compared to basic research. *PLOS One*. 2013;8(4): doi: 10.1371/journal.pone.0062395.

46. Meho LI, Rogers Y. Citation counting, citation ranking, and h-index of human-computer interaction researchers: a comparison of Scopus and Web of Science. *J Assoc Inf Sci Technol*. 2008;59(11):1711-26.

47. Selek S, Saleh A. Use of h index and g index for American academic psychiatry. *Scientometrics*. 2014;99(2):541-8.

48. Kali A. Scientific impact and altmetrics. *Indian J Pharmacol*. 2015;47(5):570-1.

49. Neylon C, Wu S. Article-level metrics and the evolution of scientific impact. *PLOS Biol*. 2009;7(11): doi: 10.1371/journal.pbio.1000242.

50. Sahel J-A. Quality versus quantity: assessing individual research performance. *Sci Transl Med*. 2011;3(84): doi: 10.1126/scitranslmed.3002249.

51. Pinnock D, Whittingham K, Hodgson LJ. Reflecting on sharing scholarship, considering clinical impact and impact factor. *Nurse Educ Today*. 2012;32(7):744-6.

52. Eyre-Walker A, Stoletzki N. The assessment of science: the relative merits of post-publication review, the impact factor, and the number of citations. *PLOS Biol*. 2013;11(10).

53. Ferrer-Sapena A, Sanchez-Perez EA, Peset F, Gonzalez L-M, Aleixandre-Benavent R. The Impact Factor as a measuring tool of the prestige of the journals in research assessment in mathematics. *Res Eval*. 2016;25(3):306-14.

54. Moustafa K. Aberration of the citation. *Account Res*. 2016;23(4):230-44.

55. Abramo G, D'Angelo CA. Refrain from adopting the combination of citation and journal metrics to grade publications, as used in the Italian national research assessment exercise (VQR 2011-2014). *Scientometrics*. 2016;109(3):2053-65.

56. Páll-Gergely B. On the confusion of quality with impact: a note on Pyke's m-index. *BioScience*. 2015;65(2):117.

57. Niederkrotenthaler T, Dorner TE, Maier M. Development of a practical tool to measure the impact of publications on the society based on focus group discussions with scientists. *BMC Public Health*. 2011;11(588): doi: 10.1186/471-2458-11-588.

58. Kreines EM, Kreines MG. Control model for the alignment of the quality assessment of scientific documents based on the analysis of content-related context. *J Comput Syst Sci*. 2016;55(6):938-47.

59. DiBartola SP, Hinchcliff KW. Metrics and the scientific literature: deciding what to read. *J Vet Intern Med*. 2017;31(3):629-32.

60. Szymanski BK, Lluis de la Rosa J, Krishnamoorthy M. An internet measure of the value of citations. *J Inf Sci*. 2012;185(1):18-31.

61. Bloching PA, Heinzl H. Assessing the scientific relevance of a single publication over time. *S Afr J Sci*. 2013;109(9/10): doi: 10.1590/sajs.2013/20130063.

62. Benchimol Barbosa PR. Comments on paper by Thomas et al: how to evaluate "quality of publication". *Arq Bras Cardiol*. 2011;97(1):88-9.

63. Benchimol-Barbosa PR, Ribeiro RL, Barbosa EC. Further comments on the paper by Thomas et al: how to evaluate "quality of publication". *Arq Bras Cardiol*. 2011;97(1):88.

64. Benchimol-Barbosa PR, Ribeiro RL, Barbosa EC. Additional comments on the paper by Thomas et al: how to evaluate "quality of publication". *Arq Bras Cardiol*. 2011;97(1):88-9.

65. Slim K, Dupre A, Le Roy B. Impact factor: an assessment tool for journals or for scientists? *Anaesth Crit Care Pain Med*. 2017;36(6):347-8.

66. Diem A, Wolter SC. The use of bliometrics to measure research performance in education sciences. *Res High Edu*. 2013;54(1):86-114.

67. Bornmann L, Leydesdorff L. Does quality and content matter for citedness? A comparison with para-textual factors and over time. *J Informetr*. 2015;9(3):419-29.

68. Santangelo GM. Article-level assessment of influence and translation in biomedical research. *Mol Biol Cell*. 2017;28(11):1401-8.

69. Ravenscroft J, Liakata M, Clare A, Duma D. Measuring scientific impact beyond academia: an assessment of existing impact metrics and proposed improvements. *PLOS One*. 2017;12(3).

70. Trueger NS, Thoma B, Hsu CH, et al. The altmetric score: a new measure for article-level dissemination and impact. *Ann Emerg Med*. 2015;66(5):549-53.

71. Welk G, Fischman MG, Greenleaf C, et al. Editorial board position statement regarding the declaration on research assessment (DORA) - recommendations rith respect to journal impact factors. *Res Q Exerc Sport*. 2014;85(4):429-30.

72. Taylor DR, Michael LM, II, Klimo P, Jr. Not everything that matters can be measured and not everything that can be measured matters response. *J Neurosurg*. 2015;123(3):544-5.

73. Christopher MM. Weighing the impact (factor) of publishing in veterinary journals. *J Vet Sci*. 2015;17(2):77-82.

74. Jokic M. H-index as a new scientometric indicator. *Biochemia Med*. 2009;19(1):5-9.

75. Bornmann L, Pudovkin AI. The journal impact factor should not be discarded. *J Korean Med Sci*. 2017;32(2):180-2.

76. Franceschini F, Galetto M, Maisano D, Mastrogiacomo L. The success-index: an alternative approach to the h-index for evaluating an individual's research output. *Scientometrics*. 2012;92(3):621-41.

77. Prathap G. Citation indices and dimensional homogeneity. *Curr Sci*. 2017;113(5):853-5.

78. Saad G. Applying the h-index in exploring bibliometric properties of elite marketing scholars. *Scientometrics*. 2010;83(2):423-33.

79. Duffy RD, Jadidian A, Webster GD, Sandell KJ. The research productivity of academic psychologists: assessment, trends, and best practice recommendations. *Scientometrics*. 2011;89(1):207-27.

80. Prathap G. Evaluating journal performance metrics. *Scientometrics*. 2012;92(2):403-8.

81. Lando T, Bertoli-Barsotti L. A new bibliometric index based on the shape of the citation distribution. *PLOS One*. 2014;9(12): doi: 10.1371/journal.pone.0115962.

82. Bornmann L, Wallon G, Ledin A. Is the h index related to (standard) bibliometric measures and to the assessments by peers? An investigation of the h index by using molecular life sciences data. *Res Eval*. 2008;17(2):149-56.

83. Pepe A, Kurtz MJ. A measure of total research impact independent of time and discipline. *PLOS One*. 2012;7(11):e46428.

84. Haslam N, Laham S. Early-career scientific achievement and patterns of authorship: the mixed blessings of publication leadership and collaboration. *Res Eval*. 2009;18(5):405-10.

85. Ioannidis JPA, Klavans R, Boyack KW. Multiple citation indicators and their composite across scientific disciplines. *PLOS Biol*. 2016;14(7): doi: 10.1371/journal.pbio.1002501.

86. van Leeuwen T. Testing the validity of the Hirsch-index for research assessment purposes. *Res Eval*. 2008;17(2):157-60.

87. Ouimet M, Bedard P-O, Gelineau F. Are the h-index and some of its alternatives discriminatory of epistemological beliefs and methodological preferences of faculty members? The case of social scientists in Quebec. *Scientometrics*. 2011;88(1):91-106.

88. Kshettry VR, Benzel EC. Research productivity and fellowship training in neurosurgery. *World Neurosurg*. 2013;80(6):787-8.

89. Biswal AK. An absolute index (Ab-index) to measure a researcher's useful contributions and productivity. *PLOS One*. 2013;8(12): doi: 10.1371/journal.pone.0084334.

90. Tschudy MM, Rowe TL, Dover GJ, Cheng TL. Pediatric academic productivity: pediatric benchmarks for the h- and g-indices. *J Pediatr*. 2016;169:272-6.

91. Azer SA, Azer S. Bibliometric analysis of the top-cited gastroenterology and hepatology articles. *BMJ Open*. 2016;6(2): doi: 10.1136/bmjopen-2015-009889.

92. Joshi MA. Bibliometric indicators for evaluating the quality of scientifc publications. *J Contemp Dent Pract*. 2014;15(2):258-62.

93. Danielson J, McElroy S. Quantifying published scholarly works of experiential education directors. *Am J Pharm Edu*. 2013;77(8):167.

94. Ion D, Andronic O, Bolocan A, Al-Moushaly R, Paduraru DN. Tendencies on traditional metrics. *Chirurgia (Bucur)*. 2017;112(2):117-23.

95. Suiter AM, Moulaison HL. Supporting scholars: an analysis of academic library websites' documentation on metrics and impact. *J Acad Librariansh*. 2015;41(6):814-20.

96. Butler JS, Kaye ID, Sebastian AS, et al. The evolution of current research impact metrics from bibliometrics to altmetrics? *Clin Spine Surg*. 2017;30(5):226-8.

97. Krapivin M, Marchese M, Casati F. Exploring and understanding scientific metrics in citation networks. In: Zhou J, editor. Complex Sciences, Pt 2. Lecture Notes of the Institute for Computer Sciences Social Informatics and Telecommunications Engineering. 52009. p. 1550-63.

98. Carpenter TA. Comparing digital apples to digital apples: background on niso's effort to build an infrastructure for new forms of scholarly assessment. *Inf Serv Use*. 2014;34(1-2):103-6.

99. Gasparyan AY, Nurmashev B, Yessirkepov M, et al. The journal impact factor: moving toward an alternative and combined scientometric approach. *J Korean Med Sci* 2017;32(2):173-9.

100. Moed HF, Halevi G. Multidimensional assessment of scholarly research impact. *J Assoc Inf Sci Technol*. 2015;66(10):1988-2002.

101. Chuang K-Y, Olaiya MT, Ho Y-S. Bibliometric analysis of the Polish Journal of Environmental Studies (2000-11). *Pol J Environ Stud*. 2012;21(5):1175-83.

102. van Noorden R. A profusion of measures. *Nature*. 2010;465(7300):864-6.

103. van Noorden R. Love thy lab neighbour. *Nature*. 2010;468(7327):1011-.

104. Dinsmore A, Allen L, Dolby K. Alternative perspectives on impact: the potential of ALMs and altmetrics to inform funders about research impact. *PLOS Biol*. 2014;12(11):e1002003.

105. Cress PE. Using altmetrics and social media to supplement impact factor: maximizing your article's academic and societal impact. *Aesthet Surg J*. 2014;34(7):1123-6.

106. Moreira JAG, Zeng XHT, Amaral LAN. The distribution of the asymptotic number of citations to sets of publications by a researcher or from an academic department are consistent with a discrete lognormal model. *PLOS One*. 2015;10(11): doi: 10.1371/journal.pone.0143108.

107. Waljee JF. Discussion: are quantitative measures of academic productivity correlated with academic rank in plastic surgery? A national study. *Plast Reconstr Surg*. 2015;136(3):622-3.

108. Fazel S, Wolf A. What is the impact of a research publication? *Evid Based Ment Health*. 2017;20(2):33-4.

109. Eysenbach G. Can tweets predict citations? Metrics of social impact based on Twitter and correlation with traditional metrics of scientific impact. *J Med Internet Res*. 2011;13(4): doi: 10.2196/jmir.012.

110. Hoffmann CP, Lutz C, Meckel M. Impact factor 2.0: applying social network analysis to scientific impact assessment. In: Sprague RH, editor. 2014 47th Hawaii International Conference on System Sciences. Proceedings of the Annual Hawaii International Conference on System Sciences 2014. p. 1576-85.

111. Maggio LA, Meyer HS, Artino AR. Beyond citation rates: a real-time impact analysis of health professions education research using altmetrics. *Acad Med*. 2017;92(10):1449-55.

112. Raj A, Carr PL, Kaplan SE, et al. Longitudinal analysis of gender differences in academic productivity among medical faculty across 24 medical schools in the United States. *Acad Med*. 2016;91(8):1074-9.

113. Markel TA, Valsangkar NP, Bell TM, et al. Endangered academia: preserving the pediatric surgeon scientist. *J Pediatr Surg*. 2017;52(7):1079-83.

114. Mirnezami SR, Beaudry C, Lariviere V. What determines researchers' scientific impact? A case study of Quebec researchers. *Sci Public Policy*. 2016;43(2):262-74.

115. Napolitano LM. Scholarly activity requirements for critical care fellowship program directors: what should it be? How should we measure it? *Crit Care Med*. 2016;44(12):2293-6.

116. Bai X, Xia F, Lee I, Zhang J, Ning Z. Identifying anomalous citations for objective evaluation of scholarly article impact. *PLOS One*. 2016;11(9): doi: 10.1371/journal.pone.0162364.

117. Gao C, Wang Z, Li X, Zhang Z, Zeng W. PR-Index: using the h-Index and PageRank for determining true impact. *PLOS One*. 2016;11(9): doi: 10.1371/journal.pone.0161755.

118. Assimakis N, Adam M. A new author's productivity index: p-index. *Scientometrics*. 2010;85(2):415-27.

119. Petersen AM, Succi S. The Z-index: a geometric representation of productivity and impact which accounts for information in the entire rank-citation profile. *J Informetr*. 2013;7(4):823-32.

120. Claro J, Costa CAV. A made-to-measure indicator for cross-disciplinary bibliometric ranking of researchers performance. *Scientometrics*. 2011;86(1):113-23.

121. Sahoo BK, Singh R, Mishra B, Sankaran K. Research productivity in management schools of India during 1968-2015: a directional benefit-of-doubt model analysis. *Omega Int J Manage S*. 2017;66:118-39.

122. Aragon AM. A measure for the impact of research. *Sci Rep*. 2013;3: doi: 10.1038/srep01649.

123. Shibayama S, Baba Y. Impact-oriented science policies and scientific publication practices: the case of life sciences in Japan. *Res Policy*. 2015;44(4):936-50.

124. Tijdink JK, Schipper K, Bouter LM, et al. How do scientists perceive the current publication culture? A qualitative focus group interview study among Dutch biomedical researchers. *BMJ Open*. 2016;6(2): doi: 10.1136/bmjopen-2015-008681.

125. Crespo JA, Li Y, Ruiz-Castillo J. The measurement of the effect on citation inequality of differences in citation practices across scientific fields. *PLOS One*. 2013;8(3): doi: 10.1371/journal.pone.0058727.

126. da Silva JAT. Does China need to rethink its metrics- and citation-based research rewards policies? *Scientometrics*. 2017;112(3):1853-7.

127. Devos P. Research and bibliometrics: a long history. *Clin Res Hepatol Gastroenterol*. 2011;35(5):336-7.

128. Slyder JB, Stein BR, Sams BS, et al. Citation pattern and lifespan: a comparison of discipline, institution, and individual. *Scientometrics*. 2011;89(3):955-66.

129. Zhou Y-B, Lu L, Li M. Quantifying the influence of scientists and their publications: distinguishing between prestige and popularity. *New J Phys*. 2012;14: doi: 10.1088/367-2630/14/3/033033.

130. Sorensen AA, Weedon D. Productivity and impact of the top 100 cited Parkinson's disease investigators since 1985. *J Parkinsons Dis*. 2011;1(1):3-13.

131. Jeang K-T. H-index, mentoring-index, highly-cited and highly-accessed: how to evaluate scientists? *Retrovirology*. 2008;5(106).

132. Franceschini F, Maisano D. Publication and patent analysis of European researchers in the field of production technology and manufacturing systems. *Scientometrics*. 2012;93(1):89-100.

133. Sibbald SL, MacGregor JCD, Surmacz M, Wathen CN. Into the gray: a modified approach to citation analysis to better understand research impact. *J Med Libr Assoc*. 2015;103(1):49-54.

134. Sutherland WJ, Goulson D, Potts SG, Dicks LV. Quantifying the impact and relevance of scientific research. *PLOS One*. 2011;6(11):e27537.

135. Nature Editorial Team. Announcement: Nature journals support the San Francisco Declaration on Research Assessment. *Nature*. 2017;544(7651):394.

136. Pugh EN, Jr., Gordon SE. Embracing the principles of the San Francisco Declaration of Research Assessment: Robert Balaban's editorial. *J Gen Physiol*. 2013;142(3):175.

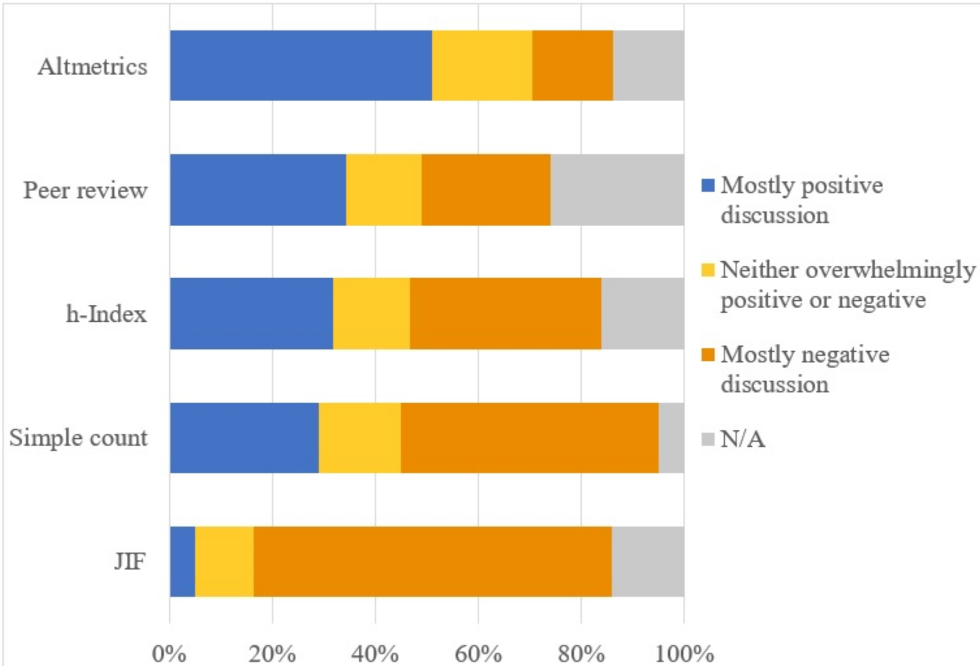
137. Zhang L, Rousseau R, Sivertsen G. Science deserves to be judged by its contents, not by its wrapping: revisiting Seglen's work on journal impact and research evaluation. *PLOS One*. 2017;12(3): doi: 10.1371/journal.pone.0174205.

138. San Francisco Declaration on Research Assessment (DORA). DORA—ASCB. Retrieved from: http://www.ascb.org/dora/

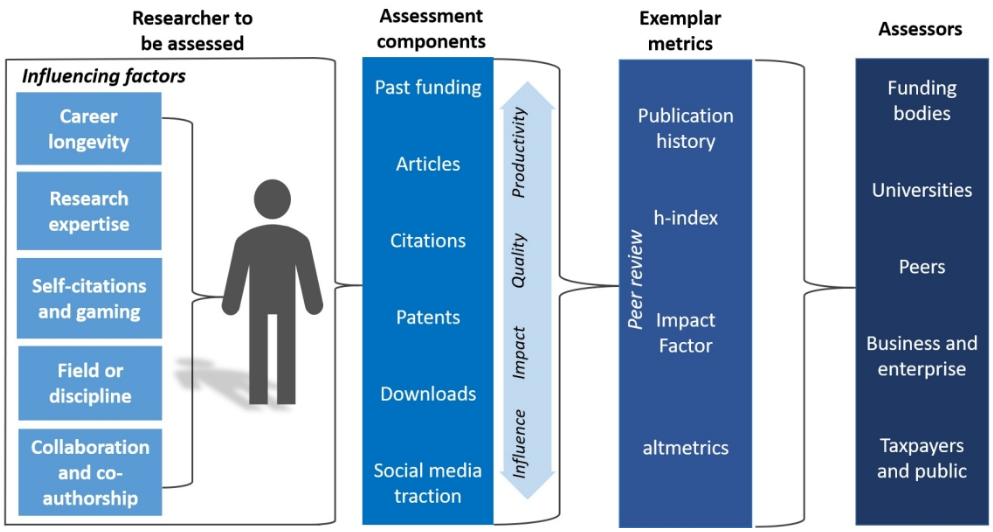
139. Cabezas-Clavijo A, Delgado-Lopez-Cozar E. Google Scholar and the h-index in biomedicine: the popularization of bibliometric assessment. *Med Intensiva*. 2013;37(5):343-54.

140. Iyengar R, Wang Y, Chow J, Charney DS. An integrated approach to evaluate faculty members' research performance. *Acad Med*. 2009;84(11):1610-6.

141. Jacso P. Eigenfactor and article influence scores in the journal citation reports. *Online Inform Rev*. 2010;34(2):339-48.



203x139mm (96 x 96 DPI)



466x248mm (96 x 96 DPI)

Appendix 1: Summary table of included articles and the metrics or models they discuss

Publication Details				Metric or Model Assessing an Individual's Research Achievement						
First author	Year	Journal name	Format^	Peer-review	Simple Counts	h-index	JIF	Other	Alt-metrics	New
Abramo	2016	Scientometrics	ED					Y		
Agarwal	2016	Asian Journal of Andrology	ED		Y	Y	Y	Y	Y	
Ahmad	2013	Anesthesia and Analgesia	EM		Y					
Aixela	2015	Perspectives: Studies in Translatology	ED	Y		Y	Y	Y		
Akl	2012	Canadian Medical Association Journal	EM	Y						
Albion	2012	Australian Educational Researcher	EM			Y	Y	Y		
Alguliyev	2016	Journal of Scientometric Research	EM				Y	Y		
Allen	2010	ScienceAsia	ED			Y	Y			
Anderson	2008	Scientometrics	ED			Y				Y
Anderson	2017	Applied Economics	EM	Y		Y	Y			
Anfossi	2015	International Journal of Dermatology	EM				Y			
Antunes	2015	Revista do Colegio Brasileiro de Cirurgioes	EM	Y		Y				
Aoun	2013	World Neurosurgery	RE	Y		Y	Y			
Aragon	2013	Nature Scientific Reports	EM							Y
Armado	2017	Transinformação	EM			Y		Y		
Assimakis	2010	Scientometrics	EM							Y
Azer	2016	Education Forum				Y	Y	Y		
Babineau	2014	The Western Journal of Emergency Medicine	EM			Y				

Baccini	2014	Scientometrics	EM			Y	Y	Y	
Badar	2016	Aslib Journal of Information Management	EM	Y			Y		
Bai	2016	PLOS One	EM		Y	Y	Y	Y	Y
Bala	2013	Journal of Clinical Epidemiology	EM				Y		
Balaban	2013	Journal of General Physiology	ED	Y					
Balandin	2009	Augmentative and Alternative Communication	ED			Y	Y		
Barczynski	2009	Journal of Human Kinetics	ED				Y	Y	
Bastian	2017	Journal of Bone and Joint Surgery-American Volume	EM			Y			
Baum	2011	SAGE	EM	Y			Y		
Beck	2017	Research Evaluation	EM	Y					
Beirlant	2010	Scandinavian Journal of Statistics	EM			Y			
Belikov	2015	f1000 Research	EM			Y			Y
Bellini	2012	The Lancet	ED		Y	Y	Y		
Belter	2015	Journal of The Medical Library Association	ED	Y		Y			
Benchimol-Barbosa	2011	Arquivos Brasileiros de Cardiologia	ED				Y		
Benway	2009	Urology	ED	Y	Y	Y			
Bertuzzi	2013	Molecular Biology of the Cell	ED				Y		
Bharathi	2013	PLOS One	ED			Y			
Bini	2008	Electronic Transactions on Numerical Analysis	EM						Y
Birks	2014	Health Services Research & Policy	EM	Y		Y			
Biswal	2013	PLOS One	ED			Y		Y	
Bloch	2016	Research Evaluation	EM					Y	

Bloching	2013	South African Journal of Science	EM	Y						Y
Bollen	2016	Scientometrics	ED	Y						Y
Bolli	2014	Circulation Research	ED							
Bornmann	2009	EMBO Reports	ED			Y	Y			
Bornmann	2015	Journal of Informetrics	EM	Y	Y	Y	Y			
Bornmann	2016	EMBO Reports	ED		Y	Y	Y			
Bornmann	2014	Scientometrics	EM		Y	Y				
Bornmann	2008	Research Evaluation	EM	Y	Y	Y	Y	Y		
Bornmann	2017	Journal of Informetrics	EM		Y	Y	Y	Y		
Bornmann	2017	Journal of Korean Medical Science	ED				Y	Y		
Bould	2011	British Journal of Anaesthesia	EM			Y				
Bradshaw	2016	PLOS One	EM		Y	Y	Y	Y		
Brown	2011	American Journal of Occupational Therapy	ED			Y	Y	Y		
Buela-Casal	2012	Scientometrics	EM				Y			
Buela-Casal	2010	Revista de Psicodidáctica	ED		Y	Y	Y	Y	Y	
Butler	2017	Clinical Spine Surgery	ED						Y	
Cabazas Clavijo	2013	Medicina Intensiva (English edition)	RE		Y	Y	Y			
Cagan	2013	Disease Models & Mechanisms	ED				Y			
Callaway	2016	Nature	ED				Y			
Calver	2013	Grumpy Scientists	ED		Y	Y	Y	Y		
Calver	2015	Australian Universities Review	ED					Y		
Caminiti	2015	BMC Health Services Research	RE							Y

Cantin	2015	International Journal of Morphology	EM			Y				
Carpenter	2014	Academic Emergency Medicine	ED			Y	Y	Y	Y	
Carpenter	2014	Information Service and Use	ED				Y		Y	
Castelnuovo	2010	Clinical Practice & Epidemiology in Mental Health	RE			Y	Y		Y	Y
Castillo	2010	American Journal of Neuroradiology	ED			Y		Y		
Chiari	2016	Nurse Education Today	EM	Y						
Choi	2014	Journal of Radiation Oncology	EM	Y		Y		Y		Y
Choi	2009	International Journal of Radiation Oncology, Biology, Physics	EM		Y	Y				
Chopra	2016	Aesthetic Surgery Journal	EM			Y				
Choudhri	2015	Radiographics	ED		Y	Y	Y			
Chowdhury	2015	PLOS One	EM	Y		Y				
Christopher	2015	Journal of Veterinary Cardiology	ED				Y			
Chung	2012	Scientometrics	EM						Y	
Ciriminna	2013	Chemistry Central Journal	ED		Y	Y	Y	Y		
Claro	2011	Scientometrics	EM							
Cleary	2010	International Journal of Mental Health Nursing	ED			Y				
Cone	2013	Academic Emergency Medicine	ED			Y				
Cone	2012	Academic Emergency Medicine	ED				Y			
Cordero-Villafafila	2015	Revista de Psiquiatría y Salud Mental (English Edition)	ED			Y	Y	Y		Y
Costas	2011	Scientometrics	EM		Y			Y		
Costas	2009	Journal of the American Society for Information Science and Technology	EM		Y		Y			

Crespo	2013	PLOS One	EM		Y	Y				Y
Cress	2014	Aesthetic Surgery Journal	ED				Y		Y	
Crotty		European Heart Journal	ED			Y				
Culley	2014	Anesthesia & Analgesia	EM		Y	Y		Y		
Cynical Geographers Collective	2011	Antipode	ED		Y		Y			
Czarnecki	2013	Bulletin of the Polish Academy of Sciences	EM			Y				
da Silva	2017	Scientometrics	ED				Y	Y	Y	
Danell	2011	Journal of the American Society for Information Science and Technology	EM		Y					
Danielson	2013	American Journal of Pharmaceutical Education	EM		Y	Y		Y		
de Granda-Orive	2014	Archivos de Bronconeumología	ED		Y			Y		
De Gregori	2016	Journal of Pain Research	EM						Y	
De la Flor-Martínez M	2017	Medicina Oral Patologia Oral Y Cirugia Bucal	EM	Y		Y				
De Marchi	2016	Scientometrics	EM				Y			
De Witte	2010	Scientometrics	EM	Y						Y
Delgadillo	2016	Family & Consumer Sciences research journal	RE			Y				Y
DeLuca	2013	Academic Emergency Medicine	EM	Y		Y				
Devos	2011	Clinics and Research in Hepatology and Gastroenterology	ED			Y				
Diamandis	2017	BMC Medicine	ED				Y			
DiBartola	2017	Journal of Veterinary Internal Medicine	ED			Y	Y	Y		
Diem	2013	Research in Higher Education	EM				Y			
Ding	2011	Information Processing and Management	EM		Y	Y	Y	Y	Y	

Ding	2011	Journal of the American Society for Information Science and Technology	EM			Y	Y		Y	
Diniz-Filho	2016	Journal of Informetrics	EM	Y	Y		Y			
Dinsmore	2014	PLOS Biology	ED						Y	
Dodson	2012	Biochemical and Biophysical Research Communications	EM	Y		Y	Y			Y
Donato	2014	Revista Portuguesa De Pneumologia	ED				Y			
Doyle	2015	Molecular Psychiatry	EM		Y					
Duffy	2011	Scientometrics	EM		Y	Y		Y		
Duffy	2008	Journal of Counseling Psychology	EM		Y	Y		Y		Y
Durieux	2010	Radiology	RE			Y	Y	Y	Y	
Ebadi	2016	Scientometrics	EM					Y		Y
Eblen	2016	PLOS One	EM	Y						
Efron	2011	Clinical and Experimental Optometry	EM		Y	Y		Y		
Ekpo	2016	Journal of Medical Imaging and Radiation Sciences	EM			Y	Y	Y		Y
El Emam	2012	Journal of Medical Internet Research	EM		Y	Y	Y			
Ellson	2009	Journal of Business Research	ED							
Eloy	2014	Otolaryngology–Head and Neck Surgery	EM	Y		Y	Y	Y		
Eloy	2013	Laryngoscope	EM			Y				
Esposito	2010	European Journal of Oral Implantology.	ED			Y				
Eyre-Walker	2013	PLOS Biology	EM	Y	Y		Y			
Eysenbach	2011	Journal of Medical Internet Research	EM		Y	Y	Y		Y	
Fabry	2017	GMS Journal for Medical Education	ED	Y			Y		Y	

Fang	2016	eLIFE	EM	Y						
Fazel	2017	Evidence-based Mental Health	EM	Y				Y	Y	
Fedderke	2015	Research Policy	EM		Y	Y				
Feethman	2015	Veterinary Record	ED				Y			
Ferrer-Sapena	2016	Research Evaluation	ED		Y		Y	Y	Y	Y
Filler	2014	Academic Medicine	EM					Y		
Finch	2010	Bioessays	ED			Y	Y	Y		
Flaatten	2016	Acta Anaesthesiologica Scandinavica	ED			Y	Y			
Franceschet	2010	Journal of Informetrics	EM				Y	Y		
Franceschini	2012	Scientometrics	EM					Y		Y
Franceschini	2012	Scientometrics	EM			Y	Y	Y		Y
Franceschini	2012	Scientometrics	EM		Y	Y		Y		
Frittelli	2016	Journal of the Association for Information Science and Technology	EM			Y	Y			Y
Frixione	2016	PLOS One	EM	Y					Y	
Fujita	2017	IEEE 41st Annual Computer Software and Applications Conference (COMPSAC)	EM	Y	Y					
Gambadauro	2007	European Journal of Obstetrics & Gynecology and Reproductive Biology	ED				Y			
Gao	2016	PLOS One	ED			Y				Y
Garcia-Perez	2015	Scientometrics	EM		Y			Y		
Garcia-Perez	2009	Spanish Journal of Psychology	EM		Y	Y				
Garner	2017	Journal of Neurointerventional Surgery	RE		Y	Y				

Gasparyan	2017	Journal of Korean Medical Science	ED				Y	Y	Y	
Gast	2014	Plastic and Reconstructive Surgery	EM		Y	Y				
Gast	2014	Plastic & Reconstructive Surgery	EM			Y		Y		
Gaughan	2008	Research Evaluation	EM					Y		
Gefen	2011	Journal of Biomechanics	LE	Y		Y				
Giminez-Toledo	2016	Scientometrics	EM					Y		
Glänzel	2014	Transinformação	ED			Y		Y		
Good	2015	Research Evaluation	ED					Y		
Gorraiz	2010	LIBER Quarterly	ED		Y		Y		Y	
Gracza	2008	Library Collections Acquisitions & Technical Services	ED			Y	Y			
Grisso	2017	Journal of Women's Health	EM	Y						
Grzybowski	2017	Clinics in Dermatology	ED				Y			
Gumpenberger	2016	Scientometrics.	ED	Y		Y	Y		Y	
Haddad	2014	The Bone and Joint Journal	ED				Y			
Haddow	2015	Research Evaluation	EM							
Haeffner-Cavaillon	2009	Archivum Immunologiae et Therapiae Experimentalis	ED	Y		Y	Y	Y		
Halbach	2011	Annals of Anatomy	EM		Y	Y		Y		
Hall	2015	Tourism Management	ED				Y			
Halvorson	2016	Implications for Training in the Health Professions	EM		Y	Y				
Hamidreza	2013	Acta Informatica Medica	EM			Y				
Hammarfelt	2017	Research Evaluation	EM	Y		Y	Y			
Han	2013	ISSI	EM	Y			Y			Y

Han	2010	Journal of Animal and Veterinary Advances	EM			Y	Y			
Haslam	2009	Research Evaluation	EM		Y	Y	Y			
Haslam	2010	European Journal of Social Psychology	EM			Y	Y	Y	Y	
Healy	2011	Breast Cancer Research and Treatment	EM			Y				
Heinzl	2012	AIP Conference Proceedings	ED			Y	Y	Y		
Henrekson	2011	The Manchester School	EM		Y	Y	Y	Y		
Herteliu	2017	Publications	EM			Y				
Hew	2017	Telematics and Informatics	EM		Y	Y	Y			
Hicks	2015	Nature	ED			Y	Y			
Hicks	2015	Nature	ED			Y	Y			
Hoffman	2014	47th Hawaii International Conference on System Sciences	O			Y	Y		Y	
Holliday	2010	International Journal of General Medicine	EM	Y			Y			Y
Houser	2017	Leukos	ED			Y	Y			
Hughes	2015	International Journal of Radiation Oncology Biology Physics NB Conference supplement	EM		Y	Y				
Hunt	2011	Acta Neuropsychiatrica	ED			Y	Y			
Hutchins	2016	PLOS Biology	EM							Y
Hyman	2014	Molecular Biology of the Cell	ED							
Ibrahim	2015	New Library World	EM	Y	Y	Y				Y
Ioannidis	2016	PLOS Biology	EM		Y	Y				Y
Ion	2017	Chirurgia	RE			Y	Y	Y		
Iyendar	2009	Academic Medicine	EM				Y			Y

Jackson	2015	Medical Journal of Australia	ED	Y						
Jackson	2011	PLOS One	EM					Y		
Jacob	2007	Scientometrics	EM		Y		Y			
Jacso	2010	Online Information Review	EM				Y	Y		
Jacso	2008	Online Information Review	ED			Y				
Jalil	2013	IEEE International Conference on Teaching, Assessment and Learning for Engineering (TALE)	EM				Y			
Jamjoom	2015	Neurosciences	EM			Y				
Jamjoom	2016	World Neurosurgery	EM			Y				
Jan	2016	Journal of Scientometric Research	EM			Y		Y		
Javey	2012	American Chemical Society	ED			Y	Y			
Jeang	2008	Retrovirology	ED			Y				Y
Jokic	2009	Biochemia Medica	ED		Y	Y	Y			
Joshi	2014	The Journal of Contemporary Dental Practice	ED			Y		Y		
Joynson	2015	f1000 Research	EM							
Kaatz	2015	Academic Medicine	EM	Y						
Kaatz	2016	Academic Medicine	EM	Y						
Kali	2015	Indian Journal of Pharmacology	ED		Y				Y	
Kalra	2013	Journal of Neurosurgery-Pediatrics	EM			Y		Y		
Kaltman	2014	Circulation Research	EM		Y					
Kapoor	2013	The Annals of Medical and Health Sciences Research	ED				Y			
Kellner	2008	Anais Da Academia Brasileira De Ciencias	EM			Y				

Khan	2013	World Neurology	EM			Y				
Knudson	2015	Quest	EM		Y					
Kosmulski	2012	Research Evaluation	ED		Y		Y			
Krapivin	2009	Complex Sciences	EM		Y	Y			Y	Y
Kreiman	2011	Frontiers in Computational Neuroscience	ED	Y	Y		Y		Y	
Kreines	2016	Journal of Computer and Systems Sciences International	EM							Y
Kshettry	2013	World Neurosurgery	ED			Y		Y		
Kulasagareh	2010	European Archives of Oto-Rhino-Laryngology	EM			Y				
Kulczycki	2017	Journal of Informetrics	ED			Y				
Kumar	2009	Iete Technical Review	ED		Y	Y	Y			
Kuo	2017	Computers in Human Behavior	EM						Y	
Lando	2014	PLOS One	EM		Y	Y				Y
Lariviere	2010	Journal of the American Society for Information Science and Technology	EM				Y			
Lariviere	2016	PLOS One	EM		Y					
Lariviere	2011	Journal of Informetrics	EM					Y		
Lauer	2015	The New England Journal of Medicine	ED	Y						
Law	2013	Asia Pacific Journal of Tourism Research	EM	Y	Y		Y			
Lee	2009	Journal of neurosurgery	EM			Y				
Leff	2009	International Journal of COPD	ED				Y			
Leydesdorff	2016	Scientometrics	ED			Y	Y	Y		
Li	2015	Science	EM	Y						

Li	2016	In: Nah FFH, Tan CH, eds. Hci in Business, Government, and Organizations: Ecommerce and Innovation, Pt I. Vol 97512016:61-71.	EM	Y						
Liang	2015	IEEE International Conference on Smart City/SocialCom/SustainCom	EM							Y
Liao	2011	Decision Support Systems	EM		Y		Y			
Lindner	2015	PLOS One	EM	Y	Y					
Lindner	2016	American Journal of Evaluation	EM	Y						
Lippi	2009	Clinical Chemistry and Laboratory Medicine	ED			Y	Y			
Lippi	2013	Clinica Chimica Acta	EM			Y	Y			
Lippi	2017	Annals of Translational Medicine	EM			Y	Y			Y
Lissoni	2011	Industrial and Corporate Change	EM				Y			
Littman	2017	Medical Education Online	EM		Y	Y	Y			
Liu	2011	Management Information Systems	EM		Y			Y	Y	
Lopez	2015	Journal of Surgical Education	EM	Y		Y				
Lopez	2015	Journal of Hand Surgery America	EM		Y	Y				
Lortie	2013	Scientometrics	EM		Y		Y			
Lovegrove	2008	BioScience	EM	Y		Y		Y		
Lozano	2017	Current Science	ED		Y	Y		Y		
MacMasters	2017	Academic Psychiatry	EM		Y	Y				
Maggio	2017	Academic Medicine	EM			Y			Y	
Mali	2017	Science & Public Policy	EM							
Markel	2017	Journal of Pediatric Surgery	EM		Y	Y		Y		

Markpin	2008	Scientometrics	EM				Y			Y
Marsh	2008	American Psychologist	EM	Y						
Marshall	2017	Otolaryngology—Head and Neck Surgery	EM				Y			
Marzolla	2016	Journal of Informetrics	EM	Y		Y		Y		
Mas-Bleder	2013	Scientometrics	EM		Y			Y		
Matsas	2012	Brazilian Journal of Physics	EM							Y
Maunder	2007	La Revue Canadienne de Psychiatrie	EM				Y	Y		Y
Maximin	2014	RadioGraphics	ED	Y	Y		Y		Y	
Mazloumian	2011	PLOS One	EM							Y
Mazmanian	2014	Evaluation & the Health Professions	RE					Y		
McAlister	2011	American Heart Association Journals	ED		Y		Y			
McGovern	2013	Academic Medicine	EM	Y	Y			Y		
Medo	2016	Physical Review	EM			Y		Y		
Meho	2008	Journal of the American Society for Information Science and Technology	EM		Y	Y				
Mester	2016	Interdisciplinary Description of Complex Systems	ED		Y	Y	Y			
Metcalf	2010	Radiologic Technology	EM							
Milone	2016	American Journal of Orthopedics	EM	Y		Y				Y
Minasny	2013	PeerJ	EM		Y	Y				
Mingers	2015	European Journal of Operational Research	ED		Y	Y		Y		
Mingers	2009	Journal of the Operational Research Society	EM		Y	Y				
Mingers	2017	Scientometrics	EM		Y					

Mirnezami	2016	Science and Public Policy	EM		Y			Y		
Misteli	2013	The Journal of Cell Biology	ED				Y			
Moed	2015	Journal of the Association for Information Science and Technology	RE						Y	
Moed	2009	Archivum Immunologiae et Therapia Experimentalis	ED			Y	Y	Y		
Mooij	2014	Scientometrics	EM					Y		Y
Moppett	2011	British Journal of Anaesthesia	EM	Y	Y	Y		Y	Y	
Moreira	2015	PLOS One	EM			Y	Y		Y	Y
Morel	2009	PLOS Neglected Tropic Diseases	EM			Y				Y
Moustafa	2016	Accountability in Research-Policies and Quality Assurance	ED		Y					
Murphy	2011	Irish Journal of Medical Science	EM		Y		Y			
Murphy	2017	Nature	ED					Y		
Mutz	2015	Journal of the Association for Information Science and Technology	EM	Y						
Mutz	2012	Zeitschrift fur Psychologie	EM	Y						
Nah	2009	Journal of The American Society for Information Science and Technology	EM				Y	Y		
Napolitano	2016	Critical Care Medicine	ED		Y			Y		
Nature Editorial Office	2013	Nature Letters	ED		Y		Y			
Nature Editorial Office	2017	Nature	ED				Y			
Neufeld	2011	Research Evaluation	EM	Y		Y				
Neylon	2009	PLOS Biology	ED		Y		Y			

Nicol	2007	Medical Journal of Australia	EM	Y	Y		Y			
Nicolini	2008	Scientometrics	EM				Y	Y		
Niederkrotenthaler	2011	BMC Public Health	EM							Y
Nielsen	2017	Studies in Higher Education	EM				Y	Y		
Nigam	2012	Indian Journal of Dermatology, Venerology and Leprology	ED			Y				
Nightingale	2013	Nurse Education in Practice	EM		Y	Y	Y		Y	
Nosek	2010	Personality and Social Psychology Bulletin	EM			Y				Y
Nykl	2015	Journal of Informetrics	EM	Y		Y	Y			
O'Brien	2012	Oikos	ED							
O'Connor	2010	European Journal of Cancer Care	ED				Y	Y		
Okhovati	2016	Global Journal of Health Science	EM	Y	Y	Y	Y	Y		
Oliveira	2013	Revista Paulista de Pediatria	EM		Y	Y	Y	Y		
Oliveira	2011	Arquivos Brasileiros de Cardiologia	EM		Y	Y	Y			
Oliveira	2013	Scientometrics	EM		Y	Y	Y	Y		
Opthof	2009	Netherlands Heart Journal	EM			Y	Y			
Orduna-Malea	2015	El Profesional de la Información	ED	Y	Y	Y	Y		Y	Y
Osterloh	2015	Evaluation Review	EM	Y	Y		Y			
Ouimet	2011	Scientometrics	EM			Y		Y		
Pagani	2015	Scientometrics	RE		Y		Y			Y
Pagel	2011	British Journal of Anaesthesia	EM			Y				
Pagel	2011	Anaesthesia	EM			Y		Y		
Pagel	2015	Original Investigations in Education	EM		Y	Y		Y		

Paik	2014	Surgical Education	EM			Y				
Pan	2014	Science Reports	EM			Y	Y			Y
Pandit	2011	Anaesthesia	ED		Y	Y		Y		
Patel	2013	Journal of the Royal Society of Medicine	EM	Y	Y	Y	Y	Y		Y
Patel	2011	Journal of the Royal Society of Medicine	RE		Y	Y	Y	Y		
Patrow	2011	Journal of Postgraduate Medicine	ED			Y				
Pepe	2012	PLOS One	EM			Y				Y
Pereyra-Rojas	2017	Frontiers in Psychology	EM	Y		Y		Y		
Perlin	2017	Journal of Informetrics	EM		Y		Y			
Persson	2014	Acta Physiologica	ED						Y	
Peters	2017	Journal of Infometrics	ED				Y			
Petersen	2013	Journal of Informetrics	EM							Y
Petersen	2010	Physical Review	EM							
Pinnock	2012	Nurse Education Today	ED		Y		Y			
Põder	2017	Trames-Journal of the Humanities and Social Sciences	EM			Y				Y
Prabhu	2017	World Neurosurgery	ED			Y	Y	Y	Y	
Prathap	2016	Scientometrics	EM		Y		Y			
Prathap	2012	Scientometrics	EM			Y	Y	Y		
Prathap	2014	Scientometrics	EM			Y				Y
Prathap	2017	Current Science	ED		Y	Y	Y			Y
Pringle	2008	Learned Publishing	ED		Y	Y	Y	Y		
Pshetizky	2009	Journal of the American Board of Family Medicine	EM		Y		Y			

Pugh Jr	2013	Journal of General Physiology	ED				Y			
Pulina	2007	Italian Journal of Animal Science	EM		Y	Y	Y	Y		
Pyke	2015	BioScience	ED							Y
Qi	2016	Scientometrics	EM		Y					
Quigley	2012	Journal of Cancer Education	EM			Y				
Rad	2012	Academic Radiology	EM			Y				
Radicchi	2008	Proceedings of the National Academy of Sciences of the United States of America	EM		Y	Y		Y		Y
Radicchi	2012	Journal of Informetrics	EM		Y			Y		
Raj	2016	Academic Medicine	EM		Y	Y		Y		
Ramasesha	2011	Current Science	ED		Y	Y	Y	Y		
Rana	2013	Journal of Cancer Education	EM		Y	Y				
Ravenscroft	2017	PLOS One	EM			Y	Y	Y	Y	
Rey-Rocha	2015	Scientometrics	EM		Y					
Rezek	2011	Academic Radiology	EM							
Ribas	2015	Proceedings of the 24th International Conference on World Wide Web	O	Y	Y	Y				Y
Ribas	2015	arXiv	ED							Y
Ricker	2009	Interciencia	ED	Y			Y			Y
Rieder	2010	Langenbeck's Archives of Surgery	ED			Y		Y		
Robinson	2011	Journal of School Psychology	ED				Y			
Rodriguez-Navarro	2011	PLOS One	EM							Y
Ronai	2012	Pigment Cell and Melanoma research	ED	Y	Y					

Rons	2009	Research Evaluation	EM							
Rosati	2016	Journal of Cardiac Surgery	EM			Y				
Ruane	2009	Scientometrics	EM		Y	Y				Y
Saad	2010	Scientometrics	EM			Y				
Safdar	2015	Society for Academic Emergency Medicine (SAEM)	EM	Y						
Sahel	2011	Science Translational Medicine	ED		Y	Y	Y			
Sahoo	2017	Omega	EM		Y	Y	Y			Y
Saleem	2011	Internal Archives of Medicine	ED			Y	Y			
Sangam	2008	Current Science	ED			Y	Y			
Santangelo	2017	Molecular Biology of the Cell	ED				Y	Y		
Saraykar	2017	Academic Psychiatry	EM			Y				
Sarli	2016	Missouri Medicine	ED				Y	Y	Y	
Satyanarayana	2008	Indian Journal of Medical Research	ED			Y	Y			
Saxena	2013	Journal of Pharmacology Pharmacotherapeutics	EM			Y	Y	Y		Y
Sebire	2008	Ultrasound in Obstetrics and Gynaecology	ED			Y		Y	Y	
Selek	2014	Scientometrics	EM		Y	Y		Y		
Seo	2017	Management Decision	EM				Y			
Shanta	2013	Journal of Medical Physics	ED		Y	Y	Y			
Shibayama	2015	Research Policy	EM		Y		Y			
Sibbald	2015	Journal of the Medical Library Association	ED							Y
Simons	2008	Science	ED				Y			
Sittig	2015	MEDINFO 2015: eHealth-enabled Health	EM		Y	Y				Y

Slim	2017	Anaesthesia, Critical Care & Pain Medicine	ED			Y	Y		Y	
Slyder	2011	Scientometrics	EM		Y					
Smeyers	2011	Journal of Philosophy of Education	ED		Y		Y			
Smith	2008	Bone & Joint Journal	ED				Y			
Soares de Araujo	2011	Revista Brasileira de Medicina do Esporte	EM			Y	Y	Y		
Sobhy	2016	Embo Reports	ED				Y			
Sobkowicz	2015	Journal of Artificial Societies and Social Simulation	EM	Y						
Solarino	2012	Annals of Geophysics	RE		Y	Y	Y			Y
Sood	2015	Eplasty	EM			Y				
Sorenson	2011	Journal of Parkinson's Disease	EM		Y	Y				Y
Spaan	2009	Medical & Biological Engineering & Computing	ED			Y	Y			
Spearman	2010	Journal of Neurosurgery	EM			Y				
Spreckelsen	2011	BMC Medical Informatics and Decision Making	EM			Y	Y	Y		
Staller	2017	Qualitative Social Work	ED		Y	Y			Y	
Stallings	2013	Proceedings of the National Academy of Sciences of the United States of America	EM		Y	Y				Y
Street	2009	Health Research Policy and System	EM	Y						
Stroebe	2010	American Psychologist	ED		Y			Y		
Stroobants	2013	Nature	ED							
Sturmer	2013	Revista Brasileira De Fisioterapia	EM		Y	Y				
Suiter	2015	The Journal of Academic Librarianship	EM			Y	Y	Y	Y	
Suminski	2012	The Journal of the American Osteopathic Association	EM		Y		Y	Y		

Surla	2017	The Electronic Library	ED		Y		Y			Y
Susarla	2015	Plastic and Reconstructive surgery	EM		Y	Y				
Susarla	2015	Journal of Dental Education	EM	Y		Y				
Sutherland	2011	PLOS One	EM	Y			Y			
Svider	2013	Laryngoscope	EM			Y				
Svider	2014	Ophthalmology	EM	Y		Y				
Svider	2013	Laryngoscope	EM	Y		Y				
Svider	2013	Laryngoscope	EM			Y		Y		
Swanson	2016	Annals of Plastic Surgery	EM			Y				
Szklo	2008	Epidemiology	ED				Y			
Szymanski	2012	Information Sciences	EM			Y	Y	Y		Y
Taborsky	2007	International Journal of Behavioural Biology	ED	Y						
Tan	2016	The Annals of Applied Statistics	EM		Y	Y	Y		Y	Y
Tandon	2015	National Academy Science Letters-India	ED				Y			
Taylor	2015	Poultry Science	ED			Y	Y		Y	
Teixeira	2013	PLOS One	EM			Y				
Tenreiro Machado	2017	Entropy	EM	Y				Y		
Thelwall	2017	Aslib Journal of Information Management	EM						Y	
Therattil	2016	Annals of Plastic Surgery	EM			Y				
Thomaz	2011	Arquivos Brasileiros De Cardiologia	ED			Y	Y	Y		
Thorngate	2014	Advances in Social Simulation	EM	Y						
Tijdink	2016	BMJ Open	EM							

Timothy	2015	Tourism Management	ED				Y			
Torrisi	2014	Scientometrics	EM	Y		Y	Y	Y		
Tricco	2017	PLOS One	RE	Y						
Trueger	2015	Annals of Emergency Medicine	ED			Y	Y		Y	
Tschudy	2016	Journal of Pediatrics	EM			Y		Y		
Tse	2008	Nature	ED			Y	Y			Y
Tuitt	2011	Canadian Journal of Gastroenterology	EM			Y	Y	Y		
Usmani	2011	Sudanese Journal of Paediatrics	ED			Y	Y			
Valsangkar	2016	Surgery	EM		Y	Y		Y		
van Arensbergen	2012	Higher Education Policy	EM	Y						
van den Besselaar	2009	Research Evaluation	EM	Y	Y					
van Eck	2013	PLOS One	EM		Y					
van Leeuwen	2008	Research Evaluation	EM			Y				
van Leeuwen	2012	Research Evaluation	EM	Y						
van Noorden	2010	Nature	ED			Y	Y	Y	Y	
van Wesel	2016	Science and Engineering Ethics	EM							
Vaughan	2017	Scientometrics	EM						Y	
Verma	2015	Proceedings of the National Academy of Sciences of the United States of America	ED	Y			Y			
Vico	2015	Prometheus	EM	Y						
Vieira	2011	Scientometrics	EM							Y
Vinkler	2012	Journal of Informetrics	ED					Y		

Vinyard	2016	Computers in libraries	ED			Y	Y		Y	
von Bartheld	2015	PeerJ	EM			Y	Y	Y		
Wacogne	2016	Archives of Disease in Childhood-Education and Practice Edition	ED			Y	Y	Y	Y	
Wagner	2012	Research Evaluation	ED		Y					Y
Waisbren	2008	Journal of Women's Health	EM							
Walijee	2015	Plastic and Reconstructive Surgery	ED						Y	
Walker	2010	BMC Medical Education	EM		Y		Y	Y		
Wallace	2012	PLOS One	EM	Y	Y					
Walters	2011	Journal of the American Society for Information Science and Technology	EM	Y	Y		Y			
Waltman	2013	In: Gorraiz J, Schiebel E, Gumpenberger C, Horlesberger M, Moed H, eds. 14th International Society of Scientometrics and Informetrics Conference	EM		Y	Y				Y
Waltman	2013	Journal of Informetrics	EM		Y					
Wang	2013	Science	EM			Y	Y	Y		Y
Ward	2012	Anaesthesia	ED							
Watson	2015	Journal of Pediatric Surgery	EM		Y	Y				
Welk	2014	Research Quarterly for Exercise and Sport	ED				Y			
Wieczorek	2016	Financial Environment and Business Development	ED		Y	Y	Y			
Wildgaard	2014	Scientometrics	RE		Y	Y	Y	Y		
Williamson	2008	Family Medicine	EM							Y
Wootton	2013	Health Research Policy and Systems	EM	Y			Y			Y
Würtz	2016	Annals of Epidemiology	RE			Y				

Wykes	2013	Journal of Mental Health	ED			Y	Y			
Yaminfirooz	2015	The Electronic Library	EM			Y				Y
Yang	2013	Journal of Informetrics	EM	Y		Y				Y
Yates	2015	Source Code for Biology and Medicine	EM	Y						
Yu	2016	Computers in Human Behaviour	EM						Y	
Ze	2012	International Conference on Intelligent Computing	EM		Y	Y				
Zhang	2012	Scientometrics	EM							Y
Zhang	2017	PLOS One	EM		Y		Y			
Zhang	2012	Scientometrics	EM		Y	Y		Y		
Zhao	2014	Scientometrics	EM	Y			Y	Y		
Zhou	2012	New Journal of Physics	EM			Y				Y
Zhu	2015	arXiv	EM							Y
Zhuo	2008	Molecular Pain	EM	Y		Y				Y
Zima	2008	Biochemia Medica	ED			Y	Y			
Zou	2016	Scientometrics	EM		Y	Y				Y
Zupetic	2017	Academic Radiology	EM		Y					
Zycxkowski	2010	Scientometrics	ED							Y

^Empirical (EM); Editorial/Opinion (ED); Review (RE); Other (O).

Appendix 2: New models and metrics for assessing an individual researcher's achievement (2007-2017)

First author	Year	Journal name	Level	Metric or Model	Name	Basis	Description
Anderson	2008	Scientometrics	Researcher	Metric	Tapered h-index	h-index	It accounts for the tapered distribution of citations.
Aragon	2013	Nature Scientific Reports	Both	Metric	Scientist impact (Φ)	Author contributions and citation counts	Instead of the total number of citations, the proposed measure Φ (Scientist Impact) aims at discerning the genuine number of people (specifically lead authors) the paper (or first author) has had an impact upon by removing self-citation. In other words, Φ aims at measuring the paper's reach.
Assimakis	2010	Scientometrics	Researcher	Metric	The Golden Productivity Index	Author contribution and publication count	A rank dependent index that measures the productivity of an individual researcher by evaluating the number of papers as well as the rank of co-authorship. It emphasizes the first author's contribution.
Bai	2016	PLOS One	Researcher	Metric	COIRank algorithm	Network analysis	Quantifies scientific impact by reproducing the accumulated COI relationship in the scientific community. COIRank focuses on improving PageRank though setting a weight for PageRank algorithm and promotes the performance in identifying influential articles. It therefore accounts for self-citation and citation by others at the same institution.
Belikov	2015	f1000 Research	Researcher	Metric	L-index	h-index and author contribution	Accounts for co-author contribution by designating citations to each individual author according to their order on a paper. It also considers the age of publications, favoring newer ones. However, if a scientist has made a significant scientific breakthrough and ceases publications, his or her L-index will remain high regardless. It ranges from 0.0-9.9.
Bini	2008	Electronic Transactions on Numerical Analysis	Both	Metric	Information not available	Citation count	Proposes to integrate models for evaluating papers, authors, and journals based on citations, co-authorship and publications. After the one-class model for ranking scientific publications, they introduced the two-class model which ranks papers and authors, and the three-class model for ranking papers, authors, and journals.

Bloching	2013	South African Journal of Science	Article	Metric	TAPSIF-temporally averaged paper-specific impact factor	Citation count and IF	Calculated from a paper's average number of citations per year (including the publication year) combined with bonus cites for the publishing journal's prestige–which is taken as the journal impact factor from the publication year. Annual TAPSIF values of all the papers by an author can be combined to measure the overall scientific relevance of that author (temporally averaged author-specific impact factor TAASIF).
Bollen	2016	Scientometrics	Researcher	Model	Equal Allocation Model	Peer-review	A novel model in which each researcher is allocated funding and is required to donate a proportion of that funding to other researchers--hence uses crowd wisdom to fund scientists.
Caminiti	2015	BMC Health Services Research	Researcher	Metric	Information not available	Citation count	This work in progress suggests a mixture of 12 easily retrievable indicators (bibliometric and citation parameters, as well as "hidden" activities such as teaching, mentoring etc). The weighting system was constructed considering the hypothesized effort for all indicators. The chosen indicators and attributed scores still remain to be validated. Modified from Wooton, Health Res Policy Syst. 2013;11:2; Smith, Br Med J. 2001;323(7312):528–8.; and Mezrich J Am Coll Radiol. 2007;4(7):471–8.
Castelnuovo	2010	Clinical Practice & Epidemiology in Mental Health	Researcher	Metric	Single Researcher Impact Factor	IF	This metric takes into account publications (journal articles, books, oral and poster presentations in scientific meetings); products (e.g., software, CD-ROM, videos, databases); and activities (reported scientific activities such as scientific positions or positions in conferences organization, participation in journal editorial boards, activities on human resources education, and participation in international funding projects). Minimum and maximum values are assigned to each task for national and international impact.
Claro	2011	Scientometrics	Researcher	Metric	The x-index	IF and author contribution	Aims to enable cross-disciplinary comparison and uses indicators of both quality and quantity, taking into account the number of publications a researcher has published, and then calculating a publication score for each. This considers number of authors on the paper and the journal's 5-year impact factor; it is also normalized by the journals in which the author tends to publish (rather than top-down classification of a field). Also uses a co-authorship share coefficient. Therefore, aims to determine relative contribution to a paper and normalize by field. While requiring only modest data extraction and processing efforts, it is not based on individual article citations but that of the journal (JIF), which can have limitations.

Cordero-Villafafila	2015	Revista de Psiquiatría y Salud Mental (English Edition)	Both	Metric	RC Algorithim	IF	The first English-language publication of this metric, it quantitatively evaluates the personal impact factor of the scientific production of isolated researchers. It also an individual form (RCγ) and group form (RCγG), and is able to assess personal impact of individual publications, 2 or a group of them. It also provides a procedure to classify research centers of different types based on the impact (FRCγG) made by their results amongst researchers of the same field. One of the limitations of the RC algorithm is, precisely, its dependence on said bibliographic databases, which have a strong pre-eminence of studies published in English.
Crespo	2015	PLOS One	Other	Metric	Exchange Rate	Citation count	This is an average-based indicator that is used to explore differential citation rates between disciplines by using it as a normalization factor. It is not suitable for assessing individual researchers but provides insight into comparison across disciplines.
De Witte	2010	Scientometrics	Researcher	Metric	RES-score - Research Evaluation Score	Data Envelopment Analysis	Authors present a methodology to aggregate multidimensional research output, using a tailored version of the non-parametric Data Envelopment Analysis model. This they claim is a more accurate representation of a research performance.
Delgadillo	2016	Family & Consumer Sciences Research Journal	Both	Metric	HLA-index	h-index	This index, actually originally published in a book by Harzing (2011), normalizes the h-index to take into account career stage and discipline.
Dodson	2012	Biochemical and Biophysical Research Communications	Researcher	Metric	SP-index	IF	This metric is said to quantify the scientific production of researchers, representing the product of the annual citation number by the accumulated impact factors of the journals in which the papers are published, divided by the annual number of published papers.
Duffy	2008	Journal of Counseling Psychology	Both	Metric	IRPI - Integrated Research Productivity Index	Citation count	This metric statistically combines an individual's author-weighted publications (AWS), average times cited by other publications (MC), and years since first publication (Y) into a comprehensive score, calculated as (AWS x MC)/Y. It thereby accounts for differences in career length.
Ebadi	2016	Scientometrics	Researcher	Model	iSEER	Machine learning	An intelligent machine learning framework for scientific evaluation of researchers (iSEER) considers various "influencing factors of different types" (e.g., funding, collaboration pattern, performance such as quantity and impact of papers, efficiency). It can be used as a complementary tool to overcome limitations in peer-review.

Ekpo	2016	Journal of Medical Imaging and Radiation Sciences	Researcher	Metric	TotalImpact	Author contribution, publication count and citation count	For each of the authors, the total number of publications in peer-reviewed journals (P), total number of citations (C), international collaboration metrics, number of citations per publication (CPP), h-index, and i10-index are extracted (using SciVal). This metric assessed whether authors were leading the research or coauthoring by judging their position in the list of authors for each article. Authors listed as first, second, or last (FSL) were classified as lead researchers, and those listed in-between as coauthors. Each author's total impact was then quantified by: TotalImpact=P×C×FSL.
Franceschini	2012	Scientometrics	Both	Metric	Information not available	Citation counts and h-index	A study specific measurement that includes the number of publications/patents and their citations and also quantifies average number of co-authors relating to publications/patents of one researcher (an indicator of tendency for co-authorship). It also uses the minimum and maximum years: the oldest publication/patent and the year relating to their latest one. This provide an indication of the temporal extension of the publishing or patenting activity of a researcher. They also use the most-cited is publication/patent of a researcher, representing the "jewel in the crown" in terms of impact/diffusion. These metrics are also scalable to teams though, where the h-spectrum is h-values to a group of researchers (including average and medium), and the h-group is the h-index of the union of publications patents associated with publications/patents.
Franceschini	2012	Scientometrics	Researcher	Metric	The Success-Index	Citation counts, NSP-index by Komulski (2011)	This metric is based on Komulski's (2011) NSP (number of successful papers) index, with the exception that for each publication the comparison term is sometimes replaced by a more appropriate indicator of propensity to cite, determined on the basis of a representative sample of publications. While it is more complicated than the original, it is insensitive to differential propensity to cite and therefore suitable for comparisons between authors of different fields.

Frittelli	2016	Journal of the Association for Information Science and Technology	Researcher	Metric	SRM - Scientific Research Measures	h-index and calculus	Proposes a novel class of measures (SRM) based on calculus principles that rank a scientist's research performance by taking into account the whole citation curve of a researcher (their performance curve - number of citations of each publication, in decreasing order of citations). The performance cures can be chosen flexibly (e.g., to reflect seniority, characteristics of a field). They extend this idea by proposing Dual SRMs, which are based on theories of risk-measures. It better distinguishes researchers with the same citation curve.
Gao	2016	PLOS One	Both	Metric	PR-index - PageRank Index	Network analysis and h-index	This metric uses PageRank score calculation combined with h-index calculation to measure author impact. It considers publication and citation quantity but also takes a publication's citation network into consideration. This means the index will rank majority authors higher by applying PageRank based on the publication citation relationship (distinguishing higher quality citations from lower ones).
Han	2013	Institute of Strategic Studies Islamabad	Both	Metric	New Evaluation Index	Network analysis	The new evaluation index takes into account direct and indirect references, direct and indirect citations, and citation network.
Holliday	2010	International Journal of General Medicine	Article	Model	Modified Delphi technique of peer-review	Peer-review	This paper reports using the modified Delphi process to appraise and rank research applications, with experts rating each application's scientific merit, originality, the adequacy of the study design to achieve the research goals, and whether the potential impact of the study would warrant its funding. While its ease of administration, reproducibility, and accessibility makes this a useful adjunct to the traditional processes of grant selection, it does not directly assess individual researcher's but their work.
Hutchins	2016	PLOS Biology	Both	Metric	iCite	Citation count	This is used for individual articles and normalizes their citation score by adding in co-citation metrics.
Ibrahim	2015	New Library World	Both	Metric	Hx	h-index and author contribution	This metric is a hybridization of two indicators based on the individual h-index (weighted by the average number of co-authors for each paper) and h-index contemporary weighted by qualitative factors (conferences and journal in which a researcher participated or published). It accounts for the period of citations and number of authors on a paper, is applicable at all levels and for any discipline of research, takes conferences into consideration, and is thought to reduce unscientific practices such as integration of authors who have not genuinely contributed.

Ioannidis	2016	PLOS Biology	Researcher	Metric	Composite	Citation count, h-index and author contribution	A study-specific composite metric based: on total number of citations in, for example, 2013 (NC), total number of citations received in 2013 to papers for which the researcher is single author (NS), total number of citations received in 2013 to papers for which the author is single or first author (NSF), total number of citations received in 2013 to papers for which the researcher is single, first, or last author (NSFL). Added to these are the h-index and modified h-index. The indicators are standardized (NC, H, Hm, NS, NSF, NSFL), giving each a standardized value from 0 to 1, where 1 is given to the researcher with the highest raw value for the respective indicator. The six standardized indicators are then summed to generate the composite index C. Well-tested and validated using factor analysis, which yielded two factors: bulk impact (NC and H), author order and co-authorship-adjusted impact (Hm, NS, NSF, and NSFL).
Iyendar	2009	Academic Medicine	Researcher	Model	RD - Research Density and Individual Impact Factor	IF	RD measures the ability to obtain grants at a point in time, while IFF reflects the quality of research. The adopted methodology compares the impact factor of an investigator's articles with those of the top journals within their own field. Each investigator identified the top three journals in his or her field. The average impact factor of these three journals was used as the benchmark for that investigator. Each faculty member was then asked to calculate his or her own individual impact factor (IIF) for two consecutive years, using 75% of their benchmark as target. This benchmark was selected after reviewing results of comparisons of investigators' IIFs with their self-defined benchmarks at several multiples (50%, 75%, and 100%). We used 75% of the self-defined benchmark as the target, because it is unlikely for every paper to be published in the best journal in the field, and yet 75% reflects the reasonably high standard of the research quality that MSSM strives for. The data were collated and the IIF of each faculty member was computed as the ratio of his or her impact factor to 75% of his or her self-defined benchmark, expressed as a percentage.
Jeang	2008	Retrovirology	Researcher	Metric	Mentoring Index	h-index	Argues that good mentoring should be a significant consideration of one's contribution to science. It focuses on using the h-index of previous trainees in evaluating established researchers. It is thought this index could encourage the development of long-lasting mentoring relationships.

Krapivin	2009	Complex Sciences	Both	Metric	PaperRank and PR-hirsch	Network analysis and h-index	Based on PageRank, which has been very successful in ranking web pages, essentially considering the reputation of the web page referring to a given page, and the outgoing link density (i.e., pages P linked by pages L where L has few outgoing links are considered more important than pages P cited by pages L where L has many outgoing links). PaperRank (PR) applies page rank to papers by considering papers as web pages and citations as links, and hence trying to consider not only citations when ranking papers, but also taking into account the rank of the citing paper and the density of outgoing citations from the citing paper. The PR-Hirsch is a modification of the H-index based on the same PageRank approach. PR and PR-Hirsch are complementary to citation-based metrics, capable of capturing information present in the whole citation network, namely the "weight" (the reputation or authority) of a citing paper.
Kreines	2016	Journal of Computer and Systems Sciences International	Article	Model	Information not available	Citation count and IF	Proposes a model for assessing quality in the content of individual articles using computational analysis with bibliometric and scientometric data (number of citations and the journal's IF).
Lando	2014	PLOS One	Article	Metric	[illegible]-index	h-index	This index considers the most elite papers and rewards papers of high impact and based on the form of the citation distribution. It is thought to outperform the h-index in terms of accuracy and sensitivity to the form of the citation distribution, while being strongly correlated with other important h-type indices. It rewards the more regular and reliable researchers.
Liang	2015	IEEE International Conference on Smart City/SocialCom/ SustainCom	Both	Model	Temporal tracking model		The temporal research evolution model takes into account individual output, researcher profile and experiences

Lippi	2017	Annals of Translational Medicine	Researcher	Metric	SIF-Scientist Impact Factor	IF	This metric is calculated as all citations of articles published in the two years following the publication year of the articles, divided by the overall number of articles published in that year. For example, the SIF for the year 2017 would be obtained by dividing all citations in the years 2015–2016 to articles published in the year 2014, divided by the overall number of articles published in the year 2014. The total number of recent citations is normalized according to the number of recently published articles, limiting the bias emerging from publishing a large number of scarcely cited articles; and the output measure reliably reflects the recent scientific impact of the scientist, so complementing an overall career indicator, such as the h-index.
Markpin	2008	Scientometrics	Other	Metric	ACIF - Article-Count Impact Factor	IF	This is proposed as a journal-level metric that is calculated as the total number of articles cited in the current year divided by the number of articles published in 1st and 2nd year. Note that is based on the number of articles that were cited, rather than the times cited of the cited articles. However, it could be used for individual researchers.
Matsas	2012	Brazilian Journal of Physics	Both	Metric	NIF - Normalized Impact Factor	IF	Introduces a normalized impact factor that looks at the researchers influence on their scientific community by assessing the degree to which they have been influenced by their community. Looks each of an author's publications, the number of co-authors, references in the article and citations it has received. From the way it is calculated: "in a closed community of identical individuals (i.e., who publish, reference and are cited by each other at the same rate), all members have NIF = 1." Leaders in a field are then those with a NIF greater than or equal to 1 i.e., they influence their peers at least as much as they are influenced by them.
Maunder	2007	La Revue Canadienne de Psychiatrie	Article	Metric	Citation Ratio	Citation count	This metric is designed to overcome systematic differences amongst niche fields by comparing the impact of a particular paper to the average impact of a paper in its journal. A ratio above 1 indicates relatively greater success.
Mazloumian	2011	PLOS One	Article	Metric	Boost Factor	Citation count	This metric calculates when a particular research gains scientific authority, that is, they publish some groundbreaking work that then leads to an upswing in citations of their earlier papers. It is able to model the trend of the "rich get richer", a cascade of citations and is too improve the "signal-to-noise" ratio in citation rates by detecting sudden changes in citations.

Milone	2016	American Journal of Orthopedics	Article	Metric	Information not available	Publication count	A study specific measurement simply calculated by taking the mean of first and last authored publications.
Mooji	2014	Scientometrics	Both	Model	Information not available	Peer-review, altmetrics, citation count	This paper proposes a comprehensive and new framework for assessing research quality assessment which utilizes intrinsic (i.e., the internal quality of a publication) and extrinsic indicators (i.e., citation counts, web-based influence). It uses peer-review ratings for the former and bibliometric and altmetric data at the individual article and author levels for the latter. One limit includes that the assessment of extrinsic factors is still biased in terms of multi-author papers. This framework builds in a quality check on peer-review.
Moreira	2015	PLOS One	Researcher	Metric	μ	Information not available	Suggests accumulated citations from an author's aggregated publications follow an asymptotic number, and then use a lognormal model. Creates μ as a scale of expected citability of a researcher's publication. It is able to be used at all career stages and indicates more of quality over quantity.
Morel	2009	PLOS Neglected Tropic Diseases	Researcher	Metric	Information not available	Network Analysis	Co-citation networks generated using SNA of publications, to identify groups and individuals with high collaboration rates.
Niederkroten thaler	2011	BMC Public Health	Article	Model	Information not available	Information not available	A tool designed to measure the societal impact of research publications. It consists of three quantitative dimensions: (1) the aim of a publication, (2) the efforts of the authors to translate their research results, and, if translation was accomplished, (3) (a) the size of the area where translation was accomplished (regional, national or international), (b) its status (preliminary versus permanent) and (c) the target group of the translation (individuals, subgroup of population, total population).
Nosek	2010	Personality and Social Psychology Bulletin	Researcher	Metric	Ics-Individual researcher career-stage impact	Citation count	Produces career-stage metric of scientific impact based on citation counts. Its development was based on extensive data collection to produce a regression of expected growth of impact over time. It, therefore, reflects the distance from one's expected impact at a given career stage.
Pagani	2015	Scientometrics	Article	Metric	Methodi Ordinatio	IF	Based on IF, number of citations and year of publication in a normalized, weighted mathematical equation. It is a potential way to define scientific relevance.

Pan	2014	Science Reports	Researcher	Metric	Author Impact Factor (AIF)		Defined as the AIF of an author A in year t is the average number of citations given by papers published in year t to papers published by A in a period of Δt years before year t. Uses a time window of years for calculation.
Patel	2013	Journal of the Royal Society of Medicine	Researcher	Model	sRM - statistical Regression Model	Citation count	Used to estimate the number of high visibility (based on citation count) publications of each researcher.
Pepe	2012	PLOS One	Researcher	Metric	TORI - Total Research Impact	Citation count	Includes non-self-citations accrued by the researcher, number of authors on cited paper, and number of bibliographic references to generate the cumulative output of a scholar by summing the impact of every external citation accrued in his/her career. This removes biases associated with citation counts.
Petersen	2013	Journal of Informetrics	Researcher	Metric	Z	h-index	Z is aimed at correcting the h-index's penalty (which in some cases neglects 75% of an author's body of work) by including the total number of citations for their work in the metric.
Põder	2017	Trames-Journal of the Humanities and Social Sciences	Researcher	Metric	(Current or predicted) impact rate of researcher	Citation count	Based on the citations per year squared, this metric provides a means of assessing acceleration/impact and is based on time series data. This is more sensitive to productivity overtime and can go down unlike the h-index.
Prathap	2014	Scientometrics	Researcher	Metric	Z-index	h-index	Purporting to include quality, quantity and consistency, it accounts for the high-end of research performance, while compensating for the skewness of citation-publication distributions.
Radicchi	2008	Proceedings of the National Academy of Sciences of the United States of America	Article	Metric	Relative Indicator - cf	Citation count	The relative indicator is used to deal with the fact that different fields have different citation patterns and allows for comparisons of the success of articles in different fields.
Ribas	2015	Proceedings of the 24th International Conference on World Wide Web	Both	Metric	P-score	Citation count	It associates a reputation with publication venues based on the publication patterns of reference groups, composed by researchers, in a given area of knowledge. Although the choice of reference groups can be made by using available citation data, the P-score metric itself does not depend on citation data. It uses just publication records of researchers and research groups; that is, the papers and the venues where they published in.

Ricker	2009	Interciencia	Researcher	Model	Rule-based peer-review	Peer-review	Computer generated peer-review, which is positive as researchers get peer-review feedback. Can also measure evaluators select certain criteria of interest, important journals of interest based on field.
Ruane	2009	Scientometrics	Both	Metric	h1-index	h-index	A measure of supervision quality, it gives the supervisor h1 index calculated by the h-indexes of their PhD students.
Sahoo	2017	Omega	Researcher	Model	Composite indicator	h-index, IF, citation counts	Calculated based on the relative weight of the six indicators of journal tier, total citations, author h-index, number of papers, impact factor, and journal h-index.
Saxena	2013	Journal of Pharmacology Pharmacotherapeutics	Researcher	Metric	ORPI - Original Research Publication Index	Citation count	Indicates originality, productivity, and visibility, by including total number of original articles, citations, accounting for self-citations, and the total number of citable articles (i.e., including reviews and case reports). Also accounts for author order and career length.
Sibbald	2015	Journal of the Medical Library Association	Both	Model	Modified approach to citation analysis	Citation count	Includes grey literature in the citation analysis search process and involves quantitative and qualitative methods of analysis to gain a better understanding of how a research paper was used. However, this is more expensive and time consuming than traditional metrics.
Sittig	2015	MEDINFO 2015: eHealth-enabled Health	Researcher	Model	The Biomedical Informatics Researchers ranking website	Information not available	This new system was developed to overcome previous scientific productivity ranking strategies. However, it is limited to biomedical informatics.
Sorenson	2011	Journal of Parkinson's Disease	Both	Metric	"Broad impact" citations	Citation count	Citations from those outside the field are used as a measure of broader impact.
Surla	2017	The Electronic Library	Researcher	Metric	Research Impact Factor	IF	Allows a measure of scientific influence of a researcher in their relative scientific area.
Szymanski	2012	Information Sciences	Both	Metric	CENTs - sCientific currENcy Tokens and the I-index	Citation count and h-index	An accumulation of "cents" based on the number of non-self-citations. This is also the premise behind the i-index, whereby papers a ranked according to CENTs rather than just all citations.

Tan	2016	The Annals of Applied Statistics	Article	Model	Information not available	Citation count	Proposes to use two established models in the creation of a third. The proposed model provides a structural understanding of the field variation in citation behavior and a measure of visibility for individual articles adjusted for citation probabilities within/between topics.
Vieira	2011	Scientometrics	Researcher	Metric	hnf-index	h-index	Considers the different cultures of citation of each field and the number of authors per publication, and hence can be used to measure researcher performance.
Wagner	2012	Research Evaluation	Researcher	Metric	I3 - Integrated impact indicator	Citation count	A framework for integrating citations and non-parametric statistics of percentiles, which allow highly cited papers to be weighted more than less-cited ones.
Waltman	2013		Article	Metric	HCP – Highly cited publications index	Citation count	A simple model in which the number of citations of a publication depends not only on the scientific impact of the publication but also on other ‘random’ factors. Does not account for productivity.
Wang	2013	Science	Article	Model	Mechanistic model for citation dynamics	Citation count	Authors demonstrate a predictable course for citations of single articles over time, purporting, therefore, to create more reliable predictive index of individual impact.
Williamson	2008	Family Medicine	Researcher	Metric	Information not available	Too broad to classify	Quantifies activities within three domains: teaching, service and research and scholarly activity. A time intensive- process that is suitable for promotion within institutions, but not grant funding or more macro-scale assessments.
Wootton	2013	Health Research Policy and Systems	Researcher	Metric	R - Simple indicator of researcher output		Formula is R=g+p+s and comprises grant income (g), publications (peer-reviewed and weighted by JIF; p) and numbers of PhD students supervised (no credit for submission after the due date of submission; s).
Yaminfirooz	2015	The Electronic Library	Both	Metric	mh-index	h-index	Use to identify differences in the impact of authors with the same h-index, and differences between the outputs of influential researchers working in a certain field and the ones publishing only a few papers during a year, can track the impact of highly cited papers.
Yang	2013	Journal of Informetrics	Researcher	Metric	A-index - Axiomatic approach	Citation count and author contribution	Allows for evaluation of individual researcher in the team context (i.e., co-authorship networks).

Zhang	2012	Scientometrics	Both	Model	Scientometric age pyramid	Information not available	Accounts for the different ages of academics, different fields, co-authorship patterns and analysis of journals. The pyramid represents the number of publications on one side and number of citations on the other side.
Zhou	2012	New Journal of Physics	Both	Metric	AP Algorithm	Citation count	Considers the prestige of the scientists citing the article but assumes equal contribution of each author to the paper.
Zhu	2015	arXiv	Researcher	Metric	The hip index - Influence-primed h-index	h-index	The hip-index weights citations by how many times a reference is mentioned, which is thought to make it a better indicator of researcher performance.
Zhuo	2008	Omega	Other	Metric	Z factor	IF	Uses both the number of publications and the impact factors of the journals in which they were published.
Zou	2016	Scientometrics	Researcher	Metric	S-ZP index	IF	Metric based on journal impact factor of publications and author order.
Zycxkowski	2010	Scientometrics	Both	Metric	C - Citation matrix	h-index	A scheme based on weighing the citation based on previous scientific achievements and authors citing the paper.

Reporting checklist for systematic review and meta-analysis.

Based on the PRISMA guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

Upload your completed checklist as an extra file when you submit to a journal.

In your methods section, say that you used the PRISMA reporting guidelines, and cite them as:

Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement

		Reporting Item	Page Number
	#1	Identify the report as a systematic review, meta-analysis, or both.	Title page
Structured summary	#2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number	2
Rationale	#3	Describe the rationale for the review in the context of what is already known.	4
Objectives	#4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	4-5
Protocol and	#5	Indicate if a review protocol exists, if and where it	Review protocol

registration		can be accessed (e.g., Web address) and, if available, provide registration information including the registration number.	exists but is unpublished
Eligibility criteria	#6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rational	5-6
Information sources	#7	Describe all information sources in the search (e.g., databases with dates of coverage, contact with study authors to identify additional studies) and date last searched.	4
Search	#8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	4
Study selection	#9	State the process for selecting studies (i.e., for screening, for determining eligibility, for inclusion in the systematic review, and, if applicable, for inclusion in the meta-analysis).	4-6
Data collection process	#10	Describe the method of data extraction from reports (e.g., piloted forms, independently by two reviewers) and any processes for obtaining and confirming data from investigators.	5-6 and Appendix 1
Data items	#11	List and define all variables for which data were sought (e.g., PICOS, funding sources), and any assumptions and simplifications made.	Page 5 and Appendix 1
Risk of bias in individual studies	#12	Describe methods used for assessing risk of bias in individual studies (including specification of whether this was done at the study or outcome level, or both), and how this information is to be used in any data synthesis.	5
Summary measures	#13	State the principal summary measures (e.g., risk ratio, difference in means).	The primary outcome measure was methods to assess research achievement.

Planned methods of analyis	#14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I2) for each meta-analysis.	5-6
Risk of bias across studies	#15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	5
Additional analyses	#16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	7-11
Study selection	#17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	6-7
Study characteristics	#18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citation.	7-11
Risk of bias within studies	#19	Present data on risk of bias of each study and, if available, any outcome-level assessment (see Item 12).	5
Results of individual studies	#20	For all outcomes considered (benefits and harms), present, for each study: (a) simple summary data for each intervention group and (b) effect estimates and confidence intervals, ideally with a forest plot.	7-11
Synthesis of results	#21	Present the main results of the review. If meta-analyses are done, include for each, confidence intervals and measures of consistency.	Not applicable to this review.
Risk of bias across studies	#22	Present results of any assessment of risk of bias across studies (see Item 15).	5
Additional analysis	#23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	Not applicable to this review.
Summary of Evidence	#24	Summarize the main findings, including the strength of evidence for each main outcome; consider their	13-16

		relevance to key groups (e.g., health care providers, users, and policy makers	
Limitations	#25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review level (e.g., incomplete retrieval of identified research, reporting bias).	16
Conclusions	#26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	16-17
Funding	#27	Describe sources of funding or other support (e.g., supply of data) for the systematic review; role of funders for the systematic review.	18

BMJ Open

The Comprehensive Researcher Achievement Model (CRAM): a framework for measuring researcher achievement, impact and influence derived from a systematic literature review of metrics and models

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-025320.R1
Article Type:	Research
Date Submitted by the Author:	18-Nov-2018
Complete List of Authors:	Braithwaite, Jeffrey; Macquarie University, Australian Institute of Health Innovation Herkes, Jessica; Macquarie University, Australian Institute of Health Innovation Churruca, Kate; Macquarie University, Australian Institute of Health Innovation; Macquarie University Long , Janet; Australian Institute of Health Innovation, Centre for Healthcare Resilience and Implementation Science Pomare, Chiara; Macquarie University Faculty of Medicine and Health Sciences, Australian Institute of Health Innovation Boyling, Claire; Macquarie University Faculty of Medicine and Health Sciences, Australian Institute of Health Innovation Bierbaum, Mia; Macquarie University, Australian Institute of Health Innovation Clay-Williams, Robyn; Macquarie University, Australian Institute of Health Innovation Rapport, Frances ; Macquarie University, Australian Institute of Health Innovation Shih, Patti; Macquarie University, Australian Institute of Health Innovation Hogden, Anne; Macquarie University, Australian Institute of Health Innovation Ellis, Louise A.; Macquarie University, Institute of Health Innovation Ludlow, Kristiana; Macquarie University, Australian Institute of Health Innovation Austin, Elizabeth; Macquarie University Faculty of Medicine and Health Sciences, Australian Institute of Health Innovation Seah, Rebecca; Macquarie University Faculty of Medicine and Health Sciences, Australian Institute of Health Innovation McPherson, Elise; Macquarie University, Australian Institute of Health Innovation Hibbert, Peter; Macquarie University Faculty of Medicine and Health Sciences, Faculty of Medicine and Health Sciences; University of South Australia Division of Health Sciences, Westbrook, Johanna; Macquarie University Faculty of Medicine and Health Sciences, Australian Institute of Health Innovation

Primary Subject Heading:	Research methods
Secondary Subject Heading:	Health services research
Keywords:	Researcher assessment, Research metrics, h-index, Journal impact factor, Comprehensive Researcher Achievement Model (CRAM), Citations

SCHOLARONE™
Manuscripts

The Comprehensive Researcher Achievement Model (CRAM): a framework for measuring researcher achievement, impact and influence derived from a systematic literature review of metrics and models

Authors

Professor Jeffrey Braithwaite (JB)*[1], BA, MIR (Hons), MBA, DipLR, PhD, FIML, FCHSM, FFPHRCP (UK), FACSS, Hon FRACMA, FAHMS

Ms Jessica Herkes (JH) [1], BSc (Adv), MRes

Dr Kate Churruca (KC) [1], BA (Hons) Psych, PhD

Dr Janet C Long (JCL) [1], BSc (Hons), MN (Ed), CertOpthNurs, PhD, FISQua

Ms Chiara Pomare (CP) [1], BPsych (Hons), MRes

Ms Claire Boyling (CB) [1], BHSc (Health Promotion)

Ms Mia Bierbaum (MB) [1], BSc (Biomedical), B.Ed, Grad Dip TESOL, MPH

Dr Robyn Clay-Williams (RC-W) [1], BEng, PhD

Professor Frances Rapport (FR) [1], BA (Hons), Cert Ed, FRSA, MPhil, PhD

Dr Patti Shih (PS) [1], BA(Hons), M.Pub.Pol., PhD

Dr Anne Hogden (AH) [1], BA (Hons), B SpPath, PhD, FISQua

Dr Louise A Ellis (LAE) [1], BPsych (Hons), PhD

Ms Kristiana Ludlow (KL) [1], BPsych (Hons), MRes

Dr Elizabeth Austin (EA) [1], BA (Hons) Psych, PhD

Ms Rebecca Seah (RS) [1], BSc Psychology (Hons I) Bcomm

Ms Elise McPherson (EM) [1], BA, BSc(Hons)

Mr Peter Hibbert (PH)[1], B.App.Sc (Physio), Grad.Dip. Comp, Grad.Dip. Econ, FAAQHC

Professor Johanna I Westbrook (JIW) [1], BAppSc, GradDipAppEpid, MHA, PhD

[1]Australian Institute of Health Innovation, Macquarie University, Sydney, Australia

***Corresponding Author**

Level 6, 75 Talavera Rd

Macquarie University, North Ryde

New South Wales, Australia, 2109

e: Jeffrey.braithwaite@mq.edu.au

ABSTRACT

Objectives Effective researcher assessment is key to decisions about funding allocations, promotion and tenure. We aimed to identify what is known about methods for assessing researcher achievements, leading to a new composite assessment model.

Design We systematically reviewed the literature via the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) framework.

Data sources All Web of Science databases (including Core Collection, MEDLINE, and BIOSIS Citation Index) to the end of 2017.

Eligibility criteria (1) English language, (2) published in the last 10 years (2007-2017), (3) full text was available, and (4) the article discussed an approach to the assessment of an individual researcher's achievements.

Data extraction and synthesis Articles were allocated amongst four pairs of reviewers for screening, with each pair was randomly assigned 5% of their allocation to review concurrently against inclusion criteria, with inter-rater reliability assessed using Cohen's Kappa (κ). The κ statistic showed agreement ranged from moderate to almost perfect (0.4848-0.9039). Following screening, selected articles underwent full text review and bias assessed.

Results Four hundred and seventy-eight articles were included in the final review. Established approaches developed prior to our inclusion period (e.g., citations and outputs, h-index, journal impact factor), remained dominant in the literature and in practice. New bibliometric methods and models emerged in the last 10 years including: measures based on PageRank algorithms or "altmetric" data, methods to apply peer judgement, and techniques to assign values to publication quantity and quality. Each assessment method tended to prioritize certain aspects of achievement over others.

Conclusions All metrics and models focus on an element or elements, at the expense of others. A new composite design, the Comprehensive Researcher Achievement Model (CRAM) is presented which supersedes past anachronistic models. The CRAM is modifiable to a range of applications.

Keywords: Researcher assessment; Research metrics; h-index; Journal impact factor; citations; outputs; Comprehensive Researcher Achievement Model (CRAM)

Article Summary

Strengths and limitations of this study

- A large, diverse dataset of over 478 articles, containing many ideas for assessing researcher performance, was analyzed
- Strengths of the review include executing a wide-ranging search strategy, and the consequent high number of included articles for review; the results are limited by the literature itself, e.g., new metrics were not mentioned in the articles, and therefore not captured in the results
- A new model combining multiple factors to assess researcher performance is now available
- Its strengths include combining quantitative and qualitative components in the one model
- The CRAM model, despite being evidence-oriented, is a generic one and now needs to be applied in the field

INTRODUCTION

Judging researchers' achievements and academic impact continues to be an important means of allocating scarce research funds and assessing candidates for promotion or tenure. It has historically been carried out through some form of expert peer judgement, to assess the number and quality of outputs, and in more recent decades, citations to them. This approach requires judgements regarding the weight which should be assigned to the number of publications, their quality, where they were published, and their downstream influence or impact. There are significant questions about the extent to which human judgement based on these criteria is an effective mechanism for making these complex assessments in a consistent and unbiased way.(1-3) Criticisms of peer assessment, even when underpinned by relatively impartial productivity data, include the propensity for bias, inconsistency among reviewers, nepotism, group-think and subjectivity.(4-7)

To compensate for these limitations, approaches have been proposed that rely less on subjective judgement and more on objective indicators.(3, 8-10) Indicators of achievement focus on one or a combination of four aspects: quantity of researcher outputs (*productivity*); value of outputs (*quality*); outcomes of research outputs (*impact*); and relations between publications or authors and the wider world (*influence*).(11-15) Online publishing of journal articles has provided the opportunity to easily track citations and user interactions (e.g., number of article downloads) and thus has provided a new set of indices against which individual researchers, journals and articles can be compared and the relative worth of contributions assessed and valued.(14) These relatively new metrics have been collectively termed *bibliometrics*(16) when based on citations and numbers of publications, or *altmetrics*(17) when calculated by alternative online measures of impact such as number of downloads or social media mentions.(16)

The most established metrics for inferring researcher achievement are the h-index and the Journal Impact Factor (JIF). The JIF measures the average number of citations of an article in the journal over the previous year, and hence is a good indication of journal quality but is increasingly regarded as a primitive measure of quality for individual researchers.(18) The h-index, proposed by Hirsch in 2005,(19) attempts to portray a researcher's productivity and impact in one data point. The h-index is defined as the number (*h*) of articles published by a researcher that have received a citation count of at least *h*. Use of the h-index has become widespread, reflected in its inclusion in author profiles on online databases such as Google Scholar and Scopus.

Also influenced by the advent of online databases, there has been a proliferation of other assessment models and metrics,(16) many of which purport to improve upon existing approaches.(20, 21) These include methods that assess the impact of articles measured by: downloads or online views received; practice change related to specific research; take-up by the scientific community; or mentions in social media.

Against the backdrop of growth in metrics and models for assessing researchers' achievements, there is a lack of guidance on the relative strengths and limitations of these different approaches. Understanding them is of fundamental importance to funding bodies that drive the future of research, tenure and promotion committees, and more broadly for providing insights into how we recognize and value the work of science and scientists, particularly those researching in medicine and healthcare. This review aimed to identify approaches to assessing researchers' achievements published in the academic literature over the last 10 years, considering their relative strengths and limitations and drawing on this to propose a new composite assessment model.

METHOD

Search Strategy

All Web of Science databases (eight in total, including Web of Science Core Collection, MEDLINE, and BIOSIS Citation Index) were searched using terms related to researcher achievement (*researcher excellence, track record, researcher funding, researcher perform*, relative to opportunity, researcher potential, research* career pathway, academic career pathway, funding system, funding body, researcher impact, scientific* productivity, academic productivity, top researcher, researcher ranking, grant application, researcher output, h*index, i*index, impact factor, individual researcher*) and approaches to its assessment (*model, framework, assess*, evaluat*, *metric*, measur*, criteri*, citation*, unconscious bias, rank**) with "*" used as an unlimited truncation to capture variation in search terms, as seen in **Appendix 1**. These two searches were combined (using "*and*") and results were downloaded into EndNote, the reference management software.

Study Selection

After removing duplicate references in EndNote,(22) articles were allocated amongst pairs of reviewers (MB-JCL, CP-CB, KL-JH, KC-LAE) for screening against inclusion criteria. Following established procedures,(23, 24) each pair was randomly assigned 5% of their allocation to review concurrently against inclusion criteria, with inter-rater reliability assessed using Cohen's Kappa (κ). The κ statistic was calculated for pairs of researchers, with agreement ranging from moderate to almost perfect (0.4848-0.9039).(25) Following the abstract and title screen, selected articles underwent full text review. Reasons for exclusion were recorded.

Inclusion Criteria

The following inclusion criteria were operationalized: (1) English language, (2) published in the last 10 years (2007-2017), (3) full text for the article was available, and (4) the article discussed an approach to the assessment of an individual researcher's achievements (at the researcher or singular output-level). The research followed the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) framework.(26) Empirical and non-empirical articles were included, because many articles proposing new approaches to assessment, or discussing the limitations of existing ones, are not level one evidence or research-based.

Data Extraction

Data from the included articles were extracted, including: the country of article origin, the characteristics of the models or metrics discussed, the perspective the article presented on the metric or model (positive, negative, indeterminable) including any potential benefits or limitations of the assessment model (and if these were perceived or based on some form of evidence). A customised data extraction sheet was developed in Microsoft Excel, trialed among members of the research team and subsequently refined. This information was synthesized for each model and metric identified through narrative techniques. The publication details and classification of each paper are contained in **Appendix 2**.

Appraisal of the Literature

Due to the prevalence of non-empirical articles in this field (e.g., editorial contributions, commentaries), it was determined that a risk of bias tool such as the Quality Assessment Tool could not be applied.(27) Rather, assessors were trained in multiple meetings (October 24, October 30, November 13, 2017) to critically assess the quality of articles. Given the topic of the review (focusing on the publication process), the type of models and metrics identified (i.e., more metrics that use publication metrics) may influence the cumulative evidence and subsequently create a risk of bias. In addition, three researchers (JH, EM, CB) reviewed every included article, to extract documented conflicts of interests of authors.

Patient and public involvement

Patients and the public were not involved in this systematic review.

RESULTS

The final dataset consisted of 478 academic articles. The data screening process is presented in **Figure 1**.

Figure 1. Data screening and extraction process for academic articles

<Insert Figure 1>

Of the 478 included papers (see **Appendix 2** for a summary), 295 (61.7%) had an empirical component, which ranged from interventional studies that assessed researcher achievement as an outcome measure (e.g., a study measuring the outcomes of a training program),(28) as a predictor(29-31) (e.g., a study that demonstrated the association between number of citations early in one's career and later career productivity), or reported a descriptive analysis of a new metric.(32, 33) One hundred and sixty-six (34.7%) papers were not empirical, including editorial or opinion contributions that discussed the assessment of research achievement, or proposed models for assessing researcher achievement. Seventeen papers (3.6%) were reviews that considered one or more elements of assessing researcher achievements. The quality of these contributions ranged in terms of the risk of bias in the viewpoint expressed. Only for 19 papers (4.0%) did the authors declare a potential conflict of interest.

Across the study period, 78 articles (16.3%) involved authors purporting to propose new models or metrics. Most articles described or cited pre-existing metrics and largely discussed their perceived strengths and limitations. **Figure 2** shows the proportion of positive or negative discussions of five of the most common approaches to assessing an individual's research achievement (altmetrics, peer-review, h-index, simple counts, and JIF). The approach with most support was altmetrics (51.0% of articles mentioning altmetrics). The JIF was discussed with mostly negative sentiments in relevant articles (69.4%).

Figure 2. Percentages of positive and negative discussion regarding selected commonly used metrics for assessing individual researchers (n=478 articles)

<Insert Figure 2>

Legend: Positive discussion refers to articles that discuss the metric in a favorable light or focus on the strengths of the metric; negative discussion refers to articles that focus on the limitations or shortcomings of the metric.

Citation-Based Metrics

Publication and Citation Counts

One hundred and fifty-three papers (32.0%) discussed the use of publication and citation counts for purposes of assessing researcher achievement, with papers describing them as a simple “traditional but somewhat crude measure”,(34) as well as the building blocks for other metrics.(35) A researcher’s number of publications, commonly termed an n-index,(36) was suggested by some to indicate researcher productivity,(14) rather than quality, impact or influence of these papers.(37) On the other hand, the literature suggested that numbers of citations indicated the academic impact of an individual publication or researcher’s body of work, calculated as an author’s cumulative or mean citations per article.(38) Some studies found support for the validity of citation counts and publications in that they were correlated with other indications of a researcher’s achievement, such as awards and grant funding,(39, 40) and predictive of long term success in a field.(41) For example, one paper argued that having larger numbers of publications and being highly cited early in one’s career predicted later high quality research.(42)

A number of limitations of using citation or publication counts was observed. For example, Minasny et al. (2013) highlighted discrepancies between publications and citations counts in different databases because of their differential structures and inputs.(43) Other authors(38, 44, 45) noted that citation patterns vary by discipline, which they suggested can make them inappropriate for comparing researchers from different fields. Average citations per publication were reported as highly sensitive to change or could be skewed if, for example, a researcher has one heavily-cited article.(46, 47) A further disadvantage is the lag-effect of citations,(48, 49) and that in most models citations and publications count equally for all co-authors, despite potential differential contributions.(50) Some also questioned the extent to which citations actually indicated quality or impact, noting that a paper may influence clinical practice more than academic thinking.(51) Indeed, a paper may be highly cited because it is useful (e.g., a review), controversial, or even by chance, making citations a limited indication of quality or impact.(40, 50, 52) In addition to limitations, numerous authors made the point that focusing on citation and publication counts can have unintended, negative consequences for the assessment of researcher achievement, potentially leading to gaming and manipulation, including self-citations and gratuitous authorship.(53, 54)

Singular Output-Level Approaches

Forty-one papers (8.6%) discussed models and metrics at the singular output or article-level that could be used to infer researcher achievement. The components of achievement they reported assessing were typically quality or impact.(55, 56) For example, some papers reported attempts to examine the quality of a single article by assessing its content.(57, 58) Among the metrics identified in the literature, the immediacy index (II) focused on impact by measuring the average number of cites an article received in the year it was published.[59] Similarly, Finch suggested adapting the Source Normalized Impact per Publication (SNIP; a metric used for journal-level calculations across different fields of research) to the article-level.(21)

Many of the article-level metrics identified could also be upscaled to produce researcher-level indications of academic impact. For example, the sCientific currENcy Tokens (CENTs), proposed by Szymanski et al. (2012), involved giving a "cent" for each new non-self-citation a publication received; CENTs are then used as the basis for the researcher-level i-index, which follows a similar approach as the h-index, but removes self-citations.[60] The TAPSIF (Temporally-Averaged Paper-Specific Impact Factor) calculates an article's average number of citations per year combined with bonus cites for the publishing journal's prestige, and can be aggregated to measure the overall relevance of a researcher (Temporally Averaged Author-Specific Impact Factor; TAASIF).(61)

Journal impact factor

The JIF, commonly recognized as a journal-level measure of quality,(59, 62-64) was discussed in 211 (44.1%) of the papers reviewed in relation to assessing singular outputs or individual researchers. A number of papers described the JIF being used informally to assess an individual's research achievement at the singular output-level, and formally in countries such as France and China.(65) It implies article quality because it is typically a more competitive process to publish in journals with high impact factors.(66) Indeed, the JIF was found to be the best predictor of a paper's propensity to receive citations.(67)

The JIF has a range of limitations when used to indicate journal quality,(68) including that it is disproportionally affected by highly cited, outlier articles,(41, 69) and is susceptible to "gaming" by editors.(17, 70) Other criticisms focused on using the JIF to assess individual articles or the researchers who author them.(71) Some critics claimed that using the JIF to measure an individual's achievement encourages researchers to publish in higher-impact but less-appropriate journals for their field—which ultimately means their article may not be read by relevant researchers.(72, 73) Furthermore, the popularity of a journal was argued to be a poor indication of the quality of any one article, with the citation distributions for calculating JIF found to be heavily skewed (i.e., a small subset of papers receive the bulk of the citations while some may receive none).(18) Ultimately, many commentators argued that the JIF is an inappropriate metric to assess individual researchers because it is an aggregate metric of a journal's publication, and expresses nothing about any individual paper.(21, 49, 50, 74) However, Bornmann et al. (2017) suggested one case in which it would be appropriate to use JIF for assessing individual researchers: in relation to their recently published papers that had not had the opportunity to accumulate citations.(75)

Researcher-Level Approaches

h-index

The h-index was among the most commonly discussed metrics in the literature (254 [53.1%] of the papers reviewed); in many of these papers, it was described by authors as more sophisticated than citation and publication counts, but still straightforward, logical and intuitive.(76-78) Authors noted its combination of productivity (h publications) and impact indicators (h citations) as being more reliable(79, 80) and stable than average citations per publications(41) because it is not skewed by the influence of one popular article.(81) One study found that the h-index correlated with other metrics more difficult to obtain.(78) It also showed convergent validity with peer-reviewed assessments(82) and was found to be a good predictor of future achievement.(41)

However because of the lag-effect with citations and publications, the h-index increases with a researcher's years of activity in the field, and cannot decrease, even if productivity later declines.(83) Hence, numerous authors suggested it was inappropriate for comparing researchers at different career stages,(84) or those early in their career.(70) The h-index was also noted as being susceptible to many of the critiques leveled against citation counts, including potential for gaming, and inability to reflect differential contributions by co-authors.(85) Because disciplines differ in citation patterns(86) some studies noted variations in author h-indices between different methodologies(87) and within medical subspecialties.(88) Some therefore argued that the h-index should not be used as the sole measure of a researcher's achievement.(88)

h-index variants

A number of modified versions of the h-index were identified; these purported to draw on its basic strengths of balancing productivity with impact while redressing perceived limitations. For example, the g-index measures global citation performance,(89) and was defined similarly to the h-index but with more weight given to highly cited articles by assuming the top g articles have received at least g^2 citations.(90) Azer and Azer (2016) argued it was a more useful measure of researcher productivity.(91) Another variant of the h-index identified, the m-quotient, was suggested to minimize the potential to favor senior academics by accounting for the time passed since a researcher has begun publishing papers.(92, 93) Other h-index variations reported in the articles reviewed attempted to account for author contributions, such as the h-maj index, which includes only articles in which the researcher played a core role (based on author order); and the weighted h-index, which assigns credit points according to author order.(89, 94)

Recurring Issues with Citation-Based Metrics

The literature review results suggested that no one citation-based metric was ideal for all purposes. All of the common metrics examined focused on one aspect of an individual's achievement, and thus failed to account for other aspects of achievement. The limitations with some of the frequently used citation-based metrics are listed in **Box 1**.

Box 1. Common limitations in the use of citation-based metrics

1. Challenges with reconciling differences in citation patterns across varying fields of study
2. Time-dependency issues stemming from differences in career length of researchers
3. Prioritizing impact over merit, or quality over quantity, or vice versa
4. The lag-effect of citations
5. Gaming and the ability of self-citation to distort metrics
6. Failure to account for author order
7. Contributions from authors to a publication are viewed as equal when they may not be
8. Perpetuate "publish or perish" culture
9. Potential to stifle innovation in favor of what is popular

Non-Citation Based Approaches

altmetrics

In contradistinction with the metrics discussed above, fifty-four papers (11.3%) discussed altmetrics (or "alternative metrics"), which included a wide range of techniques to measure non-traditional, non-citation based usage of articles, that is, influence.(17) Altmetric measures included the number of online article views,(95) bookmarks,(96) downloads,(41) PageRank algorithms(97) and attention by mainstream news,(65) in books(98) and social media, for example, in blogs, commentaries, online topic reviews or tweets.(99, 100) These metrics typically measure the "web visibility" of an output.(101) A notable example is the social networking site for researchers and scientists, ResearchGate, which uses an algorithm to score researchers based on the use of their outputs, including citations, reads, and recommendations.(102)

A strength of altmetrics lies in providing a measure of influence promptly after publication.(70, 103, 104) Moreover, altmetrics allows tracking of the downloads of multiple sources (e.g., students, the general public, clinicians, as well as academics) and multiple types of format (e.g., reports and policy documents),(105) which are useful in gauging a broader indication of impact or influence, compared to more traditional metrics that solely or largely measure acknowledgement by experts in the field through citations.(17)

Disadvantages noted in the articles reviewed included that altmetrics calculations have been established by commercial enterprises such as *Altmetrics LLC (London, UK)* and other competitors,(106) and there may be fees levied for their use. The application of these metrics has also not been standardized.(98) Furthermore, it has been argued that, because altmetrics are cumulative and typically at the article-level, they provide more an indication of influence or even popularity,(107) instead of quality or productivity.(108) Hence, one study suggested no correlation between attention on Twitter and expert analysis of an article's originality, significance or rigour.(109) Another showed that Tweets predict citations.(110) Overall, further work needs to assess the value of altmetric scores in terms of their association with other traditional indicators of achievement.(111) Notwithstanding this, there were increasing calls to consider altmetrics alongside more conventional metrics in assessing researchers and their work.(112)

Past Funding

A past record of being funded by national agencies was identified as a common measurement of individual academic achievement (particularly productivity, quality and impact) in a number of papers, and has been argued to be a reliable method that is consistent across medical research.(113-115) For example, the NIH's (National Institute of Health's) RePORT (Research Portfolio Online Reporting Tools) system encourages public accountability for funding by providing online access to reports, data and NIH-funded research projects.(113, 116)

New Metrics and Models Identified

The review also identified and assessed new metrics and models that were proposed during the review period, many of which had not gained widespread acceptance or use. While there was considerable heterogeneity and varying degrees of complexity among the 78 new approaches identified, there were also many areas of overlap in their methods and purposes. For example, some papers reported on metrics that used a PageRank algorithm,(117, 118) a form of network analysis based on structural characteristics of publications (e.g., co-authorship or citation patterns).(14) Metrics based on PageRank purported to measure both the direct and indirect impact of a publication or researcher. Other approaches considered the relative contributions of authors to a paper in calculating productivity.(119) Numerous metrics and models that built upon existing approaches were also reported.(120) For example, some developed composite metrics that included a publication's JIF alongside an author contribution measure(121) or other existing metrics.(122) However, each of these approaches reported limitations, in addition to their strengths or improvements upon other methods. For example, in focusing on productivity, a metric necessarily often neglected impact.(123) **Appendix 3** provides a summary of these new or re-fashioned metrics and models, with details of their basis and purpose.

DISCUSSION

This systematic review identified a large number of diverse metrics and models for assessing an individual's research achievement that have been developed in the last 10 years (2007-2017), as evidenced in **Appendix 3.** At the same time, other approaches that pre-dated our study time period of 2007-2017 were also discussed frequently in the literature reviewed, including the h-index and JIF. All metrics and models proposed had their relative strengths, based on the components of achievement they focused on, and their sophistication or transparency.

The review also identified and assessed new metrics and over the past few decades. Peer-review has been increasingly criticized for reliance on subjectivity and propensity for bias,(7) and there have been arguments that the use of specific metrics may be a more objective and fair approach for assessing individual research achievement. However, this review has highlighted that even seemingly objective measures have a range of shortcomings. For example, there are inadequacies in comparing researchers at different career stages, and across disciplines with different citation patterns.(86) Furthermore, the use of citation-based metrics can lead to gaming and potential ethical misconduct by contributing to a "publish or perish" culture in which researchers are under pressure to maintain or improve their publication records.(124, 125) New methods and adjustments to existing metrics have been proposed to explicitly address some of these limitations; for example, normalizing metrics with "exchange rates" to remove discipline-specific variation in citation patterns, thereby making metric scores more comparable for researchers working in disparate fields.(126, 127) Normalization techniques have also been used to assess researchers' metrics with greater recognition of their relative opportunity and career longevity.(128)

Other criticisms of traditional approaches center less on how they calculated achievement, and more on what they understood or assumed about its constituent elements. In this review, the measurement of impact or knowledge gain was often exclusively tied to citations.(129) Some articles proposed novel approaches to using citations as a measure of impact, such as giving greater weight to citations from papers that were themselves highly cited(130) or that come from outside the field in which the paper was published.(131) However, even other potential means of considering scientific contributions and achievement, such as mentoring, were still ultimately tied to citations because mentoring was measured by the publication output of mentees.(132)

A focus only on citations was widely thought to disadvantage certain types of researchers. For example, researchers who aim to publish with a focus on influencing practice may target more specialized or regional journals that do not have high JIFs, where their papers will be read by the appropriate audience and findings implemented, but they may not be well-cited.(51) In this regard, categorizing the type of journal in which an article has been published in terms of its focus (e.g., industry, clinical, regional/national) may go some way toward recognizing those publications that have a clear knowledge translation intention, and therefore prioritize real-world impact over academic impact.(124) There were only a few other approaches identified that captured broader conceptualizations of knowledge gain, such as practical impact or wealth generation for the economy, and these too were often simplistic, such as including patents and their citations(133) or altmetric data.(98) While altmetrics hold potential in this regard, their use has not been standardized,(98) and they come with their own limitations, with suggestions that they reflect popularity more so than real world impact.(107) Other methodologies have been proposed for assessing knowledge translation and real-world impact, but these can often be labor intensive.(134) For example, Sutherland et al. (2011)(135) suggested that assessing individual research outputs in light of specific policy objectives, through peer-review based scoring, may be a strategy, but this is typically not feasible in situations such as grant funding allocation, where there are time-constraints and large applicant pools to assess.

In terms of how one can make sense of the validity of many of these emerging approaches for assessing an individual's research achievements, metrics should demonstrate their legitimacy empirically, as well as having a theoretical basis for their use and clearly differentiating what aspects of quality, achievement or impact they purport to examine.(55, 67) If the recent, well-publicized(136-138) San Francisco Declaration on Research Assessment (DORA)(139) is anything to go by, internationally there is a move away from the assessment of individual researchers using the JIF and the journal in which the research has been published.

Figure 3. The Comprehensive Researcher Achievement Model (CRAM)

<Insert Figure 3>

There is momentum, instead, for assessment of researcher achievements on the basis of a wider mix of measures, hence our proposed Comprehensive Researcher Achievement Model (CRAM) (**Figure 3**). On the left-hand side of this model is the researcher to be assessed, and key characteristics that influence the assessment. Among these factors, some (i.e., field or discipline, co-authorship, career longevity) can be controlled for depending on the metric, while other components, such as gaming or the research topic (i.e., whether it is "trendy" or innovative) are less amenable to control or even prediction. Online databases, which track citations and downloads and measure other forms of impact, hold much potential and will likely be increasingly used in the future to assess both individual researchers and their outputs. Hence, assessment components (past funding, articles, citations, patents, downloads, and some media traction) included in our model are those primarily accessible online.

Strengths and Limitations

The findings of this review suggest assessment components should be used with care, and with recognition of how they can be influenced by other factors, and what aspects of achievement they reflect (i.e., productivity, quality, impact, influence). No metric or model singularly captures all aspects of achievement, and hence use of a range, such as the examples in our model, is advisable. CRAM recognizes that the configuration and weighting of assessment methods will depend on the assessors and their purpose, the resources available for the assessment process, and access to assessment components. Our results must be interpreted in light of our focus on academic literature. The limits of our focus on peer-reviewed literature were evident in the fact some new metrics were not mentioned in articles, and therefore not captured in our results. While we defined impact broadly at the outset, overwhelmingly the literature we reviewed focused on academic, citation-based impact. Furthermore, although we assessed bias in the ways documented, the study design limited our ability to apply a standardized quality assessment tool.

CONCLUSION

There is no ideal model or metric by which to assess individual researcher achievement. We have proposed a generic model, designed to minimize risk of the use of any one or a smaller number of metrics, but it is not proposed as an ultimate solution. The mix of assessment components and metrics will depend on the purpose. Greater transparency in approaches used to assess achievement including their evidence-base is required.(37) Any model used to assess achievement for purposes such as promotion or funding allocation should include some quantitative components, based on robust data, and be able to be rapidly updated, presented with confidence intervals, and normalized.(37) The assessment process should be difficult to manipulate, and explicit about the components of achievement being measured. As such, no current metric suitably fulfills all these criteria. The best strategy to assess an individual's research achievement is likely to involve the use of multiple approaches(140) in order to dilute the influence and potential disadvantages of any one metric, while providing more rounded picture of a researcher's achievement;(85, 141) this is what the CRAM aims to contribute.

All-in-all, achievement in terms of impact and knowledge gain is broader than the number of articles published or their citation rates, and yet most metrics have no means of factoring in these broader issues. Altmetrics hold promise in complementing citation-based metrics and assessing more diverse notions of impact, but usage of this type of tool requires further standardization.(98) Finally, despite the limitations of peer-review, the role of expert judgement should not be discounted.(41) Metrics are perhaps best applied as a complement or check on the peer-review process, rather than the sole means of assessment of an individual's research achievements.(142)

Acknowledgements

None.

Competing Interests

The authors have declared that no competing interests exist.

Funding

The work on which this paper is based was funded by the Australian National Health and Medical Research Council (NHMRC) for work related to an assessment of its peer review processes being conducted by the Council. Staff of the Australian Institute of Health Innovation undertook this systematic review for Council as part of that assessment. Other than specifying what they would like to see from a literature review, NHMRC had no role in the conduct of the systematic review, or the decision to publish.

Data sharing statement

All data has been made available as Appendices.

Author Contributions

JB conceptualized and drafted the manuscript, revised it critically for important intellectual content, and led the study. JH, KC and JCL made substantial contributions to the design, analysis and revision of the work and critically reviewed the manuscript for important intellectual content. CP, CB, MB, RC-W, FR, PS, AH, LAE, KL, EA, RS and EM carried out the initial investigation, sourced and analyzed the data and revised the manuscript for important intellectual content. PH and JIW critically commented on the manuscript, contributed to the revision and editing of the final manuscript and reviewed the work for important intellectual content. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

REFERENCES

1. Ibrahim N, Chaibi AH, Ben Ahmed M. New scientometric indicator for the qualitative evaluation of scientific production. *New Libr World*. 2015;116(11-12):661-76. doi:10.1108/nlw-01-2015-0002
2. Aixela FJ, Rovira-Esteva S. Publishing and impact criteria, and their bearing on translation studies: in search of comparability. *Perspectives-Studies in Translatology*. 2015;23(2):265-83. doi:10.1080/0907676x.2014.972419
3. Belter CW. Bibliometric indicators: opportunities and limits. *J Med Libr Assoc*. 2015;103(4):219-21. doi:10.3163/1536-5050.103.4.014
4. Frixione E, Ruiz-Zamarripa L, Hernandez G. Assessing individual intellectual output in scientific research: Mexico's national system for evaluating scholars performance in the humanities and the behavioral sciences. *PLOS One*. 2016;11(5): doi: 10.1371/journal.pone.0155732. doi:10.1371/journal.pone.0155732
5. Marzolla M. Assessing evaluation procedures for individual researchers: the case of the Italian national scientific qualification. *J Informetr*. 2016;10(2):408-38. doi:10.1016/j.joi.2016.01.009
6. Marsh HW, Jayasinghe UW, Bond NW. Improving the peer-review process for grant applications-reliability, validity, bias, and generalizability. *Am Psychol*. 2008;63(3):160-8. doi:10.1037/0003-066x.63.3.160
7. Kaatz A, Magua W, Zimmerman DR, et al. A quantitative linguistic analysis of national institutes of health R01 application critiques from investigators at one institution. *Acad Med*. 2015;90(1):69-75. doi:10.1097/acm.0000000000000442
8. Aoun SG, Bendok BR, Rahme RJ, et al. Standardizing the evaluation of scientific and academic performance in neurosurgery-critical review of the "h" index and its variants. *World Neurosurg*. 2013;80(5):E85-E90. doi:10.1016/j.wneu.2012.01.052
9. Hicks D, Wouters P, Waltman L, et al. Bibliometrics: the Leiden Manifesto for research metrics. *Nature*. 2015;520(7548):429-31. doi:10.1038/520429a
10. King J. A review of bibliometric and other science indicators and their role in research evaluation. *J Inf Sci*. 1987;13(5):261-76. doi:10.1177/016555158701300501
11. Abramo G, Cicero T, D'Angelo CA. A sensitivity analysis of researchers' productivity rankings to the time of citation observation. *J Informetr*. 2012;6(2):192-201. doi:10.1016/j.joi.2011.12.003
12. Arimoto A. Declining symptom of academic productivity in the Japanese research university sector. *High Educ*. 2015;70(2):155-72. doi:10.1007/s10734-014-9848-4
13. Carey RM. Quantifying scientific merit is it time to transform the impact factor? *Circ Res*. 2016;119(12):1273-5. doi:10.1161/circresaha.116.309883
14. Durieux V, Gevenois PA. Bibliometric indicators: quality measurements of scientific publication. *Radiology*. 2010;255(2):342-51. doi:10.1148/radiol.09090626
15. Selvarajoo K. Measuring merit: take the risk. Science. 2015;347(6218):139-40.
16. Wildgaard L, Schneider JW, Larsen B. A review of the characteristics of 108 author-level bibliometric indicators. *Scientometrics*. 2014;101(1):125-58. doi:10.1007/s11192-014-1423-3
17. Maximin S, Green D. The science and art of measuring the impact of an article. *Radiographics*. 2014;34(1):116-8. doi:10.1148/rg.341134008
18. Callaway E. Publishing elite turns against impact factor. *Nature*. 2016;535(7611):210-1.
19. Hirsch JE. An index to quantify an individual's scientific research output. *Proc Natl Acad Sci USA*. 2005;102(46):16569-72.

20. Bollen J, Crandall D, Junk D, et al. An efficient system to fund science: from proposal review to peer-to-peer distributions. *Scientometrics.* 2017;110(1):521-8. doi:10.1007/s11192-016-2110-3
21. Finch A. Can we do better than existing author citation metrics? *Bioessays*. 2010;32(9):744-7. doi:10.1002/bies.201000053
22. EndNote. Clarivate Analytics; 2017.
23. Schlosser RW. Appraising the quality of systematic reviews. *Focus: Technical Briefs*. 2007;17:1-8.
24. Braithwaite J, Herkes J, Ludlow K, et al. Association between organisational and workplace cultures, and patient outcomes: systematic review. *BMJ Open*. 2017;7(11):e017708.
25. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33(1):159-74.
26. Shamseer L, Moher D, Clarke M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. *BMJ.* 2015;2(349):g7647.
27. Hawker S, Payne S, Kerr C, et al. Appraising the evidence: reviewing disparate data systematically. *Qual Health Res*. 2002;12(9):1284-99.
28. Thorngate W, Chowdhury W. By the numbers: track record, flawed reviews, journal space, and the fate of talented authors. In: Kaminski B, Koloch G, editors. Advances in Social Simulation: Proceedings of the 9th Conference of the European Social Simulation Association. Advances in Intelligent Systems and Computing. 229. Heidelberg, Germany: Springer Berlin; 2014. p. 177-88.
29. Sood A, Therattil PJ, Chung S, et al. Impact of subspecialty fellowship training on research productivity among academic plastic surgery faculty in the United States. *Eplasty*. 2015;15:e50.
30. Mutz R, Bornmann L, Daniel H-D. Testing for the fairness and predictive validity of research funding decisions: a multilevel multiple imputation for missing data approach using ex-ante and ex-post peer evaluation data from the Austrian science fund. *J Assoc Inf Sci Technol.* 2015;66(11):2321-39. doi:10.1002/asi.23315
31. Rezek I, McDonald RJ, Kallmes DF. Pre-residency publication rate strongly predicts future academic radiology potential. *Acad Radiol.* 2012;19(5):632-4. doi:10.1016/j.acra.2011.11.017
32. Knudson D. Kinesiology faculty citations across academic rank. *Quest.* 2015;67(4):346-51. doi:10.1080/00336297.2015.1082144
33. Wang D, Song C, Barabasi A-L. Quantifying long-term scientific impact. *Science.* 2013;342(6154):127-32. doi:10.1126/science.1237825
34. Efron N, Brennan NA. Citation analysis of Australia-trained optometrists. *Clin Exp Optom*. 2011;94(6):600-5. doi:10.1111/j.1444-0938.2011.00652.x
35. Perlin MS, Santos AAP, Imasato T, et al. The Brazilian scientific output published in journals: a study based on a large CV database. *J Informetr.* 2017;11(1):18-31. doi:10.1016/j.joi.2016.10.008
36. Stallings J, Vance E, Yang J, et al. Determining scientific impact using a collaboration index. *Proc Natl Acad Sci USA*. 2013;110(24):9680-5. doi:10.1073/pnas.1220184110
37. Kreiman G, Maunsell JHR. Nine criteria for a measure of scientific output. *Front Comput Neurosci.* 2011;5(48): doi: 10.3389/fncom.2011.00048. doi:10.3389/fncom.2011.00048
38. Mingers J. Measuring the research contribution of management academics using the Hirsch-index. *J Oper Res Soc.* 2009;60(9):1143-53. doi:10.1057/jors.2008.94

39. Halvorson MA, Finlay AK, Cronkite RC, et al. Ten-year publication trajectories of health services research career development award recipients: collaboration, awardee characteristics, and productivity correlates. *Eval Health Prof.* 2016;39(1):49-64. doi:10.1177/0163278714542848
40. Stroebe W. The graying of academia: will it reduce scientific productivity? *Am Psychol*. 2010;65(7):660-73. doi:10.1037/a0021086
41. Agarwal A, Durairajanayagam D, Tatagari S, et al. Bibliometrics: tracking research impact by selecting the appropriate metrics. *Asian J Androl*. 2016;18(2):296-309. doi:10.4103/1008-682x.171582
42. Jacob JH, Lehrl S, Henkel AW. Early recognition of high quality researchers of the German psychiatry by worldwide accessible bibliometric indicators. *Scientometrics.* 2007;73(2):117-30. doi:10.1007/s11192-006-1729-x
43. Minasny B, Hartemink AE, McBratney A, et al. Citations and the h-index of soil researchers and journals in the Web of Science, Scopus, and Google Scholar. *Peerj.* 2013;1: doi: 10.7717/peerj.183. doi:10.7717/peerj.183
44. Gorraiz J, Gumpenberger C. Going beyond citations: SERUM - a new tool provided by a network of libraries. *Liber Quarterly.* 2010;20(1):80-93.
45. van Eck NJ, Waltman L, van Raan AFJ, et al. Citation analysis may severely underestimate the impact of clinical research as compared to basic research. *PLOS One*. 2013;8(4): doi: 10.1371/journal.pone.0062395. doi:10.1371/journal.pone.0062395
46. Meho LI, Rogers Y. Citation counting, citation ranking, and h-index of human-computer interaction researchers: a comparison of Scopus and Web of Science. *J Assoc Inf Sci Technol.* 2008;59(11):1711-26. doi:10.1002/asi.20874
47. Selek S, Saleh A. Use of h index and g index for American academic psychiatry. *Scientometrics.* 2014;99(2):541-8. doi:10.1007/s11192-013-1204-4
48. Kali A. Scientific impact and altmetrics. *Indian J Pharmacol.* 2015;47(5):570-1. doi:10.4103/0253-7613.165184
49. Neylon C, Wu S. Article-level metrics and the evolution of scientific impact. *PLOS Biol.* 2009;7(11): doi: 10.1371/journal.pbio.1000242. doi:10.1371/journal.pbio.1000242
50. Sahel J-A. Quality versus quantity: assessing individual research performance. *Sci Transl Med.* 2011;3(84): doi: 10.1126/scitranslmed.3002249. doi:10.1126/scitranslmed.3002249
51. Pinnock D, Whittingham K, Hodgson LJ. Reflecting on sharing scholarship, considering clinical impact and impact factor. *Nurse Educ Today.* 2012;32(7):744-6. doi:10.1016/j.nedt.2012.05.031
52. Eyre-Walker A, Stoletzki N. The assessment of science: the relative merits of post-publication review, the impact factor, and the number of citations. *PLOS Biol.* 2013;11(10). doi:10.1371/journal.pbio.1001675
53. Ferrer-Sapena A, Sanchez-Perez EA, Peset F, et al. The Impact Factor as a measuring tool of the prestige of the journals in research assessment in mathematics. *Res Eval.* 2016;25(3):306-14. doi:10.1093/reseval/rvv041
54. Moustafa K. Aberration of the citation. *Account Res.* 2016;23(4):230-44.
55. Abramo G, D'Angelo CA. Refrain from adopting the combination of citation and journal metrics to grade publications, as used in the Italian national research assessment exercise (VQR 2011-2014). *Scientometrics*. 2016;109(3):2053-65. doi:10.1007/s11192-016-2153-5
56. Páll-Gergely B. On the confusion of quality with impact: a note on Pyke's m-index. *BioScience*. 2015;65(2):117. doi:10.1093/biosci/biu207

57. Niederkrotenthaler T, Dorner TE, Maier M. Development of a practical tool to measure the impact of publications on the society based on focus group discussions with scientists. *BMC Public Health*. 2011;11(588): doi: 10.1186/471-2458-11-588. doi:10.1186/1471-2458-11-588

58. Kreines EM, Kreines MG. Control model for the alignment of the quality assessment of scientific documents based on the analysis of content-related context. *J Comput Syst Sci.* 2016;55(6):938-47. doi:10.1134/s1064230716050099

59. DiBartola SP, Hinchcliff KW. Metrics and the scientific literature: deciding what to read. *J Vet Intern Med*. 2017;31(3):629-32. doi:10.1111/jvim.14732

60. Szymanski BK, Lluis de la Rosa J, Krishnamoorthy M. An internet measure of the value of citations. *J Inf Sci.* 2012;185(1):18-31. doi:10.1016/j.ins.2011.08.005

61. Bloching PA, Heinzl H. Assessing the scientific relevance of a single publication over time. *S Afr J Sci.* 2013;109(9/10): doi: 10.1590/sajs.2013/20130063.

62. Benchimol Barbosa PR. Comments on paper by Thomas et al: how to evaluate "quality of publication". *Arq Bras Cardiol.* 2011;97(1):88-9.

63. Benchimol-Barbosa PR, Ribeiro RL, Barbosa EC. Further comments on the paper by Thomas et al: how to evaluate "quality of publication". *Arq Bras Cardiol.* 2011;97(1):88.

64. Benchimol-Barbosa PR, Ribeiro RL, Barbosa EC. Additional comments on the paper by Thomas et al: how to evaluate "quality of publication". *Arq Bras Cardiol.* 2011;97(1):88-9.

65. Slim K, Dupre A, Le Roy B. Impact factor: an assessment tool for journals or for scientists? *Anaesth Crit Care Pain Med.* 2017;36(6):347-8. doi:10.1016/j.accpm.2017.06.004

66. Diem A, Wolter SC. The use of bliometrics to measure research performance in education sciences. *Res High Edu.* 2013;54(1):86-114. doi:10.1007/s11162-012-9264-5

67. Bornmann L, Leydesdorff L. Does quality and content matter for citedness? A comparison with para-textual factors and over time. *J Informetr.* 2015;9(3):419-29. doi:10.1016/j.joi.2015.03.001

68. Santangelo GM. Article-level assessment of influence and translation in biomedical research. *Mol Biol Cell*. 2017;28(11):1401-8. doi:10.1091/mbc.E16-01-0037

69. Ravenscroft J, Liakata M, Clare A, et al. Measuring scientific impact beyond academia: an assessment of existing impact metrics and proposed improvements. *PLOS One.* 2017;12(3). doi:10.1371/journal.pone.0173152

70. Trueger NS, Thoma B, Hsu CH, et al. The altmetric score: a new measure for article-level dissemination and impact. *Ann Emerg Med.* 2015;66(5):549-53. doi:10.1016/j.annemergmed.2015.04.022

71. Welk G, Fischman MG, Greenleaf C, et al. Editorial board position statement regarding the declaration on research assessment (DORA) - recommendations rith respect to journal impact factors. *Res Q Exerc Sport*. 2014;85(4):429-30. doi:10.1080/02701367.2014.964104

72. Taylor DR, Michael LM, II, Klimo P, Jr. Not everything that matters can be measured and not everything that can be measured matters response. *J Neurosurg.* 2015;123(3):544-5.

73. Christopher MM. Weighing the impact (factor) of publishing in veterinary journals. *J Vet Sci.* 2015;17(2):77-82. doi:10.1016/j.jvc.2015.01.002

74. Jokic M. H-index as a new scientometric indicator. Biochemia Med. 2009;19(1):5-9.

75. Bornmann L, Pudovkin AI. The journal impact factor should not be discarded. *J Korean Med Sci.* 2017;32(2):180-2.

76. Franceschini F, Galetto M, Maisano D, et al. The success-index: an alternative approach to the h-index for evaluating an individual's research output. *Scientometrics.* 2012;92(3):621-41. doi:10.1007/s11192-011-0570-z

77. Prathap G. Citation indices and dimensional homogeneity. *Curr Sci*. 2017;113(5):853-5.

78. Saad G. Applying the h-index in exploring bibliometric properties of elite marketing scholars. *Scientometrics*. 2010;83(2):423-33. doi:10.1007/s11192-009-0069-z

79. Duffy RD, Jadidian A, Webster GD, et al. The research productivity of academic psychologists: assessment, trends, and best practice recommendations. *Scientometrics.* 2011;89(1):207-27. doi:10.1007/s11192-011-0452-4

80. Prathap G. Evaluating journal performance metrics. *Scientometrics*. 2012;92(2):403-8. doi:10.1007/s11192-012-0746-1

81. Lando T, Bertoli-Barsotti L. A new bibliometric index based on the shape of the citation distribution. *PLOS One*. 2014;9(12): doi: 10.1371/journal.pone.0115962. doi:10.1371/journal.pone.0115962

82. Bornmann L, Wallon G, Ledin A. Is the h index related to (standard) bibliometric measures and to the assessments by peers? An investigation of the h index by using molecular life sciences data. *Res Eval.* 2008;17(2):149-56. doi:10.3152/095820208x319166

83. Pepe A, Kurtz MJ. A measure of total research impact independent of time and discipline. *PLOS One.* 2012;7(11):e46428. doi:10.1371/journal.pone.0046428

84. Haslam N, Laham S. Early-career scientific achievement and patterns of authorship: the mixed blessings of publication leadership and collaboration. *Res Eval.* 2009;18(5):405-10. doi:10.3152/095820209x481075

85. Ioannidis JPA, Klavans R, Boyack KW. Multiple citation indicators and their composite across scientific disciplines. *PLOS Biol*. 2016;14(7): doi: 10.1371/journal.pbio.1002501. doi:10.1371/journal.pbio.1002501

86. van Leeuwen T. Testing the validity of the Hirsch-index for research assessment purposes. *Res Eval.* 2008;17(2):157-60. doi:10.3152/095820208x319175

87. Ouimet M, Bedard P-O, Gelineau F. Are the h-index and some of its alternatives discriminatory of epistemological beliefs and methodological preferences of faculty members? The case of social scientists in Quebec. *Scientometrics.* 2011;88(1):91-106. doi:10.1007/s11192-011-0364-3

88. Kshettry VR, Benzel EC. Research productivity and fellowship training in neurosurgery. World Neurosurg. 2013;80(6):787-8. doi:10.1016/j.wneu.2013.10.005

89. Biswal AK. An absolute index (Ab-index) to measure a researcher's useful contributions and productivity. *PLOS One*. 2013;8(12): doi: 10.1371/journal.pone.0084334. doi:10.1371/journal.pone.0084334

90. Tschudy MM, Rowe TL, Dover GJ, et al. Pediatric academic productivity: pediatric benchmarks for the h- and g-indices. *J Pediatr*. 2016;169:272-6. doi:10.1016/j.jpeds.2015.10.030

91. Azer SA, Azer S. Bibliometric analysis of the top-cited gastroenterology and hepatology articles. *BMJ Open.* 2016;6(2): doi: 10.1136/bmjopen-2015-009889. doi:10.1136/bmjopen-2015-009889

92. Joshi MA. Bibliometric indicators for evaluating the quality of scientifc publications. *J Contemp Dent Pract*. 2014;15(2):258-62.

93. Danielson J, McElroy S. Quantifying published scholarly works of experiential education directors. *Am J Pharm Edu*. 2013;77(8):167.

94. Ion D, Andronic O, Bolocan A, et al. Tendencies on traditional metrics. *Chirurgia (Bucur)*. 2017;112(2):117-23. doi:10.21614/chirurgia.112.2.117

95. Suiter AM, Moulaison HL. Supporting scholars: an analysis of academic library websites' documentation on metrics and impact. *J Acad Librariansh*. 2015;41(6):814-20. doi:10.1016/j.acalib.2015.09.004

96. Butler JS, Kaye ID, Sebastian AS, et al. The evolution of current research impact metrics from bibliometrics to altmetrics? *Clin Spine Surg*. 2017;30(5):226-8.

97. Krapivin M, Marchese M, Casati F. Exploring and understanding scientific metrics in citation networks. In: Zhou J, editor. Complex Sciences, Pt 2. Lecture Notes of the Institute for Computer Sciences Social Informatics and Telecommunications Engineering. 52009. p. 1550-63.

98. Carpenter TA. Comparing digital apples to digital apples: background on niso's effort to build an infrastructure for new forms of scholarly assessment. *Inf Serv Use.* 2014;34(1-2):103-6. doi:10.3233/isu-140739

99. Gasparyan AY, Nurmashev B, Yessirkepov M, et al. The journal impact factor: moving toward an alternative and combined scientometric approach. *J Korean Med Sci* 2017;32(2):173-9. doi:10.3346/jkms.2017.32.2.173

100. Moed HF, Halevi G. Multidimensional assessment of scholarly research impact. *J Assoc Inf Sci Technol.* 2015;66(10):1988-2002. doi:10.1002/asi.23314

101. Chuang K-Y, Olaiya MT, Ho Y-S. Bibliometric analysis of the Polish Journal of Environmental Studies (2000-11). *Pol J Environ Stud.* 2012;21(5):1175-83.

102. Vinyard M. Altmetrics: an overhyped fad or an important tool for evaluating scholarly output? Computers in Libraries. 2016;36(10):26-9.

103. van Noorden R. A profusion of measures. *Nature.* 2010;465(7300):864-6. doi:10.1038/465864a

104. van Noorden R. Love thy lab neighbour. *Nature.* 2010;468(7327):1011. doi:10.1038/4681011a

105. Dinsmore A, Allen L, Dolby K. Alternative perspectives on impact: the potential of ALMs and altmetrics to inform funders about research impact. *PLOS Biol.* 2014;12(11):e1002003. doi:10.1371/journal.pbio.1002003

106. Cress PE. Using altmetrics and social media to supplement impact factor: maximizing your article's academic and societal impact. *Aesthet Surg J.* 2014;34(7):1123-6. doi:10.1177/1090820x14542973

107. Moreira JAG, Zeng XHT, Amaral LAN. The distribution of the asymptotic number of citations to sets of publications by a researcher or from an academic department are consistent with a discrete lognormal model. *PLOS One.* 2015;10(11): doi: 10.1371/journal.pone.0143108. doi:10.1371/journal.pone.0143108

108. Waljee JF. Discussion: are quantitative measures of academic productivity correlated with academic rank in plastic surgery? A national study. *Plast Reconstr Surg.* 2015;136(3):622-3. doi:10.1097/prs.0000000000001566

109. Fazel S, Wolf A. What is the impact of a research publication? Evid Based Ment Health. 2017;20(2):33-4. doi:10.1136/eb-2017-102668

110. Eysenbach G. Can tweets predict citations? Metrics of social impact based on Twitter and correlation with traditional metrics of scientific impact. *J Med Internet Res.* 2011;13(4): doi: 10.2196/jmir.012. doi:10.2196/jmir.2012

111. Hoffmann CP, Lutz C, Meckel M. Impact factor 2.0: applying social network analysis to scientific impact assessment. In: Sprague RH, editor. 2014 47th Hawaii International Conference on System Sciences. Proceedings of the Annual Hawaii International Conference on System Sciences 2014. p. 1576-85.

112. Maggio LA, Meyer HS, Artino AR. Beyond citation rates: a real-time impact analysis of health professions education research using altmetrics. *Acad Med.* 2017;92(10):1449-55. doi:10.1097/acm.0000000000001897

113. Raj A, Carr PL, Kaplan SE, et al. Longitudinal analysis of gender differences in academic productivity among medical faculty across 24 medical schools in the United States. *Acad Med.* 2016;91(8):1074-9. doi:10.1097/acm.0000000000001251

114. Markel TA, Valsangkar NP, Bell TM, et al. Endangered academia: preserving the pediatric surgeon scientist. *J Pediatr Surg.* 2017;52(7):1079-83. doi:10.1016/j.jpedsurg.2016.12.006

115. Mirnezami SR, Beaudry C, Lariviere V. What determines researchers' scientific impact? A case study of Quebec researchers. *Sci Public Policy.* 2016;43(2):262-74. doi:10.1093/scipol/scv038

116. Napolitano LM. Scholarly activity requirements for critical care fellowship program directors: what should it be? How should we measure it? *Crit Care Med.* 2016;44(12):2293-6. doi:10.1097/ccm.0000000000002120

117. Bai X, Xia F, Lee I, et al. Identifying anomalous citations for objective evaluation of scholarly article impact. *PLOS One.* 2016;11(9): doi: 10.1371/journal.pone.0162364. doi:10.1371/journal.pone.0162364

118. Gao C, Wang Z, Li X, et al. PR-Index: using the h-Index and PageRank for determining true impact. *PLOS One.* 2016;11(9): doi: 10.1371/journal.pone.0161755. doi:10.1371/journal.pone.0161755

119. Assimakis N, Adam M. A new author's productivity index: p-index. *Scientometrics.* 2010;85(2):415-27. doi:10.1007/s11192-010-0255-z

120. Petersen AM, Succi S. The Z-index: a geometric representation of productivity and impact which accounts for information in the entire rank-citation profile. *J Informetr.* 2013;7(4):823-32. doi:https://doi.org/10.1016/j.joi.2013.07.003

121. Claro J, Costa CAV. A made-to-measure indicator for cross-disciplinary bibliometric ranking of researchers performance. *Scientometrics.* 2011;86(1):113-23. doi:10.1007/s11192-010-0241-5

122. Sahoo BK, Singh R, Mishra B, et al. Research productivity in management schools of India during 1968-2015: a directional benefit-of-doubt model analysis. *Omega Int J Manage S.* 2017;66:118-39. doi:10.1016/j.omega.2016.02.004

123. Aragon AM. A measure for the impact of research. *Sci Rep.* 2013;3: doi: 10.1038/srep01649. doi:10.1038/srep01649

124. Shibayama S, Baba Y. Impact-oriented science policies and scientific publication practices: the case of life sciences in Japan. *Res Policy.* 2015;44(4):936-50. doi:10.1016/j.respol.2015.01.012

125. Tijdink JK, Schipper K, Bouter LM, et al. How do scientists perceive the current publication culture? A qualitative focus group interview study among Dutch biomedical researchers. *BMJ Open.* 2016;6(2): doi: 10.1136/bmjopen-2015-008681. doi:10.1136/bmjopen-2015-008681

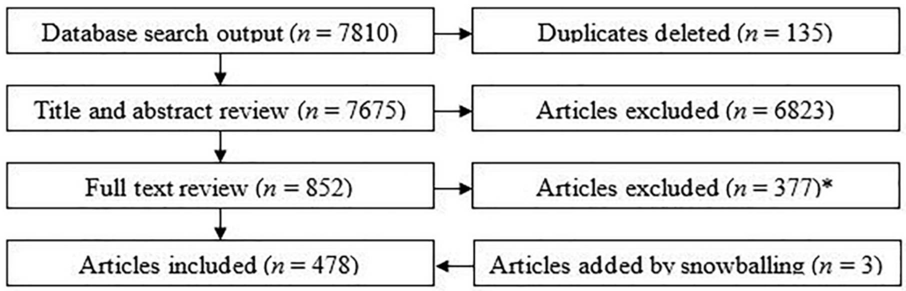
126. Crespo JA, Li Y, Ruiz-Castillo J. The measurement of the effect on citation inequality of differences in citation practices across scientific fields. *PLOS One*. 2013;8(3): doi: 10.1371/journal.pone.0058727. doi:10.1371/journal.pone.0058727

127. da Silva JAT. Does China need to rethink its metrics- and citation-based research rewards policies? *Scientometrics.* 2017;112(3):1853-7. doi:10.1007/s11192-017-2430-y

128. Devos P. Research and bibliometrics: a long history. *Clin Res Hepatol Gastroenterol.* 2011;35(5):336-7. doi:10.1016/j.clinre.2011.04.008

129. Slyder JB, Stein BR, Sams BS, et al. Citation pattern and lifespan: a comparison of discipline, institution, and individual. *Scientometrics.* 2011;89(3):955-66. doi:10.1007/s11192-011-0467-x

130. Zhou Y-B, Lu L, Li M. Quantifying the influence of scientists and their publications: distinguishing between prestige and popularity. *New J Phys*. 2012;14: doi: 10.1088/367-2630/14/3/033033. doi:10.1088/1367-2630/14/3/033033
131. Sorensen AA, Weedon D. Productivity and impact of the top 100 cited Parkinson's disease investigators since 1985. *J Parkinsons Dis*. 2011;1(1):3-13. doi:10.3233/jpd-2011-10021
132. Jeang K-T. H-index, mentoring-index, highly-cited and highly-accessed: how to evaluate scientists? *Retrovirology*. 2008;5(106). doi:10.1186/1742-4690-5-106
133. Franceschini F, Maisano D. Publication and patent analysis of European researchers in the field of production technology and manufacturing systems. *Scientometrics*. 2012;93(1):89-100. doi:10.1007/s11192-012-0648-2
134. Sibbald SL, MacGregor JCD, Surmacz M, et al. Into the gray: a modified approach to citation analysis to better understand research impact. *J Med Libr Assoc*. 2015;103(1):49-54. doi:10.3163/1536-5050.103.1.010
135. Sutherland WJ, Goulson D, Potts SG, et al. Quantifying the impact and relevance of scientific research. *PLOS One*. 2011;6(11):e27537. doi:10.1371/journal.pone.0027537
136. Nature Editorial Team. Announcement: Nature journals support the San Francisco Declaration on Research Assessment. *Nature*. 2017;544(7651):394. doi:10.1038/nature.2017.21882
137. Pugh EN, Jr., Gordon SE. Embracing the principles of the San Francisco Declaration of Research Assessment: Robert Balaban's editorial. *J Gen Physiol*. 2013;142(3):175. doi:10.1085/jgp.201311077
138. Zhang L, Rousseau R, Sivertsen G. Science deserves to be judged by its contents, not by its wrapping: revisiting Seglen's work on journal impact and research evaluation. *PLOS One*. 2017;12(3): doi: 10.1371/journal.pone.0174205. doi:10.1371/journal.pone.0174205
139. San Francisco Declaration on Research Assessment (DORA). DORA—ASCB San Francisco, US2016 [Available from: http://www.ascb.org/dora/.
140. Cabezas-Clavijo A, Delgado-Lopez-Cozar E. Google Scholar and the h-index in biomedicine: the popularization of bibliometric assessment. *Med Intensiva*. 2013;37(5):343-54. doi:10.1016/j.medin.2013.01.008
141. Iyengar R, Wang Y, Chow J, et al. An integrated approach to evaluate faculty members' research performance. *Acad Med*. 2009;84(11):1610-6. doi:10.1097/ACM.0b013e3181bb2364
142. Jacso P. Eigenfactor and article influence scores in the journal citation reports. *Online Inform Rev*. 2010;34(2):339-48. doi:10.1108/14684521011037034

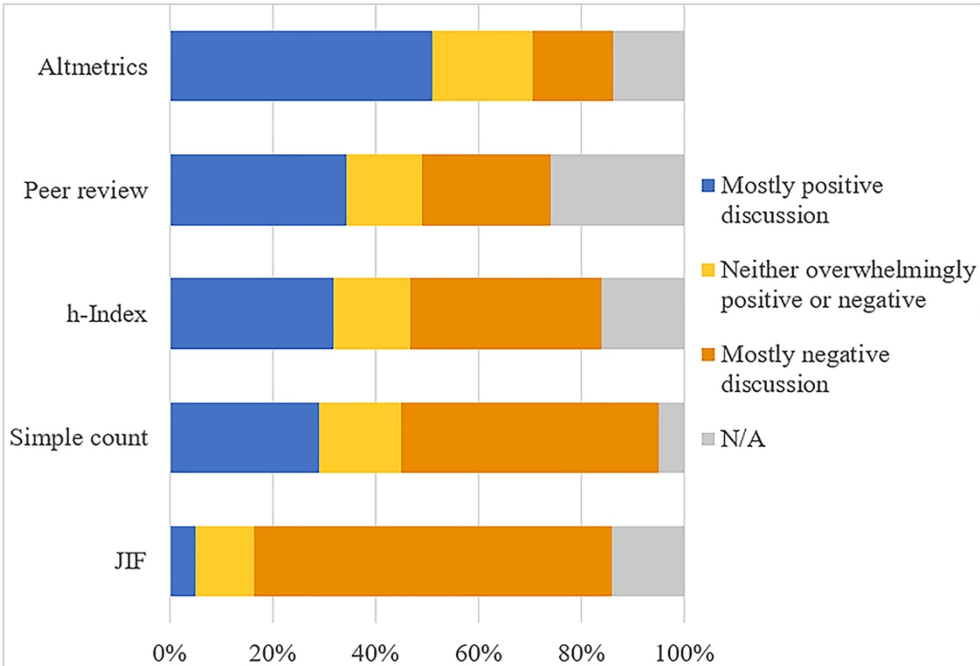


***Reasons for exclusion are noted below**

Reason for exclusion at the full text level	**Number of articles excluded**
Not in English language	47
Full text not available	62
Does not discuss assessment of an individual researcher	268
Total	**377**

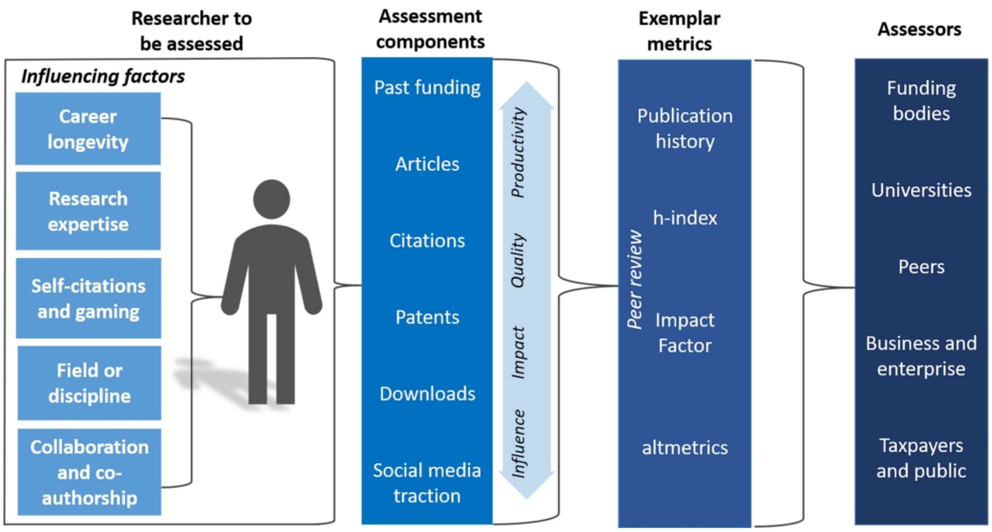
Data screening and extraction process for academic articles

279x188mm (300 x 300 DPI)



Percentages of positive and negative discussion regarding selected commonly used metrics for assessing individual researchers (n=478 articles)

279x191mm (300 x 300 DPI)



The Comprehensive Researcher Achievement Model (CRAM)

279x148mm (300 x 300 DPI)

Appendix 1: Full Search Strategy

Name of database	Web of Science Core Collection, BIOSIS Citation Index, Medline	
Platform	Web of Science [Clarivate Analytics]	
Database coverage	2007-2017	
Date exported to Reference Management Software (EndNote)	19th October 2017	
Search strategy	Model OR framework OR assess* OR evaluat*OR *metric*OR measur* OR criteri*OR citation*OR unconscious bias OR rank*	Results: 13,282,151
	AND	
	researcher excellence OR track record OR researcher funding OR researcher perform* OR relative to opportunity OR researcher potential OR research* career pathway OR academic career pathway OR funding system OR funding body OR researcher impact OR scientific* productivity OR academic productivity OR top researcher OR researcher ranking OR grant application OR researcher output OR h*index OR i*index OR impact factor OR individual researcher	Results: 11,616
	Combined sets [Auto select language based on search language]	Results: 7,530

Appendix 2: Summary table of included articles and the metrics or models they discuss

Publication Details				Metric or Model Assessing an Individual's Research Achievement						
First author	**Year**	**Journal name**	**Format^**	**Peer-review**	**Simple Counts**	**h-index**	**JIF**	**Other**	**Alt-metrics**	**New**
Abramo	2016	Scientometrics	ED					Y		
Agarwal	2016	Asian Journal of Andrology	ED		Y	Y	Y	Y	Y	
Ahmad	2013	Anesthesia and Analgesia	EM		Y					
Aixela	2015	Perspectives: Studies in Translatology	ED	Y		Y	Y	Y		
Akl	2012	Canadian Medical Association Journal	EM	Y						
Albion	2012	Australian Educational Researcher	EM			Y	Y	Y		
Alguliyev	2016	Journal of Scientometric Research	EM				Y	Y		
Allen	2010	ScienceAsia	ED			Y	Y			
Anderson	2008	Scientometrics	ED			Y				Y
Anderson	2017	Applied Economics	EM	Y		Y	Y			
Anfossi	2015	International Journal of Dermatology	EM				Y			
Antunes	2015	Revista do Colegio Brasileiro de Cirurgioes	EM	Y		Y				
Aoun	2013	World Neurosurgery	RE	Y		Y	Y			
Aragon	2013	Nature Scientific Reports	EM							Y
Armado	2017	Transinformação	EM			Y		Y		
Assimakis	2010	Scientometrics	EM							Y
Azer	2016	Education Forum				Y	Y	Y		
Babineau	2014	The Western Journal of Emergency Medicine	EM			Y				

Baccini	2014	Scientometrics	EM			Y	Y	Y	
Badar	2016	Aslib Journal of Information Management	EM	Y			Y		
Bai	2016	PLOS One	EM		Y	Y	Y	Y	Y
Bala	2013	Journal of Clinical Epidemiology	EM				Y		
Balaban	2013	Journal of General Physiology	ED	Y					
Balandin	2009	Augmentative and Alternative Communication	ED			Y	Y		
Barczynski	2009	Journal of Human Kinetics	ED				Y	Y	
Bastian	2017	Journal of Bone and Joint Surgery-American Volume	EM			Y			
Baum	2011	SAGE	EM	Y			Y		
Beck	2017	Research Evaluation	EM	Y					
Beirlant	2010	Scandinavian Journal of Statistics	EM			Y			
Belikov	2015	f1000 Research	EM			Y			Y
Bellini	2012	The Lancet	ED		Y	Y	Y		
Belter	2015	Journal of The Medical Library Association	ED	Y		Y			
Benchimol-Barbosa	2011	Arquivos Brasileiros de Cardiologia	ED				Y		
Benway	2009	Urology	ED	Y	Y	Y			
Bertuzzi	2013	Molecular Biology of the Cell	ED				Y		
Bharathi	2013	PLOS One	ED			Y			
Bini	2008	Electronic Transactions on Numerical Analysis	EM						Y
Birks	2014	Health Services Research & Policy	EM	Y		Y			
Biswal	2013	PLOS One	ED			Y		Y	
Bloch	2016	Research Evaluation	EM					Y	

Bloching	2013	South African Journal of Science	EM	Y						Y
Bollen	2016	Scientometrics	ED	Y						Y
Bolli	2014	Circulation Research	ED							
Bornmann	2009	EMBO Reports	ED			Y	Y			
Bornmann	2015	Journal of Informetrics	EM	Y	Y	Y	Y			
Bornmann	2016	EMBO Reports	ED		Y	Y	Y			
Bornmann	2014	Scientometrics	EM		Y	Y				
Bornmann	2008	Research Evaluation	EM	Y	Y	Y	Y	Y		
Bornmann	2017	Journal of Informetrics	EM		Y	Y	Y	Y		
Bornmann	2017	Journal of Korean Medical Science	ED				Y	Y		
Bould	2011	British Journal of Anaesthesia	EM			Y				
Bradshaw	2016	PLOS One	EM		Y	Y	Y	Y		
Brown	2011	American Journal of Occupational Therapy	ED			Y	Y	Y		
Buela-Casal	2012	Scientometrics	EM				Y			
Buela-Casal	2010	Revista de Psicodidáctica	ED		Y	Y	Y	Y	Y	
Butler	2017	Clinical Spine Surgery	ED						Y	
Cabazas Clavijo	2013	Medicina Intensiva (English edition)	RE		Y	Y	Y			
Cagan	2013	Disease Models & Mechanisms	ED				Y			
Callaway	2016	Nature	ED				Y			
Calver	2013	Grumpy Scientists	ED		Y	Y	Y	Y		
Calver	2015	Australian Universities Review	ED					Y		
Caminiti	2015	BMC Health Services Research	RE							Y

Cantin	2015	International Journal of Morphology	EM			Y				
Carpenter	2014	Academic Emergency Medicine	ED			Y	Y	Y	Y	
Carpenter	2014	Information Service and Use	ED				Y		Y	
Castelnuovo	2010	Clinical Practice & Epidemiology in Mental Health	RE			Y	Y		Y	Y
Castillo	2010	American Journal of Neuroradiology	ED			Y		Y		
Chiari	2016	Nurse Education Today	EM	Y						
Choi	2014	Journal of Radiation Oncology	EM	Y		Y		Y		Y
Choi	2009	International Journal of Radiation Oncology, Biology, Physics	EM		Y	Y				
Chopra	2016	Aesthetic Surgery Journal	EM			Y				
Choudhri	2015	Radiographics	ED		Y	Y	Y			
Chowdhury	2015	PLOS One	EM	Y		Y				
Christopher	2015	Journal of Veterinary Cardiology	ED				Y			
Chung	2012	Scientometrics	EM						Y	
Ciriminna	2013	Chemistry Central Journal	ED		Y	Y	Y	Y		
Claro	2011	Scientometrics	EM							
Cleary	2010	International Journal of Mental Health Nursing	ED			Y				
Cone	2013	Academic Emergency Medicine	ED			Y				
Cone	2012	Academic Emergency Medicine	ED				Y			
Cordero-Villafafila	2015	Revista de Psiquiatría y Salud Mental (English Edition)	ED			Y	Y	Y		Y
Costas	2011	Scientometrics	EM		Y			Y		
Costas	2009	Journal of the American Society for Information Science and Technology	EM		Y		Y			

Crespo	2013	PLOS One	EM		Y	Y				Y
Cress	2014	Aesthetic Surgery Journal	ED				Y		Y	
Crotty		European Heart Journal	ED			Y				
Culley	2014	Anesthesia & Analgesia	EM		Y	Y		Y		
Cynical Geographers Collective	2011	Antipode	ED		Y		Y			
Czarnecki	2013	Bulletin of the Polish Academy of Sciences	EM			Y				
da Silva	2017	Scientometrics	ED				Y	Y	Y	
Danell	2011	Journal of the American Society for Information Science and Technology	EM		Y					
Danielson	2013	American Journal of Pharmaceutical Education	EM		Y	Y		Y		
de Granda-Orive	2014	Archivos de Bronconeumología	ED		Y			Y		
De Gregori	2016	Journal of Pain Research	EM						Y	
De la Flor-Martínez M	2017	Medicina Oral Patologia Oral Y Cirugia Bucal	EM	Y		Y				
De Marchi	2016	Scientometrics	EM				Y			
De Witte	2010	Scientometrics	EM	Y						Y
Delgadillo	2016	Family & Consumer Sciences research journal	RE			Y				Y
DeLuca	2013	Academic Emergency Medicine	EM	Y		Y				
Devos	2011	Clinics and Research in Hepatology and Gastroenterology	ED			Y				
Diamandis	2017	BMC Medicine	ED				Y			
DiBartola	2017	Journal of Veterinary Internal Medicine	ED			Y	Y	Y		
Diem	2013	Research in Higher Education	EM				Y			
Ding	2011	Information Processing and Management	EM		Y	Y	Y	Y	Y	

Ding	2011	Journal of the American Society for Information Science and Technology	EM			Y	Y		Y	
Diniz-Filho	2016	Journal of Informetrics	EM	Y	Y		Y			
Dinsmore	2014	PLOS Biology	ED						Y	
Dodson	2012	Biochemical and Biophysical Research Communications	EM	Y		Y	Y			Y
Donato	2014	Revista Portuguesa De Pneumologia	ED				Y			
Doyle	2015	Molecular Psychiatry	EM	Y						
Duffy	2011	Scientometrics	EM		Y	Y		Y		
Duffy	2008	Journal of Counseling Psychology	EM		Y	Y		Y		Y
Durieux	2010	Radiology	RE			Y	Y	Y	Y	
Ebadi	2016	Scientometrics	EM					Y		Y
Eblen	2016	PLOS One	EM	Y						
Efron	2011	Clinical and Experimental Optometry	EM		Y	Y		Y		
Ekpo	2016	Journal of Medical Imaging and Radiation Sciences	EM			Y	Y	Y		Y
El Emam	2012	Journal of Medical Internet Research	EM		Y	Y	Y			
Ellson	2009	Journal of Business Research	ED							
Eloy	2014	Otolaryngology–Head and Neck Surgery	EM	Y		Y	Y	Y		
Eloy	2013	Laryngoscope	EM			Y				
Esposito	2010	European Journal of Oral Implantology.	ED			Y				
Eyre-Walker	2013	PLOS Biology	EM	Y	Y		Y			
Eysenbach	2011	Journal of Medical Internet Research	EM		Y	Y	Y		Y	
Fabry	2017	GMS Journal for Medical Education	ED	Y			Y		Y	

Fang	2016	eLIFE	EM	Y						
Fazel	2017	Evidence-based Mental Health	EM	Y				Y	Y	
Fedderke	2015	Research Policy	EM		Y	Y				
Feethman	2015	Veterinary Record	ED				Y			
Ferrer-Sapena	2016	Research Evaluation	ED		Y		Y	Y	Y	Y
Filler	2014	Academic Medicine	EM					Y		
Finch	2010	Bioessays	ED			Y	Y	Y		
Flaatten	2016	Acta Anaesthesiologica Scandinavica	ED			Y	Y			
Franceschet	2010	Journal of Informetrics	EM				Y	Y		
Franceschini	2012	Scientometrics	EM					Y		Y
Franceschini	2012	Scientometrics	EM			Y	Y	Y		Y
Franceschini	2012	Scientometrics	EM		Y	Y		Y		
Frittelli	2016	Journal of the Association for Information Science and Technology	EM			Y	Y			Y
Frixione	2016	PLOS One	EM	Y					Y	
Fujita	2017	IEEE 41st Annual Computer Software and Applications Conference (COMPSAC)	EM	Y	Y					
Gambadauro	2007	European Journal of Obstetrics & Gynecology and Reproductive Biology	ED				Y			
Gao	2016	PLOS One	ED			Y				Y
Garcia-Perez	2015	Scientometrics	EM		Y			Y		
Garcia-Perez	2009	Spanish Journal of Psychology	EM		Y	Y				
Garner	2017	Journal of Neurointerventional Surgery	RE		Y	Y				

Gasparyan	2017	Journal of Korean Medical Science	ED				Y	Y	Y	
Gast	2014	Plastic and Reconstructive Surgery	EM		Y	Y				
Gast	2014	Plastic & Reconstructive Surgery	EM			Y		Y		
Gaughan	2008	Research Evaluation	EM					Y		
Gefen	2011	Journal of Biomechanics	LE	Y		Y				
Giminez-Toledo	2016	Scientometrics	EM					Y		
Glänzel	2014	Transinformação	ED			Y		Y		
Good	2015	Research Evaluation	ED					Y		
Gorraiz	2010	LIBER Quarterly	ED		Y		Y		Y	
Gracza	2008	Library Collections Acquisitions & Technical Services	ED			Y	Y			
Grisso	2017	Journal of Women's Health	EM	Y						
Grzybowski	2017	Clinics in Dermatology	ED				Y			
Gumpenberger	2016	Scientometrics.	ED	Y		Y	Y		Y	
Haddad	2014	The Bone and Joint Journal	ED				Y			
Haddow	2015	Research Evaluation	EM							
Haeffner-Cavaillon	2009	Archivum Immunologiae et Therapiae Experimentalis	ED	Y		Y	Y	Y		
Halbach	2011	Annals of Anatomy	EM		Y	Y		Y		
Hall	2015	Tourism Management	ED				Y			
Halvorson	2016	Implications for Training in the Health Professions	EM		Y	Y				
Hamidreza	2013	Acta Informatica Medica	EM			Y				
Hammarfelt	2017	Research Evaluation	EM	Y		Y	Y			
Han	2013	ISSI	EM	Y			Y			Y

Han	2010	Journal of Animal and Veterinary Advances	EM			Y	Y			
Haslam	2009	Research Evaluation	EM		Y	Y	Y			
Haslam	2010	European Journal of Social Psychology	EM			Y	Y	Y	Y	
Healy	2011	Breast Cancer Research and Treatment	EM			Y				
Heinzl	2012	AIP Conference Proceedings	ED			Y	Y	Y		
Henrekson	2011	The Manchester School	EM		Y	Y	Y	Y		
Herteliu	2017	Publications	EM			Y				
Hew	2017	Telematics and Informatics	EM		Y	Y	Y			
Hicks	2015	Nature	ED			Y	Y			
Hicks	2015	Nature	ED			Y	Y			
Hoffman	2014	47th Hawaii International Conference on System Sciences	O			Y	Y		Y	
Holliday	2010	International Journal of General Medicine	EM	Y			Y			Y
Houser	2017	Leukos	ED			Y	Y			
Hughes	2015	International Journal of Radiation Oncology Biology Physics NB Conference supplement	EM		Y	Y				
Hunt	2011	Acta Neuropsychiatrica	ED			Y	Y			
Hutchins	2016	PLOS Biology	EM							Y
Hyman	2014	Molecular Biology of the Cell	ED							
Ibrahim	2015	New Library World	EM	Y	Y	Y				Y
Ioannidis	2016	PLOS Biology	EM		Y	Y				Y
Ion	2017	Chirurgia	RE			Y	Y	Y		
Iyendar	2009	Academic Medicine	EM				Y			Y

Jackson	2015	Medical Journal of Australia	ED	Y						
Jackson	2011	PLOS One	EM					Y		
Jacob	2007	Scientometrics	EM		Y		Y			
Jacso	2010	Online Information Review	EM				Y	Y		
Jacso	2008	Online Information Review	ED			Y				
Jalil	2013	IEEE International Conference on Teaching, Assessment and Learning for Engineering (TALE)	EM				Y			
Jamjoom	2015	Neurosciences	EM			Y				
Jamjoom	2016	World Neurosurgery	EM			Y				
Jan	2016	Journal of Scientometric Research	EM			Y		Y		
Javey	2012	American Chemical Society	ED			Y	Y			
Jeang	2008	Retrovirology	ED			Y				Y
Jokic	2009	Biochemia Medica	ED		Y	Y	Y			
Joshi	2014	The Journal of Contemporary Dental Practice	ED			Y		Y		
Joynson	2015	f1000 Research	EM							
Kaatz	2015	Academic Medicine	EM	Y						
Kaatz	2016	Academic Medicine	EM	Y						
Kali	2015	Indian Journal of Pharmacology	ED		Y				Y	
Kalra	2013	Journal of Neurosurgery-Pediatrics	EM			Y		Y		
Kaltman	2014	Circulation Research	EM		Y					
Kapoor	2013	The Annals of Medical and Health Sciences Research	ED				Y			
Kellner	2008	Anais Da Academia Brasileira De Ciencias	EM			Y				

Khan	2013	World Neurology	EM			Y				
Knudson	2015	Quest	EM		Y					
Kosmulski	2012	Research Evaluation	ED		Y		Y			
Krapivin	2009	Complex Sciences	EM		Y	Y			Y	Y
Kreiman	2011	Frontiers in Computational Neuroscience	ED	Y	Y		Y		Y	
Kreines	2016	Journal of Computer and Systems Sciences International	EM							Y
Kshettry	2013	World Neurosurgery	ED			Y		Y		
Kulasagareh	2010	European Archives of Oto-Rhino-Laryngology	EM			Y				
Kulczycki	2017	Journal of Informetrics	ED			Y				
Kumar	2009	Iete Technical Review	ED		Y	Y	Y			
Kuo	2017	Computers in Human Behavior	EM						Y	
Lando	2014	PLOS One	EM		Y	Y				Y
Lariviere	2010	Journal of the American Society for Information Science and Technology	EM				Y			
Lariviere	2016	PLOS One	EM		Y					
Lariviere	2011	Journal of Informetrics	EM					Y		
Lauer	2015	The New England Journal of Medicine	ED	Y						
Law	2013	Asia Pacific Journal of Tourism Research	EM	Y	Y		Y			
Lee	2009	Journal of neurosurgery	EM			Y				
Leff	2009	International Journal of COPD	ED				Y			
Leydesdorff	2016	Scientometrics	ED			Y	Y	Y		
Li	2015	Science	EM	Y						

Li	2016	In: Nah FFH, Tan CH, eds. Hci in Business, Government, and Organizations: Ecommerce and Innovation, Pt I. Vol 97512016:61-71.	EM	Y						
Liang	2015	IEEE International Conference on Smart City/SocialCom/SustainCom	EM							Y
Liao	2011	Decision Support Systems	EM		Y		Y			
Lindner	2015	PLOS One	EM	Y	Y					
Lindner	2016	American Journal of Evaluation	EM	Y						
Lippi	2009	Clinical Chemistry and Laboratory Medicine	ED			Y	Y			
Lippi	2013	Clinica Chimica Acta	EM			Y	Y			
Lippi	2017	Annals of Translational Medicine	EM			Y	Y			Y
Lissoni	2011	Industrial and Corporate Change	EM				Y			
Littman	2017	Medical Education Online	EM		Y	Y	Y			
Liu	2011	Management Information Systems	EM		Y			Y	Y	
Lopez	2015	Journal of Surgical Education	EM	Y		Y				
Lopez	2015	Journal of Hand Surgery America	EM		Y	Y				
Lortie	2013	Scientometrics	EM		Y		Y			
Lovegrove	2008	BioScience	EM	Y		Y		Y		
Lozano	2017	Current Science	ED		Y	Y		Y		
MacMasters	2017	Academic Psychiatry	EM		Y	Y				
Maggio	2017	Academic Medicine	EM			Y			Y	
Mali	2017	Science & Public Policy	EM							
Markel	2017	Journal of Pediatric Surgery	EM		Y	Y		Y		

Markpin	2008	Scientometrics	EM				Y			Y
Marsh	2008	American Psychologist	EM	Y						
Marshall	2017	Otolaryngology—Head and Neck Surgery	EM				Y			
Marzolla	2016	Journal of Informetrics	EM	Y		Y		Y		
Mas-Bleder	2013	Scientometrics	EM		Y			Y		
Matsas	2012	Brazilian Journal of Physics	EM							Y
Maunder	2007	La Revue Canadienne de Psychiatrie	EM				Y	Y		Y
Maximin	2014	RadioGraphics	ED	Y	Y		Y		Y	
Mazloumian	2011	PLOS One	EM							Y
Mazmanian	2014	Evaluation & the Health Professions	RE					Y		
McAlister	2011	American Heart Association Journals	ED		Y		Y			
McGovern	2013	Academic Medicine	EM	Y	Y			Y		
Medo	2016	Physical Review	EM			Y		Y		
Meho	2008	Journal of the American Society for Information Science and Technology	EM		Y	Y				
Mester	2016	Interdisciplinary Description of Complex Systems	ED		Y	Y	Y			
Metcalf	2010	Radiologic Technology	EM							
Milone	2016	American Journal of Orthopedics	EM	Y		Y				Y
Minasny	2013	PeerJ	EM		Y	Y				
Mingers	2015	European Journal of Operational Research	ED		Y	Y		Y		
Mingers	2009	Journal of the Operational Research Society	EM		Y	Y				
Mingers	2017	Scientometrics	EM		Y					

Mirnezami	2016	Science and Public Policy	EM		Y			Y		
Misteli	2013	The Journal of Cell Biology	ED				Y			
Moed	2015	Journal of the Association for Information Science and Technology	RE						Y	
Moed	2009	Archivum Immunologiae et Therapia Experimentalis	ED			Y	Y	Y		
Mooij	2014	Scientometrics	EM					Y		Y
Moppett	2011	British Journal of Anaesthesia	EM	Y	Y	Y		Y	Y	
Moreira	2015	PLOS One	EM			Y	Y		Y	Y
Morel	2009	PLOS Neglected Tropic Diseases	EM			Y				Y
Moustafa	2016	Accountability in Research-Policies and Quality Assurance	ED		Y					
Murphy	2011	Irish Journal of Medical Science	EM		Y		Y			
Murphy	2017	Nature	ED					Y		
Mutz	2015	Journal of the Association for Information Science and Technology	EM	Y						
Mutz	2012	Zeitschrift fur Psychologie	EM	Y						
Nah	2009	Journal of The American Society for Information Science and Technology	EM				Y	Y		
Napolitano	2016	Critical Care Medicine	ED		Y			Y		
Nature Editorial Office	2013	Nature Letters	ED		Y		Y			
Nature Editorial Office	2017	Nature	ED				Y			
Neufeld	2011	Research Evaluation	EM	Y		Y				
Neylon	2009	PLOS Biology	ED		Y		Y			

Nicol	2007	Medical Journal of Australia	EM	Y	Y		Y			
Nicolini	2008	Scientometrics	EM				Y	Y		
Niederkrotenthaler	2011	BMC Public Health	EM							Y
Nielsen	2017	Studies in Higher Education	EM				Y	Y		
Nigam	2012	Indian Journal of Dermatology, Venerology and Leprology	ED			Y				
Nightingale	2013	Nurse Education in Practice	EM		Y	Y	Y		Y	
Nosek	2010	Personality and Social Psychology Bulletin	EM			Y				Y
Nykl	2015	Journal of Informetrics	EM	Y		Y	Y			
O'Brien	2012	Oikos	ED							
O'Connor	2010	European Journal of Cancer Care	ED				Y	Y		
Okhovati	2016	Global Journal of Health Science	EM	Y	Y	Y	Y	Y		
Oliveira	2013	Revista Paulista de Pediatria	EM		Y	Y	Y	Y		
Oliveira	2011	Arquivos Brasileiros de Cardiologia	EM		Y	Y	Y			
Oliveira	2013	Scientometrics	EM		Y	Y	Y	Y		
Opthof	2009	Netherlands Heart Journal	EM			Y	Y			
Orduna-Malea	2015	El Profesional de la Información	ED	Y	Y	Y	Y		Y	Y
Osterloh	2015	Evaluation Review	EM	Y	Y		Y			
Ouimet	2011	Scientometrics	EM			Y		Y		
Pagani	2015	Scientometrics	RE		Y		Y			Y
Pagel	2011	British Journal of Anaesthesia	EM			Y				
Pagel	2011	Anaesthesia	EM			Y		Y		
Pagel	2015	Original Investigations in Education	EM		Y	Y		Y		

Paik	2014	Surgical Education	EM			Y				
Pan	2014	Science Reports	EM			Y	Y			Y
Pandit	2011	Anaesthesia	ED		Y	Y		Y		
Patel	2013	Journal of the Royal Society of Medicine	EM	Y	Y	Y	Y	Y		Y
Patel	2011	Journal of the Royal Society of Medicine	RE		Y	Y	Y	Y		
Patrow	2011	Journal of Postgraduate Medicine	ED			Y				
Pepe	2012	PLOS One	EM			Y				Y
Pereyra-Rojas	2017	Frontiers in Psychology	EM	Y		Y		Y		
Perlin	2017	Journal of Informetrics	EM		Y		Y			
Persson	2014	Acta Physiologica	ED						Y	
Peters	2017	Journal of Infometrics	ED				Y			
Petersen	2013	Journal of Informetrics	EM							Y
Petersen	2010	Physical Review	EM							
Pinnock	2012	Nurse Education Today	ED		Y		Y			
Põder	2017	Trames-Journal of the Humanities and Social Sciences	EM			Y				Y
Prabhu	2017	World Neurosurgery	ED			Y	Y	Y	Y	
Prathap	2016	Scientometrics	EM		Y		Y			
Prathap	2012	Scientometrics	EM			Y	Y	Y		
Prathap	2014	Scientometrics	EM			Y				Y
Prathap	2017	Current Science	ED		Y	Y	Y			Y
Pringle	2008	Learned Publishing	ED		Y	Y	Y	Y		
Pshetizky	2009	Journal of the American Board of Family Medicine	EM		Y		Y			

Pugh Jr	2013	Journal of General Physiology	ED				Y			
Pulina	2007	Italian Journal of Animal Science	EM		Y	Y	Y	Y		
Pyke	2015	BioScience	ED							Y
Qi	2016	Scientometrics	EM		Y					
Quigley	2012	Journal of Cancer Education	EM			Y				
Rad	2012	Academic Radiology	EM			Y				
Radicchi	2008	Proceedings of the National Academy of Sciences of the United States of America	EM		Y	Y		Y		Y
Radicchi	2012	Journal of Informetrics	EM		Y			Y		
Raj	2016	Academic Medicine	EM		Y	Y		Y		
Ramasesha	2011	Current Science	ED		Y	Y	Y	Y		
Rana	2013	Journal of Cancer Education	EM		Y	Y				
Ravenscroft	2017	PLOS One	EM			Y	Y	Y	Y	
Rey-Rocha	2015	Scientometrics	EM		Y					
Rezek	2011	Academic Radiology	EM							
Ribas	2015	Proceedings of the 24th International Conference on World Wide Web	O	Y	Y	Y				Y
Ribas	2015	arXiv	ED							Y
Ricker	2009	Interciencia	ED	Y			Y			Y
Rieder	2010	Langenbeck's Archives of Surgery	ED			Y		Y		
Robinson	2011	Journal of School Psychology	ED				Y			
Rodriguez-Navarro	2011	PLOS One	EM							Y
Ronai	2012	Pigment Cell and Melanoma research	ED	Y	Y					

Rons	2009	Research Evaluation	EM							
Rosati	2016	Journal of Cardiac Surgery	EM			Y				
Ruane	2009	Scientometrics	EM		Y	Y				Y
Saad	2010	Scientometrics	EM			Y				
Safdar	2015	Society for Academic Emergency Medicine (SAEM)	EM	Y						
Sahel	2011	Science Translational Medicine	ED		Y	Y	Y			
Sahoo	2017	Omega	EM		Y	Y	Y			Y
Saleem	2011	Internal Archives of Medicine	ED			Y	Y			
Sangam	2008	Current Science	ED			Y	Y			
Santangelo	2017	Molecular Biology of the Cell	ED				Y	Y		
Saraykar	2017	Academic Psychiatry	EM			Y				
Sarli	2016	Missouri Medicine	ED				Y	Y	Y	
Satyanarayana	2008	Indian Journal of Medical Research	ED			Y	Y			
Saxena	2013	Journal of Pharmacology Pharmacotherapeutics	EM			Y	Y	Y		Y
Sebire	2008	Ultrasound in Obstetrics and Gynaecology	ED			Y		Y	Y	
Selek	2014	Scientometrics	EM		Y	Y		Y		
Seo	2017	Management Decision	EM				Y			
Shanta	2013	Journal of Medical Physics	ED		Y	Y	Y			
Shibayama	2015	Research Policy	EM		Y		Y			
Sibbald	2015	Journal of the Medical Library Association	ED							Y
Simons	2008	Science	ED				Y			
Sittig	2015	MEDINFO 2015: eHealth-enabled Health	EM		Y	Y				Y

Slim	2017	Anaesthesia, Critical Care & Pain Medicine	ED			Y	Y		Y	
Slyder	2011	Scientometrics	EM		Y					
Smeyers	2011	Journal of Philosophy of Education	ED		Y		Y			
Smith	2008	Bone & Joint Journal	ED				Y			
Soares de Araujo	2011	Revista Brasileira de Medicina do Esporte	EM			Y	Y	Y		
Sobhy	2016	Embo Reports	ED				Y			
Sobkowicz	2015	Journal of Artificial Societies and Social Simulation	EM	Y						
Solarino	2012	Annals of Geophysics	RE		Y	Y	Y			Y
Sood	2015	Eplasty	EM			Y				
Sorenson	2011	Journal of Parkinson's Disease	EM		Y	Y				Y
Spaan	2009	Medical & Biological Engineering & Computing	ED			Y	Y			
Spearman	2010	Journal of Neurosurgery	EM			Y				
Spreckelsen	2011	BMC Medical Informatics and Decision Making	EM			Y	Y	Y		
Staller	2017	Qualitative Social Work	ED		Y	Y			Y	
Stallings	2013	Proceedings of the National Academy of Sciences of the United States of America	EM		Y	Y				Y
Street	2009	Health Research Policy and System	EM	Y						
Stroebe	2010	American Psychologist	ED		Y			Y		
Stroobants	2013	Nature	ED							
Sturmer	2013	Revista Brasileira De Fisioterapia	EM		Y	Y				
Suiter	2015	The Journal of Academic Librarianship	EM			Y	Y	Y	Y	
Suminski	2012	The Journal of the American Osteopathic Association	EM		Y		Y	Y		

Surla	2017	The Electronic Library	ED		Y		Y			Y
Susarla	2015	Plastic and Reconstructive surgery	EM		Y	Y				
Susarla	2015	Journal of Dental Education	EM	Y		Y				
Sutherland	2011	PLOS One	EM	Y			Y			
Svider	2013	Laryngoscope	EM			Y				
Svider	2014	Ophthalmology	EM	Y		Y				
Svider	2013	Laryngoscope	EM	Y		Y				
Svider	2013	Laryngoscope	EM			Y		Y		
Swanson	2016	Annals of Plastic Surgery	EM			Y				
Szklo	2008	Epidemiology	ED				Y			
Szymanski	2012	Information Sciences	EM			Y	Y	Y		Y
Taborsky	2007	International Journal of Behavioural Biology	ED	Y						
Tan	2016	The Annals of Applied Statistics	EM		Y	Y	Y		Y	Y
Tandon	2015	National Academy Science Letters-India	ED				Y			
Taylor	2015	Poultry Science	ED			Y	Y		Y	
Teixeira	2013	PLOS One	EM			Y				
Tenreiro Machado	2017	Entropy	EM	Y				Y		
Thelwall	2017	Aslib Journal of Information Management	EM						Y	
Therattil	2016	Annals of Plastic Surgery	EM			Y				
Thomaz	2011	Arquivos Brasileiros De Cardiologia	ED			Y	Y	Y		
Thorngate	2014	Advances in Social Simulation	EM	Y						
Tijdink	2016	BMJ Open	EM							

Timothy	2015	Tourism Management	ED				Y			
Torrisi	2014	Scientometrics	EM	Y		Y	Y	Y		
Tricco	2017	PLOS One	RE	Y						
Trueger	2015	Annals of Emergency Medicine	ED			Y	Y		Y	
Tschudy	2016	Journal of Pediatrics	EM			Y		Y		
Tse	2008	Nature	ED			Y	Y			Y
Tuitt	2011	Canadian Journal of Gastroenterology	EM			Y	Y	Y		
Usmani	2011	Sudanese Journal of Paediatrics	ED			Y	Y			
Valsangkar	2016	Surgery	EM		Y	Y		Y		
van Arensbergen	2012	Higher Education Policy	EM	Y						
van den Besselaar	2009	Research Evaluation	EM	Y	Y					
van Eck	2013	PLOS One	EM		Y					
van Leeuwen	2008	Research Evaluation	EM			Y				
van Leeuwen	2012	Research Evaluation	EM	Y						
van Noorden	2010	Nature	ED			Y	Y	Y	Y	
van Wesel	2016	Science and Engineering Ethics	EM							
Vaughan	2017	Scientometrics	EM						Y	
Verma	2015	Proceedings of the National Academy of Sciences of the United States of America	ED	Y			Y			
Vico	2015	Prometheus	EM	Y						
Vieira	2011	Scientometrics	EM							Y
Vinkler	2012	Journal of Informetrics	ED					Y		

Vinyard	2016	Computers in libraries	ED			Y	Y		Y	
von Bartheld	2015	PeerJ	EM			Y	Y	Y		
Wacogne	2016	Archives of Disease in Childhood-Education and Practice Edition	ED			Y	Y	Y	Y	
Wagner	2012	Research Evaluation	ED		Y					Y
Waisbren	2008	Journal of Women's Health	EM							
Walijee	2015	Plastic and Reconstructive Surgery	ED						Y	
Walker	2010	BMC Medical Education	EM		Y		Y	Y		
Wallace	2012	PLOS One	EM	Y	Y					
Walters	2011	Journal of the American Society for Information Science and Technology	EM	Y	Y		Y			
Waltman	2013	In: Gorraiz J, Schiebel E, Gumpenberger C, Horlesberger M, Moed H, eds. 14th International Society of Scientometrics and Informetrics Conference	EM		Y	Y				Y
Waltman	2013	Journal of Informetrics	EM		Y					
Wang	2013	Science	EM			Y	Y	Y		Y
Ward	2012	Anaesthesia	ED							
Watson	2015	Journal of Pediatric Surgery	EM		Y	Y				
Welk	2014	Research Quarterly for Exercise and Sport	ED				Y			
Wieczorek	2016	Financial Environment and Business Development	ED		Y	Y	Y			
Wildgaard	2014	Scientometrics	RE		Y	Y	Y	Y		
Williamson	2008	Family Medicine	EM							Y
Wootton	2013	Health Research Policy and Systems	EM	Y			Y			Y
Würtz	2016	Annals of Epidemiology	RE			Y				

Wykes	2013	Journal of Mental Health	ED			Y	Y			
Yaminfirooz	2015	The Electronic Library	EM			Y				Y
Yang	2013	Journal of Informetrics	EM	Y		Y				Y
Yates	2015	Source Code for Biology and Medicine	EM	Y						
Yu	2016	Computers in Human Behaviour	EM						Y	
Ze	2012	International Conference on Intelligent Computing	EM		Y	Y				
Zhang	2012	Scientometrics	EM							Y
Zhang	2017	PLOS One	EM		Y		Y			
Zhang	2012	Scientometrics	EM		Y	Y		Y		
Zhao	2014	Scientometrics	EM	Y			Y	Y		
Zhou	2012	New Journal of Physics	EM			Y				Y
Zhu	2015	arXiv	EM							Y
Zhuo	2008	Molecular Pain	EM	Y		Y				Y
Zima	2008	Biochemia Medica	ED			Y	Y			
Zou	2016	Scientometrics	EM		Y	Y				Y
Zupetic	2017	Academic Radiology	EM		Y					
Zycxkowski	2010	Scientometrics	ED							Y

^Empirical (EM); Editorial/Opinion (ED); Review (RE); Other (O).

Appendix 3: New models and metrics for assessing an individual researcher's achievement (2007-2017)

First author	Year	Journal name	Level	Metric or Model	Name	Basis	Description
Anderson	2008	Scientometrics	Researcher	Metric	Tapered h-index	h-index	It accounts for the tapered distribution of citations.
Aragon	2013	Nature Scientific Reports	Both	Metric	Scientist impact (Φ)	Author contributions and citation counts	Instead of the total number of citations, the proposed measure Φ (Scientist Impact) aims at discerning the genuine number of people (specifically lead authors) the paper (or first author) has had an impact upon by removing self-citation. In other words, Φ aims at measuring the papers reach.
Assimakis	2010	Scientometrics	Researcher	Metric	The Golden Productivity Index	Author contribution and publication count	A rank dependent index that measures the productivity of an individual researcher by evaluating the number of papers as well as the rank of co-authorship. It emphasizes the first author's contribution.
Bai	2016	PLOS One	Researcher	Metric	COIRank algorithm	Network analysis	Quantifies scientific impact by reproducing the accumulated COI relationship in the scientific community. COIRank focuses on improving PageRank through setting a weight for PageRank algorithm and promotes the performance in identifying influential articles. It therefore accounts for self-citation and citation by others at the same institution.
Belikov	2015	f1000 Research	Researcher	Metric	L-index	h-index and author contribution	Accounts for co-author contribution by designating citations to each individual author according to their order on a paper. It also considers the age of publications, favoring newer ones. However, if a scientist has made a significant scientific breakthrough and ceases publications, his or her L-index will remain high regardless. It ranges from 0.0-9.9.
Bini	2008	Electronic Transactions on Numerical Analysis	Both	Metric	Information not available	Citation count	Proposes to integrate models for evaluating papers, authors, and journals based on citations, co-authorship and publications. After the one-class model for ranking scientific publications, they introduced the two-class model which ranks papers and authors, and the three-class model for ranking papers, authors, and journals.

Bloching	2013	South African Journal of Science	Article	Metric	TAPSIF-temporally averaged paper-specific impact factor	Citation count and IF	Calculated from a paper's average number of citations per year (including the publication year) combined with bonus cites for the publishing journal's prestige–which is taken as the journal impact factor from the publication year. Annual TAPSIF values of all the papers by an author can be combined to measure the overall scientific relevance of that author (temporally averaged author-specific impact factor TASIF).
Bollen	2016	Scientometrics	Researcher	Model	Equal Allocation Model	Peer-review	A novel model in which each researcher is allocated funding and is required to donate a proportion of that funding to other researchers--hence uses crowd wisdom to fund scientists.
Caminiti	2015	BMC Health Services Research	Researcher	Metric	Information not available	Citation count	This work in progress suggests a mixture of 12 easily retrievable indicators (bibliometric and citation parameters, as well as "hidden" activities such as teaching, mentoring etc). The weighting system was constructed considering the hypothesized effort for all indicators. The chosen indicators and attributed scores still remain to be validated. Modified from Wooton, Health Res Policy Syst. 2013;11:2; Smith, Br Med J. 2001;323(7312):528–8.; and Mezrich J Am Coll Radiol. 2007;4(7):471–8.
Castelnuovo	2010	Clinical Practice & Epidemiology in Mental Health	Researcher	Metric	Single Researcher Impact Factor	IF	This metric takes into account publications (journal articles, books, oral and poster presentations in scientific meetings); products (e.g., software, CD-ROM, videos, databases); and activities (reported scientific activities such as scientific positions or positions in conferences organization, participation in journal editorial boards, activities on human resources education, and participation in international funding projects). Minimum and maximum values are assigned to each task for national and international impact.
Claro	2011	Scientometrics	Researcher	Metric	The x-index	IF and author contribution	Aims to enable cross-disciplinary comparison and uses indicators of both quality and quantity, taking into account the number of publications a researcher has published, and then calculating a publication score for each. This considers number of authors on the paper and the journal's 5-year impact factor; it is also normalized by the journals in which the author tends to publish (rather than top-down classification of a field). Also uses a co-authorship share coefficient. Therefore, aims to determine relative contribution to a paper and normalize by field. While requiring only modest data extraction and processing efforts, it is not based on individual article citations but that of the journal (JIF), which can have limitations.

Cordero-Villafafila	2015	Revista de Psiquiatría y Salud Mental (English Edition)	Both	Metric	RC Algorithim	IF	The first English-language publication of this metric, it quantitatively evaluates the personal impact factor of the scientific production of isolated researchers. It also an individual form (RCγ) and group form (RCγG), and is able to assess personal impact of individual publications, or a group of them. It also provides a procedure to classify research centers of different types based on the impact (FRCγG) made by their results amongst researchers of the same field. One of the limitations of the RC algorithm is, precisely, its dependence on said bibliographic databases, which have a strong pre-eminence of studies published in English.
Crespo	2015	PLOS One	Other	Metric	Exchange Rate	Citation count	This is an average-based indicator that is used to explore differential citation rates between disciplines by using it as a normalization factor. It is not suitable for assessing individual researchers but provides insight into comparison across disciplines.
De Witte	2010	Scientometrics	Researcher	Metric	RES-score - Research Evaluation Score	Data Envelopment Analysis	Authors present a methodology to aggregate multidimensional research output, using a tailored version of the non-parametric Data Envelopment Analysis model. This they claim is a more accurate representation of a research performance.
Delgadillo	2016	Family & Consumer Sciences Research Journal	Both	Metric	HLA-index	h-index	This index, actually originally published in a book by Harzing (2011), normalizes the h-index to take into account career stage and discipline.
Dodson	2012	Biochemical and Biophysical Research Communications	Researcher	Metric	SP-index	IF	This metric is said to quantify the scientific production of researchers, representing the product of the annual citation number by the accumulated impact factors of the journals in which the papers are published, divided by the annual number of published papers.
Duffy	2008	Journal of Counseling Psychology	Both	Metric	IRPI - Integrated Research Productivity Index	Citation count	This metric statistically combines an individual's author-weighted publications (AWS), average times cited by other publications (MC), and years since first publication (Y) into a comprehensive score, calculated as (AWS x MC)/Y. It thereby accounts for differences in career length.
Ebadi	2016	Scientometrics	Researcher	Model	iSEER	Machine learning	An intelligent machine learning framework for scientific evaluation of researchers (iSEER) considers various "influencing factors of different types" (e.g., funding, collaboration pattern, performance such as quantity and impact of papers, efficiency). It can be used as a complementary tool to overcome limitations in peer-review.

Ekpo	2016	Journal of Medical Imaging and Radiation Sciences	Researcher	Metric	TotalImpact	Author contribution, publication count and citation count	For each of the authors, the total number of publications in peer-reviewed journals (P), total number of citations (C), international collaboration metrics, number of citations per publication (CPP), h-index, and i10-index are extracted (using SciVal). This metric assessed whether authors were leading the research or coauthoring by judging their position in the list of authors for each article. Authors listed as first, second, or last (FSL) were classified as lead researchers, and those listed in-between as coauthors. Each author's total impact was then quantified by: TotalImpact=P×C×FSL.
Franceschini	2012	Scientometrics	Both	Metric	Information not available	Citation counts and h-index	A study specific measurement that includes the number of publications/patents and their citations and also quantifies average number of co-authors relating to publications/patents of one researcher (an indicator of tendency for co-authorship). It also uses the minimum and maximum years: the oldest publication/patent and the year relating to their latest one. This provide an indication of the temporal extension of the publishing or patenting activity of a researcher. They also use the most-cited is publication/patent of a researcher, representing the "jewel in the crown" in terms of impact/diffusion. These metrics are also scalable to teams though, where the h-spectrum is h-values to a group of researchers (including average and medium), and the h-group is the h-index of the union of publications patents associated with publications/patents.
Franceschini	2012	Scientometrics	Researcher	Metric	The Success-Index	Citation counts, NSP-index by Komulski (2011)	This metric is based on Komulski's (2011) NSP (number of successful papers) index with the exception that for each publication the comparison term is sometimes replaced by a more appropriate indicator of propensity to cite, determined on the basis of a representative sample of publications. While it is more complicated than the original, it is insensitive to differential propensity to cite and therefore suitable for comparisons between authors of different fields.

Frittelli	2016	Journal of the Association for Information Science and Technology	Researcher	Metric	SRM - Scientific Research Measures	h-index and calculus	Proposes a novel class of measures (SRM) based on calculus principles that rank a scientist's research performance by taking into account the whole citation curve of a researcher (their performance curve = number of citations of each publication, in decreasing order of citations). The performance cures can be chosen flexibly (e.g., to reflect seniority, characteristics of a field). They extend this idea by proposing Dual SRMs, which are based on theories of risk-measures. It better distinguishes researchers with the same citation curve.
Gao	2016	PLOS One	Both	Metric	PR-index - PageRank Index	Network analysis and h-index	This metric uses PageRank score calculation combined with h-index calculation to measure author impact. It considers publication and citation quantity but also takes a publication’s citation network into consideration. This means the index will rank majority authors higher by applying PageRank based on the publication citation relationship (distinguishing higher quality citations from lower ones).
Han	2013	Institute of Strategic Studies Islamabad	Both	Metric	New Evaluation Index	Network analysis	The new evaluation index takes into account direct and indirect references, direct and indirect citations, and citation network.
Holliday	2010	International Journal of General Medicine	Article	Model	Modified Delphi technique of peer-review	Peer-review	This paper reports using the modified Delphi process to appraise and rank research applications, with experts rating each application's scientific merit, originality, the adequacy of the study design to achieve the research goals, and whether the potential impact of the study would warrant its funding. While its ease of administration, reproducibility, and accessibility makes this a useful adjunct to the traditional processes of grant selection, it does not directly assess individual researcher's but their work.
Hutchins	2016	PLOS Biology	Both	Metric	iCite	Citation count	This is used for individual articles and normalizes their citation score by adding in co-citation metrics.
Ibrahim	2015	New Library World	Both	Metric	Hx	h-index and author contribution	This metric is a hybridization of two indicators based on the individual h-index (weighted by the average number of co-authors for each paper) and h-index contemporary weighted by qualitative factors (conferences and journal in which a researcher participated or published). It accounts for the period of citations and number of authors on a paper, is applicable at all levels and for any discipline of research, takes conferences into consideration, and is thought to reduce unscientific practices such as integration of authors who have not genuinely contributed.

Ioannidis	2016	PLOS Biology	Researcher	Metric	Composite	Citation count, h-index and author contribution	A study-specific composite metric based: on total number of citations in, for example, 2013 (NC), total number of citations received in 2013 to papers for which the researcher is single author (NS), total number of citations received in 2013 to papers for which the author is single or first author (NSF), total number of citations received in 2013 to papers for which the researcher is single, first, or last author (NSFL). Added to these are the h-index and modified h-index. The indicators are standardized (NC, H, Hm, NS, NSF, NSFL), giving each a standardized value from 0 to 1, where 1 is given to the researcher with the highest raw value for the respective indicator. The six standardized indicators are then summed to generate the composite index C. Well-tested and validated using factor analysis, which yielded two factors: bulk impact (NC and H), author order and co-authorship-adjusted impact (Hm, NS, NSF, and NSFL).
Iyendar	2009	Academic Medicine	Researcher	Model	RD - Research Density and Individual Impact Factor	IF	RD measures the ability to obtain grants at a point in time, while IFF reflects the quality of research. The adopted methodology compares the impact factor of an investigator's articles with those of the top journals within their own field. Each investigator identified the top three journals in his or her field. The average impact factor of these three journals was used as the benchmark for that investigator. Each faculty member was then asked to calculate his or her own individual impact factor (IIF) for two consecutive years, using 75% of their benchmark as target. This benchmark was selected after reviewing results of comparisons of investigators' IIFs with their self-defined benchmarks at several multiples (50%, 75%, and 100%). We used 75% of the self-defined benchmark as the target, because it is unlikely for every paper to be published in the best journal in the field, and yet 75% reflects the reasonably high standard of the research quality that MSSM strives for. The data were collated and the IIF of each faculty member was computed as the ratio of his or her impact factor to 75% of his or her self-defined benchmark, expressed as a percentage.
Jeang	2008	Retrovirology	Researcher	Metric	Mentoring Index	h-index	Argues that good mentoring should be a significant consideration of one's contribution to science. It focuses on using the h-index of previous trainees in evaluating established researchers. It is thought this index could encourage the development of long-lasting mentoring relationships.

Krapivin	2009	Complex Sciences	Both	Metric	PaperRank and PR-hirsch	Network analysis and h-index	Based on PageRank, which has been very successful in ranking web pages, essentially considering the reputation of the web page referring to a given page, and the outgoing link density (i.e., pages P linked by pages L where L has few outgoing links are considered more important than pages P cited by pages L where L has many outgoing links). PaperRank (PR) applies page rank to papers by considering papers as web pages and citations as links, and hence trying to consider not only citations when ranking papers, but also taking into account the rank of the citing paper and the density of outgoing citations from the citing paper. The PR-Hirsch is a modification of the H-index based on the same PageRank approach. PR and PR-Hirsch are complementary to citation-based metrics, capable of capturing information present in the whole citation network, namely the “weight” (the reputation or authority) of a citing paper.
Kreines	2016	Journal of Computer and Systems Sciences International	Article	Model	Information not available	Citation count and IF	Proposes a model for assessing quality in the content of individual articles using computational analysis with bibliometric and scientometric data (number of citations and the journal's IF).
Lando	2014	PLOS One	Article	Metric	ℓ-index	h-index	This index considers the most elite papers and rewards papers of high impact and based on the form of the citation distribution. It is thought to outperform the h-index in terms of accuracy and sensitivity to the form of the citation distribution, while being strongly correlated with other important h-type indices. It rewards the more regular and reliable researchers.
Liang	2015	IEEE International Conference on Smart City/SocialCom/ SustainCom	Both	Model	Temporal tracking model		The temporal research evolution model takes into account individual output, researcher profile and experiences

Lippi	2017	Annals of Translational Medicine	Researcher	Metric	SIF-Scientist Impact Factor	IF	This metric is calculated as all citations of articles published in the two years following the publication year of the articles, divided by the overall number of articles published in that year. For example, the SIF for the year 2017 would be obtained by dividing all citations in the years 2015–2016 to articles published in the year 2014, divided by the overall number of articles published in the year 2014. The total number of recent citations is normalized according to the number of recently published articles, limiting the bias emerging from publishing a large number of scarcely cited articles; and the output measure reliably reflects the recent scientific impact of the scientist, so complementing an overall career indicator, such as the h-index.
Markpin	2008	Scientometrics	Other	Metric	ACIF - Article-Count Impact Factor	IF	This is proposed as a journal-level metric that is calculated as the total number of articles cited in the current year divided by the number of articles published in 1st and 2nd year. Note that is based on the number of articles that were cited, rather than the times cited of the cited articles. However, it could be used for individual researchers.
Matsas	2012	Brazilian Journal of Physics	Both	Metric	NIF - Normalized Impact Factor	IF	Introduces a normalized impact factor that looks at the researchers influence on their scientific community by assessing the degree to which they have been influenced by their community. Looks each of an author's publications, the number of co-authors, references in the article and citations it has received. From the way it is calculated: "in a closed community of identical individuals (i.e., who publish, reference and are cited by each other at the same rate), all members have NIF = 1." Leaders in a field are then those with a NIF greater than or equal to 1 i.e., they influence their peers at least as much as they are influenced by them.
Maunder	2007	La Revue Canadienne de Psychiatrie	Article	Metric	Citation Ratio	Citation count	This metric is designed to overcome systematic differences amongst niche fields by comparing the impact of a particular paper to the average impact of a paper in its journal. A ratio above 1 indicates relatively greater success.
Mazloumian	2011	PLOS One	Article	Metric	Boost Factor	Citation count	This metric calculates when a particular research gains scientific authority, that is, they publish some groundbreaking work that then leads to an upswing in citations of their earlier papers. It is able to model the trend of the "rich get richer", a cascade of citations and is too improve the "signal-to-noise" ratio in citation rates by detecting sudden changes in citations.

Milone	2016	American Journal of Orthopedics	Article	Metric	Information not available	Publication count	A study specific measurement simply calculated by taking the mean of first and last authored publications.
Mooji	2014	Scientometrics	Both	Model	Information not available	Peer-review, altmetrics, citation count	This paper proposes a comprehensive and new framework for assessing research quality assessment which utilizes intrinsic (i.e., the internal quality of a publication) and extrinsic indicators (i.e., citation counts, web-based influence). It uses peer-review ratings for the former and bibliometric and altmetric data at the individual article and author levels for the latter. One limit includes that the assessment of extrinsic factors is still biased in terms of multi-author papers. This framework builds in a quality check on peer-review.
Moreira	2015	PLOS One	Researcher	Metric	µ	Information not available	Suggests accumulated citations from an author's aggregated publications follow an asymptotic number, and then use a lognormal model. Creates µ as a scale of expected citability of a researcher's publication. It is able to be used at all career stages and indicates more of quality over quantity.
Morel	2009	PLOS Neglected Tropic Diseases	Researcher	Metric	Information not available	Network Analysis	Co-citation networks generated using SNA of publications, to identify groups and individuals with high collaboration rates.
Niederkrotenthaler	2011	BMC Public Health	Article	Model	Information not available	Information not available	A tool designed to measure the societal impact of research publications. It consists of three quantitative dimensions: (1) the aim of a publication, (2) the efforts of the authors to translate their research results, and, if translation was accomplished, (3) (a) the size of the area where translation was accomplished (regional, national or international), (b) its status (preliminary versus permanent) and (c) the target group of the translation (individuals, subgroup of population, total population).
Nosek	2010	Personality and Social Psychology Bulletin	Researcher	Metric	Ics-Individual researcher career-stage impact	Citation count	Produces career-stage metric of scientific impact based on citation counts. Its development was based on extensive data collection to produce a regression of expected growth of impact over time. It, therefore, reflects the distance from one's expected impact at a given career stage.
Pagani	2015	Scientometrics	Article	Metric	Methodi Ordinatio	IF	Based on IF, number of citations and year of publication in a normalized, weighted mathematical equation. It is a potential way to define scientific relevance.

Pan	2014	Science Reports	Researcher	Metric	Author Impact Factor (AIF)		Defined as the AIF of an author A in year t is the average number of citations given by papers published in year t to papers published by A in a period of Δt years before year t. Uses a time window of years for calculation.
Patel	2013	Journal of the Royal Society of Medicine	Researcher	Model	sRM - statistical Regression Model	Citation count	Used to estimate the number of high visibility (based on citation count) publications of each researcher.
Pepe	2012	PLOS One	Researcher	Metric	TORI - Total Research Impact	Citation count	Includes non-self-citations accrued by the researcher, number of authors on cited paper and number of bibliographic references to generate the cumulative output of a scholar by summing the impact of every external citation accrued in his/her career. This removes biases associated with citation counts.
Petersen	2013	Journal of Informetrics	Researcher	Metric	Z	h-index	Z is aimed at correcting the h-index's penalty (which in some cases neglects 75% of an author's body of work) by including the total number of citations for their work in the metric.
Põder	2017	Trames-Journal of the Humanities and Social Sciences	Researcher	Metric	(Current or predicted) impact rate of researcher	Citation count	Based on the citations per year squared, this metric provides a means of assessing acceleration/impact and is based on time series data. This is more sensitive to productivity overtime and can go down unlike the h-index.
Prathap	2014	Scientometrics	Researcher	Metric	Z-index	h-index	Purporting to include quality, quantity and consistency, it accounts for the high-end of research performance, while compensating for the skewness of citation-publication distributions.
Radicchi	2008	Proceedings of the National Academy of Sciences of the United States of America	Article	Metric	Relative Indicator - cf	Citation count	The relative indicator is used to deal with the fact that different fields have different citation patterns and allows for comparisons of the success of articles in different fields.
Ribas	2015	Proceedings of the 24th International Conference on World Wide Web	Both	Metric	P-score	Citation count	It associates a reputation with publication venues based on the publication patterns of reference groups, composed by researchers, in a given area of knowledge. Although the choice of reference groups can be made by using available citation data, the P-score metric itself does not depend on citation data. It uses just publication records of researchers and research groups; that is, the papers and the venues where they published in.

Ricker	2009	Interciencia	Researcher	Model	Rule-based peer-review	Peer-review	Computer generated peer-review, which is positive as researchers get peer-review feedback. Can also measure evaluators select certain criteria of interest, important journals of interest based on field.
Ruane	2009	Scientometrics	Both	Metric	h1-index	h-index	A measure of supervision quality, it gives the supervisor h1 index calculated by the h-indexes of their PhD students.
Sahoo	2017	Omega	Researcher	Model	Composite indicator	h-index, IF, citation counts	Calculated based on the relative weight of the six indicators of journal tier, total citations, author h-index, number of papers, impact factor, and journal h-index.
Saxena	2013	Journal of Pharmacology Pharmacotherapeutics	Researcher	Metric	ORPI - Original Research Publication Index	Citation count	Indicates originality, productivity, and visibility, by including total number of original articles, citations, accounting for self-citations, and the total number of citable articles (i.e., including reviews and case reports). Also accounts for author order and career length.
Sibbald	2015	Journal of the Medical Library Association	Both	Model	Modified approach to citation analysis	Citation count	Includes grey literature in the citation analysis search process and involves quantitative and qualitative methods of analysis to gain a better understanding of how a research paper was used. However, this is more expensive and time consuming than traditional metrics.
Sittig	2015	MEDINFO 2015: eHealth-enabled Health	Researcher	Model	The Biomedical Informatics Researchers ranking website	Information not available	This new system was developed to overcome previous scientific productivity ranking strategies. However, it is limited to biomedical informatics.
Sorenson	2011	Journal of Parkinson's Disease	Both	Metric	"Broad impact" citations	Citation count	Citations from those outside the field are used as a measure of broader impact.
Surla	2017	The Electronic Library	Researcher	Metric	Research Impact Factor	IF	Allows a measure of scientific influence of a researcher in their relative scientific area.
Szymanski	2012	Information Sciences	Both	Metric	CENTs - sCientific currENcy Tokens and the I-index	Citation count and h-index	An accumulation of "cents" based on the number of non-self-citations. This is also the premise behind the i-index, whereby papers a ranked according to CENTs rather than just all citations.

Tan	2016	The Annals of Applied Statistics	Article	Model	Information not available	Citation count	Proposes to use two established models in the creation of a third. The proposed model provides a structural understanding of the field variation in citation behavior and a measure of visibility for individual articles adjusted for citation probabilities within/between topics.
Vieira	2011	Scientometrics	Researcher	Metric	hnf-index	h-index	Considers the different cultures of citation of each field and the number of authors per publication, and hence can be used to measure researcher performance.
Wagner	2012	Research Evaluation	Researcher	Metric	I3 - Integrated impact indicator	Citation count	A framework for integrating citations and non-parametric statistics of percentiles, which allow highly cited papers to be weighted more than less-cited ones.
Waltman	2013		Article	Metric	HCP – Highly cited publications index	Citation count	A simple model in which the number of citations of a publication depends not only on the scientific impact of the publication but also on other 'random' factors. Does not account for productivity.
Wang	2013	Science	Article	Model	Mechanistic model for citation dynamics	Citation count	Authors demonstrate a predictable course for citations of single articles over time, purporting, therefore, to create more reliable predictive index of individual impact.
Williamson	2008	Family Medicine	Researcher	Metric	Information not available	Too broad to classify	Quantifies activities within three domains: teaching, service and research and scholarly activity. A time intensive- process that is suitable for promotion within institutions, but not grant funding or more macro-scale assessments.
Wootton	2013	Health Research Policy and Systems	Researcher	Metric	R - Simple indicator of researcher output		Formula is R=g+p+s and comprises grant income (g), publications (peer-reviewed and weighted by JIF; p) and numbers of PhD students supervised (no credit for submission after the due date of submission; s).
Yaminfirooz	2015	The Electronic Library	Both	Metric	mh-index	h-index	Use to identify differences in the impact of authors with the same h-index, and differences between the outputs of influential researchers working in a certain field and the ones publishing only a few papers during a year, can track the impact of highly cited papers.
Yang	2013	Journal of Informetrics	Researcher	Metric	A-index - Axiomatic approach	Citation count and author contribution	Allows for evaluation of individual researcher in the team context (i.e., co-authorship networks).

Zhang	2012	Scientometrics	Both	Model	Scientometric age pyramid	Information not available	Accounts for the different ages of academics, different fields, co-authorship patterns and analysis of journals. The pyramid represents the number of publications on one side and number of citations on the other side.
Zhou	2012	New Journal of Physics	Both	Metric	AP Algorithm	Citation count	Considers the prestige of the scientists citing the article but assumes equal contribution of each author to the paper.
Zhu	2015	arXiv	Researcher	Metric	The hip index - Influence-primed h-index	h-index	The hip-index weights citations by how many times a reference is mentioned, which is thought to make it a better indicator of researcher performance.
Zhuo	2008	Omega	Other	Metric	Z factor	IF	Uses both the number of publications and the impact factors of the journals in which they were published.
Zou	2016	Scientometrics	Researcher	Metric	S-ZP index	IF	Metric based on journal impact factor of publications and author order.
Zycxkowski	2010	Scientometrics	Both	Metric	C - Citation matrix	h-index	A scheme based on weighing the citation based on previous scientific achievements and authors citing the paper.

Reporting checklist for systematic review and meta-analysis.

Based on the PRISMA guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

Upload your completed checklist as an extra file when you submit to a journal.

In your methods section, say that you used the PRISMA reporting guidelines, and cite them as:

Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement

		Reporting Item	Page Number
	#1	Identify the report as a systematic review, meta-analysis, or both.	Title page
Structured summary	#2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis	2-3

		methods; results; limitations; conclusions and implications of key findings; systematic review registration number	
Rationale	#3	Describe the rationale for the review in the context of what is already known.	4-5
Objectives	#4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	5-7
Protocol and registration	#5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address) and, if available, provide registration information including the registration number.	Review protocol exists but is unpublished
Eligibility criteria	#6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rational	5-7
Information sources	#7	Describe all information sources in the search (e.g., databases with dates of coverage, contact with study authors to identify additional studies) and date last searched.	5-7
Search	#8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	4-7, Appendix 1

Study selection	#9	State the process for selecting studies (i.e., for screening, for determining eligibility, for inclusion in the systematic review, and, if applicable, for inclusion in the meta-analysis).	4-7
Data collection process	#10	Describe the method of data extraction from reports (e.g., piloted forms, independently by two reviewers) and any processes for obtaining and confirming data from investigators.	5-7 and Appendix 2
Data items	#11	List and define all variables for which data were sought (e.g., PICOS, funding sources), and any assumptions and simplifications made.	Page 6-7 and Appendix 2
Risk of bias in individual studies	#12	Describe methods used for assessing risk of bias in individual studies (including specification of whether this was done at the study or outcome level, or both), and how this information is to be used in any data synthesis.	5-7
Summary measures	#13	State the principal summary measures (e.g., risk ratio, difference in means).	The primary outcome measure was methods to assess research achievement.
Planned methods of analyis	#14	Describe the methods of handling data and combining results of studies, if done, including	6-7

		measures of consistency (e.g., I2) for each meta-analysis.	
Risk of bias across studies	#15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	5-6
Additional analyses	#16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	8-12
Study selection	#17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	7-8
Study characteristics	#18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citation.	8-12
Risk of bias within studies	#19	Present data on risk of bias of each study and, if available, any outcome-level assessment (see Item 12).	6
Results of individual studies	#20	For all outcomes considered (benefits and harms), present, for each study: (a) simple summary data for each intervention group and (b) effect estimates and confidence intervals, ideally with a forest plot.	7-11

Synthesis of results	#21	Present the main results of the review. If meta-analyses are done, include for each, confidence intervals and measures of consistency.	Not applicable to this review.
Risk of bias across studies	#22	Present results of any assessment of risk of bias across studies (see Item 15).	4-5
Additional analysis	#23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	Not applicable to this review.
Summary of Evidence	#24	Summarize the main findings, including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., health care providers, users, and policy makers	13-17
Limitations	#25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review level (e.g., incomplete retrieval of identified research, reporting bias).	15-16
Conclusions	#26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	16-17
Funding	#27	Describe sources of funding or other support (e.g., supply of data) for the systematic review; role of funders for the systematic review.	18

BMJ Open

The Comprehensive Researcher Achievement Model (CRAM): a framework for measuring researcher achievement, impact and influence derived from a systematic literature review of metrics and models

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-025320.R2
Article Type:	Research
Date Submitted by the Author:	04-Feb-2019
Complete List of Authors:	Braithwaite, Jeffrey; Macquarie University, Australian Institute of Health Innovation Herkes, Jessica; Macquarie University, Australian Institute of Health Innovation Churruca, Kate; Macquarie University, Australian Institute of Health Innovation; Macquarie University Long , Janet; Australian Institute of Health Innovation, Centre for Healthcare Resilience and Implementation Science Pomare, Chiara; Macquarie University Faculty of Medicine and Health Sciences, Australian Institute of Health Innovation Boyling, Claire; Macquarie University Faculty of Medicine and Health Sciences, Australian Institute of Health Innovation Bierbaum, Mia; Macquarie University, Australian Institute of Health Innovation Clay-Williams, Robyn; Macquarie University, Australian Institute of Health Innovation Rapport, Frances ; Macquarie University, Australian Institute of Health Innovation Shih, Patti; Macquarie University, Australian Institute of Health Innovation Hogden, Anne; Macquarie University, Australian Institute of Health Innovation Ellis, Louise A.; Macquarie University, Institute of Health Innovation Ludlow, Kristiana; Macquarie University, Australian Institute of Health Innovation Austin, Elizabeth; Macquarie University Faculty of Medicine and Health Sciences, Australian Institute of Health Innovation Seah, Rebecca; Macquarie University Faculty of Medicine and Health Sciences, Australian Institute of Health Innovation McPherson, Elise; Macquarie University, Australian Institute of Health Innovation Hibbert, Peter; Macquarie University Faculty of Medicine and Health Sciences, Faculty of Medicine and Health Sciences; University of South Australia Division of Health Sciences, Westbrook, Johanna; Macquarie University Faculty of Medicine and Health Sciences, Australian Institute of Health Innovation

Primary Subject Heading:	Research methods
Secondary Subject Heading:	Health services research
Keywords:	Researcher assessment, Research metrics, h-index, Journal impact factor, Comprehensive Researcher Achievement Model (CRAM), Citations

The Comprehensive Researcher Achievement Model (CRAM): a framework for measuring researcher achievement, impact and influence derived from a systematic literature review of metrics and models

Authors

Professor Jeffrey Braithwaite (JB)*[1], BA, MIR (Hons), MBA, DipLR, PhD, FIML, FCHSM, FFPHRCP (UK), FACSS, Hon FRACMA, FAHMS

Ms Jessica Herkes (JH) [1], BSc (Adv), MRes

Dr Kate Churruca (KC) [1], BA (Hons) Psych, PhD

Dr Janet C Long (JCL) [1], BSc (Hons), MN (Ed), CertOpthNurs, PhD, FISQua

Ms Chiara Pomare (CP) [1], BPsych (Hons), MRes

Ms Claire Boyling (CB) [1], BHSc (Health Promotion)

Ms Mia Bierbaum (MB) [1], BSc (Biomedical), B.Ed, Grad Dip TESOL, MPH

Dr Robyn Clay-Williams (RC-W) [1], BEng, PhD

Professor Frances Rapport (FR) [1], BA (Hons), Cert Ed, FRSA, MPhil, PhD

Dr Patti Shih (PS) [1], BA(Hons), M.Pub.Pol., PhD

Dr Anne Hogden (AH) [1], BA (Hons), B SpPath, PhD, FISQua

Dr Louise A Ellis (LAE) [1], BPsych (Hons), PhD

Ms Kristiana Ludlow (KL) [1], BPsych (Hons), MRes

Dr Elizabeth Austin (EA) [1], BA (Hons) Psych, PhD

Ms Rebecca Seah (RS) [1], BSc Psychology (Hons I) Bcomm

Ms Elise McPherson (EM) [1], BA, BSc(Hons)

Mr Peter Hibbert (PH)[1], B.App.Sc (Physio), Grad.Dip. Comp, Grad.Dip. Econ, FAAQHC

Professor Johanna I Westbrook (JIW) [1], BAppSc, GradDipAppEpid, MHA, PhD

[1]Australian Institute of Health Innovation, Macquarie University, Sydney, Australia

***Corresponding Author**

Level 6, 75 Talavera Rd

Macquarie University, North Ryde

New South Wales, Australia, 2109

e: Jeffrey.braithwaite@mq.edu.au

1

ABSTRACT

Objectives Effective researcher assessment is key to decisions about funding allocations, promotion and tenure. We aimed to identify what is known about methods for assessing researcher achievements, leading to a new composite assessment model.

Design We systematically reviewed the literature via the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) framework.

Data sources All Web of Science databases (including Core Collection, MEDLINE, and BIOSIS Citation Index) to the end of 2017.

Eligibility criteria (1) English language, (2) published in the last 10 years (2007-2017), (3) full text was available, and (4) the article discussed an approach to the assessment of an individual researcher's achievements.

Data extraction and synthesis Articles were allocated amongst four pairs of reviewers for screening, with each pair was randomly assigned 5% of their allocation to review concurrently against inclusion criteria, with inter-rater reliability assessed using Cohen's Kappa (κ). The κ statistic showed agreement ranged from moderate to almost perfect (0.4848-0.9039). Following screening, selected articles underwent full text review and bias assessed.

Results Four hundred and seventy-eight articles were included in the final review. Established approaches developed prior to our inclusion period (e.g., citations and outputs, h-index, journal impact factor), remained dominant in the literature and in practice. New bibliometric methods and models emerged in the last 10 years including: measures based on PageRank algorithms or "altmetric" data, methods to apply peer judgement, and techniques to assign values to publication quantity and quality. Each assessment method tended to prioritize certain aspects of achievement over others.

Conclusions All metrics and models focus on an element or elements, at the expense of others. A new composite design, the Comprehensive Researcher Achievement Model (CRAM) is presented which supersedes past anachronistic models. The CRAM is modifiable to a range of applications.

Keywords: Researcher assessment; Research metrics; h-index; Journal impact factor; citations; outputs; Comprehensive Researcher Achievement Model (CRAM)

Article Summary

Strengths and limitations of this study

- A large, diverse dataset of over 478 articles, containing many ideas for assessing researcher performance, was analyzed
- Strengths of the review include executing a wide-ranging search strategy, and the consequent high number of included articles for review; the results are limited by the literature itself, e.g., new metrics were not mentioned in the articles, and therefore not captured in the results
- A new model combining multiple factors to assess researcher performance is now available
- Its strengths include combining quantitative and qualitative components in the one model
- The CRAM model, despite being evidence-oriented, is a generic one and now needs to be applied in the field

INTRODUCTION

Judging researchers' achievements and academic impact continues to be an important means of allocating scarce research funds and assessing candidates for promotion or tenure. It has historically been carried out through some form of expert peer judgement, to assess the number and quality of outputs, and in more recent decades, citations to them. This approach requires judgements regarding the weight which should be assigned to the number of publications, their quality, where they were published, and their downstream influence or impact. There are significant questions about the extent to which human judgement based on these criteria is an effective mechanism for making these complex assessments in a consistent and unbiased way.(1-3) Criticisms of peer assessment, even when underpinned by relatively impartial productivity data, include the propensity for bias, inconsistency among reviewers, nepotism, group-think and subjectivity.(4-7)

To compensate for these limitations, approaches have been proposed that rely less on subjective judgement and more on objective indicators.(3, 8-10) Indicators of achievement focus on one or a combination of four aspects: quantity of researcher outputs (*productivity*); value of outputs (*quality*); outcomes of research outputs (*impact*); and relations between publications or authors and the wider world (*influence*).(11-15) Online publishing of journal articles has provided the opportunity to easily track citations and user interactions (e.g., number of article downloads) and thus has provided a new set of indices against which individual researchers, journals and articles can be compared and the relative worth of contributions assessed and valued.(14) These relatively new metrics have been collectively termed *bibliometrics*(16) when based on citations and numbers of publications, or *altmetrics*(17) when calculated by alternative online measures of impact such as number of downloads or social media mentions.(16)

The most established metrics for inferring researcher achievement are the h-index and the Journal Impact Factor (JIF). The JIF measures the average number of citations of an article in the journal over the previous year, and hence is a good indication of journal quality but is increasingly regarded as a primitive measure of quality for individual researchers.(18) The h-index, proposed by Hirsch in 2005,(19) attempts to portray a researcher's productivity and impact in one data point. The h-index is defined as the number (h) of articles published by a researcher that have received a citation count of at least h. Use of the h-index has become widespread, reflected in its inclusion in author profiles on online databases such as Google Scholar and Scopus.

Also influenced by the advent of online databases, there has been a proliferation of other assessment models and metrics,(16) many of which purport to improve upon existing approaches.(20, 21) These include methods that assess the impact of articles measured by: downloads or online views received; practice change related to specific research; take-up by the scientific community; or mentions in social media.

Against the backdrop of growth in metrics and models for assessing researchers' achievements, there is a lack of guidance on the relative strengths and limitations of these different approaches. Understanding them is of fundamental importance to funding bodies that drive the future of research, tenure and promotion committees, and more broadly for providing insights into how we recognize and value the work of science and scientists, particularly those researching in medicine and healthcare. This review aimed to identify approaches to assessing researchers' achievements published in the academic literature over the last 10 years, considering their relative strengths and limitations and drawing on this to propose a new composite assessment model.

METHOD

Search Strategy

All Web of Science databases (eight in total, including Web of Science Core Collection, MEDLINE, and BIOSIS Citation Index) were searched using terms related to researcher achievement (*researcher excellence, track record, researcher funding, researcher perform*, relative to opportunity, researcher potential, research* career pathway, academic career pathway, funding system, funding body, researcher impact, scientific* productivity, academic productivity, top researcher, researcher ranking, grant application, researcher output, h*index, i*index, impact factor, individual researcher*) and approaches to its assessment (*model, framework, assess*, evaluat*, *metric*, measur*, criteri*, citation*, unconscious bias, rank**) with "*" used as an unlimited truncation to capture variation in search terms, as seen in **Appendix 1**. These two searches were combined (using "*and*") and results were downloaded into EndNote, the reference management software.

Study Selection

After removing duplicate references in EndNote,(22) articles were allocated amongst pairs of reviewers (MB-JCL, CP-CB, KL-JH, KC-LAE) for screening against inclusion criteria. Following established procedures,(23, 24) each pair was randomly assigned 5% of their allocation to review concurrently against inclusion criteria, with inter-rater reliability assessed using Cohen's Kappa (κ). The κ statistic was calculated for pairs of researchers, with agreement ranging from moderate to almost perfect (0.4848-0.9039).(25) Following the abstract and title screen, selected articles underwent full text review. Reasons for exclusion were recorded.

Inclusion Criteria

The following inclusion criteria were operationalized: (1) English language, (2) published in the last 10 years (2007-2017), (3) full text for the article was available, and (4) the article discussed an approach to the assessment of an individual researcher's achievements (at the researcher or singular output-level). The research followed the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) framework.(26) Empirical and non-empirical articles were included, because many articles proposing new approaches to assessment, or discussing the limitations of existing ones, are not level one evidence or research-based. Both quantitative and qualitative studies were included.

Data Extraction

Data from the included articles were extracted, including: the country of article origin, the characteristics of the models or metrics discussed, the perspective the article presented on the metric or model (positive, negative, indeterminable) including any potential benefits or limitations of the assessment model (and if these were perceived or based on some form of evidence). A customised data extraction sheet was developed in Microsoft Excel, trialed among members of the research team and subsequently refined. This information was synthesized for each model and metric identified through narrative techniques. The publication details and classification of each paper are contained in **Appendix 2**.

Appraisal of the Literature

Due to the prevalence of non-empirical articles in this field (e.g., editorial contributions, commentaries), it was determined that a risk of bias tool such as the Quality Assessment Tool could not be applied.(27) Rather, assessors were trained in multiple meetings (October 24, October 30, November 13, 2017) to critically assess the quality of articles. Given the topic of the review (focusing on the publication process), the type of models and metrics identified (i.e., more metrics that use publication metrics) may influence the cumulative evidence and subsequently create a risk of bias. In addition, three researchers (JH, EM, CB) reviewed every included article, to extract documented conflicts of interests of authors.

Patient and public involvement

Patients and the public were not involved in this systematic review.

RESULTS

The final dataset consisted of 478 academic articles. The data screening process is presented in **Figure 1**.

Figure 1. Data screening and extraction process for academic articles
<Insert Figure 1>

Of the 478 included papers (see **Appendix 2** for a summary), 295 (61.7%) had an empirical component, which ranged from interventional studies that assessed researcher achievement as an outcome measure (e.g., a study measuring the outcomes of a training program),(28) as a predictor(29-31) (e.g., a study that demonstrated the association between number of citations early in one's career and later career productivity), or reported a descriptive analysis of a new metric.(32, 33) One hundred and sixty-six (34.7%) papers were not empirical, including editorial or opinion contributions that discussed the assessment of research achievement, or proposed models for assessing researcher achievement. Seventeen papers (3.6%) were reviews that considered one or more elements of assessing researcher achievements. The quality of these contributions ranged in terms of the risk of bias in the viewpoint expressed. Only for 19 papers (4.0%) did the authors declare a potential conflict of interest.

Across the study period, 78 articles (16.3%) involved authors purporting to propose new models or metrics. Most articles described or cited pre-existing metrics and largely discussed their perceived strengths and limitations. **Figure 2** shows the proportion of positive or negative discussions of five of the most common approaches to assessing an individual's research achievement (altmetrics, peer-review, h-index, simple counts, and JIF). The approach with most support was altmetrics (51.0% of articles mentioning altmetrics). The JIF was discussed with mostly negative sentiments in relevant articles (69.4%).

Figure 2. Percentages of positive and negative discussion regarding selected commonly used metrics for assessing individual researchers (n=478 articles)

<Insert Figure 2>

Legend: Positive discussion refers to articles that discuss the metric in a favorable light or focus on the strengths of the metric; negative discussion refers to articles that focus on the limitations or shortcomings of the metric.

Citation-Based Metrics

Publication and Citation Counts

One hundred and fifty-three papers (32.0%) discussed the use of publication and citation counts for purposes of assessing researcher achievement, with papers describing them as a simple "traditional but somewhat crude measure",(34) as well as the building blocks for other metrics.(35) A researcher's number of publications, commonly termed an n-index,(36) was suggested by some to indicate researcher productivity,(14) rather than quality, impact or influence of these papers.(37) On the other hand, the literature suggested that numbers of citations indicated the academic impact of an individual publication or researcher's body of work, calculated as an author's cumulative or mean citations per article.(38) Some studies found support for the validity of citation counts and publications in that they were correlated with other indications of a researcher's achievement, such as awards and grant funding,(39, 40) and predictive of long term success in a field.(41) For example, one paper argued that having larger numbers of publications and being highly cited early in one's career predicted later high quality research.(42)

A number of limitations of using citation or publication counts was observed. For example, Minasny et al. (2013) highlighted discrepancies between publications and citations counts in different databases because of their differential structures and inputs.(43) Other authors(38, 44, 45) noted that citation patterns vary by discipline, which they suggested can make them inappropriate for comparing researchers from different fields. Average citations per publication were reported as highly sensitive to change or could be skewed if, for example, a researcher has one heavily-cited article.(46, 47) A further disadvantage is the lag-effect of citations,(48, 49) and that in most models citations and publications count equally for all co-authors, despite potential differential contributions.(50) Some also questioned the extent to which citations actually indicated quality or impact, noting that a paper may influence clinical practice more than academic thinking.(51) Indeed, a paper may be highly cited because it is useful (e.g., a review), controversial, or even by chance, making citations a limited indication of quality or impact.(40, 50, 52) In addition to limitations, numerous authors made the point that focusing on citation and publication counts can have unintended, negative consequences for the assessment of researcher achievement, potentially leading to gaming and manipulation, including self-citations and gratuitous authorship.(53, 54)

Singular Output-Level Approaches

Forty-one papers (8.6%) discussed models and metrics at the singular output or article-level that could be used to infer researcher achievement. The components of achievement they reported assessing were typically quality or impact.(55, 56) For example, some papers reported attempts to examine the quality of a single article by assessing its content.(57, 58) Among the metrics identified in the literature, the immediacy index (II) focused on impact by measuring the average number of cites an article received in the year it was published.[(59)] Similarly, Finch suggested adapting the Source Normalized Impact per Publication (SNIP; a metric used for journal-level calculations across different fields of research) to the article-level.(21)

Many of the article-level metrics identified could also be upscaled to produce researcher-level indications of academic impact. For example, the sCientific currENcy Tokens (CENTs), proposed by Szymanski et al. (2012), involved giving a "cent" for each new non-self-citation a publication received; CENTs are then used as the basis for the researcher-level i-index, which follows a similar approach as the h-index, but removes self-citations.[(60)] The TAPSIF (Temporally-Averaged Paper-Specific Impact Factor) calculates an article's average number of citations per year combined with bonus cites for the publishing journal's prestige, and can be aggregated to measure the overall relevance of a researcher (Temporally Averaged Author-Specific Impact Factor; TAASIF).(61)

Journal impact factor

The JIF, commonly recognized as a journal-level measure of quality,(59, 62-64) was discussed in 211 (44.1%) of the papers reviewed in relation to assessing singular outputs or individual researchers. A number of papers described the JIF being used informally to assess an individual's research achievement at the singular output-level, and formally in countries such as France and China.(65) It implies article quality because it is typically a more competitive process to publish in journals with high impact factors.(66) Indeed, the JIF was found to be the best predictor of a paper's propensity to receive citations.(67)

The JIF has a range of limitations when used to indicate journal quality,(68) including that it is disproportionally affected by highly cited, outlier articles,(41, 69) and is susceptible to "gaming" by editors.(17, 70) Other criticisms focused on using the JIF to assess individual articles or the researchers who author them.(71) Some critics claimed that using the JIF to measure an individual's achievement encourages researchers to publish in higher-impact but less-appropriate journals for their field—which ultimately means their article may not be read by relevant researchers.(72, 73) Furthermore, the popularity of a journal was argued to be a poor indication of the quality of any one article, with the citation distributions for calculating JIF found to be heavily skewed (i.e., a small subset of papers receive the bulk of the citations while some may receive none).(18) Ultimately, many commentators argued that the JIF is an inappropriate metric to assess individual researchers because it is an aggregate metric of a journal's publication, and expresses nothing about any individual paper.(21, 49, 50, 74) However, Bornmann et al. (2017) suggested one case in which it would be appropriate to use JIF for assessing individual researchers: in relation to their recently published papers that had not had the opportunity to accumulate citations.(75)

Researcher-Level Approaches

h-index

The h-index was among the most commonly discussed metrics in the literature (254 [53.1%] of the papers reviewed); in many of these papers, it was described by authors as more sophisticated than citation and publication counts, but still straightforward, logical and intuitive.(76-78) Authors noted its combination of productivity (h publications) and impact indicators (h citations) as being more reliable(79, 80) and stable than average citations per publications(41) because it is not skewed by the influence of one popular article.(81) One study found that the h-index correlated with other metrics more difficult to obtain.(78) It also showed convergent validity with peer-reviewed assessments(82) and was found to be a good predictor of future achievement.(41)

However because of the lag-effect with citations and publications, the h-index increases with a researcher's years of activity in the field, and cannot decrease, even if productivity later declines.(83) Hence, numerous authors suggested it was inappropriate for comparing researchers at different career stages,(84) or those early in their career.(70) The h-index was also noted as being susceptible to many of the critiques leveled against citation counts, including potential for gaming, and inability to reflect differential contributions by co-authors.(85) Because disciplines differ in citation patterns(86) some studies noted variations in author h-indices between different methodologies(87) and within medical subspecialties.(88) Some therefore argued that the h-index should not be used as the sole measure of a researcher's achievement.(88)

h-index variants

A number of modified versions of the h-index were identified; these purported to draw on its basic strengths of balancing productivity with impact while redressing perceived limitations. For example, the g-index measures global citation performance,(89) and was defined similarly to the h-index but with more weight given to highly cited articles by assuming the top g articles have received at least g^2 citations.(90) Azer and Azer (2016) argued it was a more useful measure of researcher productivity.(91) Another variant of the h-index identified, the m-quotient, was suggested to minimize the potential to favor senior academics by accounting for the time passed since a researcher has begun publishing papers.(92, 93) Other h-index variations reported in the articles reviewed attempted to account for author contributions, such as the h-maj index, which includes only articles in which the researcher played a core role (based on author order); and the weighted h-index, which assigns credit points according to author order.(89, 94)

Recurring Issues with Citation-Based Metrics

The literature review results suggested that no one citation-based metric was ideal for all purposes. All of the common metrics examined focused on one aspect of an individual's achievement, and thus failed to account for other aspects of achievement. The limitations with some of the frequently used citation-based metrics are listed in **Box 1**.

Box 1. Common limitations in the use of citation-based metrics

1. Challenges with reconciling differences in citation patterns across varying fields of study
2. Time-dependency issues stemming from differences in career length of researchers
3. Prioritizing impact over merit, or quality over quantity, or vice versa
4. The lag-effect of citations
5. Gaming and the ability of self-citation to distort metrics
6. Failure to account for author order
7. Contributions from authors to a publication are viewed as equal when they may not be
8. Perpetuate "publish or perish" culture
9. Potential to stifle innovation in favor of what is popular

Non-Citation Based Approaches

altmetrics

In contradistinction with the metrics discussed above, fifty-four papers (11.3%) discussed altmetrics (or "alternative metrics"), which included a wide range of techniques to measure non-traditional, non-citation based usage of articles, that is, influence.(17) Altmetric measures included the number of online article views,(95) bookmarks,(96) downloads,(41) PageRank algorithms(97) and attention by mainstream news,(65) in books(98) and social media, for example, in blogs, commentaries, online topic reviews or tweets.(99, 100) These metrics typically measure the "web visibility" of an output.(101) A notable example is the social networking site for researchers and scientists, ResearchGate, which uses an algorithm to score researchers based on the use of their outputs, including citations, reads, and recommendations.(102)

A strength of altmetrics lies in providing a measure of influence promptly after publication.(70, 103, 104) Moreover, altmetrics allows tracking of the downloads of multiple sources (e.g., students, the general public, clinicians, as well as academics) and multiple types of format (e.g., reports and policy documents),(105) which are useful in gauging a broader indication of impact or influence, compared to more traditional metrics that solely or largely measure acknowledgement by experts in the field through citations.(17)

Disadvantages noted in the articles reviewed included that altmetrics calculations have been established by commercial enterprises such as *Altmetrics LLC (London, UK)* and other competitors,(106) and there may be fees levied for their use. The application of these metrics has also not been standardized.(98) Furthermore, it has been argued that, because altmetrics are cumulative and typically at the article-level, they provide more an indication of influence or even popularity,(107) instead of quality or productivity.(108) Hence, one study suggested no correlation between attention on Twitter and expert analysis of an article's originality, significance or rigour.(109) Another showed that Tweets predict citations.(110) Overall, further work needs to assess the value of altmetric scores in terms of their association with other traditional indicators of achievement.(111) Notwithstanding this, there were increasing calls to consider altmetrics alongside more conventional metrics in assessing researchers and their work.(112)

Past Funding

A past record of being funded by national agencies was identified as a common measurement of individual academic achievement (particularly productivity, quality and impact) in a number of papers, and has been argued to be a reliable method that is consistent across medical research.(113-115) For example, the NIH's (National Institute of Health's) RePORT (Research Portfolio Online Reporting Tools) system encourages public accountability for funding by providing online access to reports, data and NIH-funded research projects.(113, 116)

New Metrics and Models Identified

The review also identified and assessed new metrics and models that were proposed during the review period, many of which had not gained widespread acceptance or use. While there was considerable heterogeneity and varying degrees of complexity among the 78 new approaches identified, there were also many areas of overlap in their methods and purposes. For example, some papers reported on metrics that used a PageRank algorithm,(117, 118) a form of network analysis based on structural characteristics of publications (e.g., co-authorship or citation patterns).(14) Metrics based on PageRank purported to measure both the direct and indirect impact of a publication or researcher. Other approaches considered the relative contributions of authors to a paper in calculating productivity.(119) Numerous metrics and models that built upon existing approaches were also reported.(120) For example, some developed composite metrics that included a publication's JIF alongside an author contribution measure(121) or other existing metrics.(122) However, each of these approaches reported limitations, in addition to their strengths or improvements upon other methods. For example, in focusing on productivity, a metric necessarily often neglected impact.(123) **Appendix 3** provides a summary of these new or re-fashioned metrics and models, with details of their basis and purpose.

DISCUSSION

This systematic review identified a large number of diverse metrics and models for assessing an individual's research achievement that have been developed in the last 10 years (2007-2017), as evidenced in **Appendix 3.** At the same time, other approaches that pre-dated our study time period of 2007-2017 were also discussed frequently in the literature reviewed, including the h-index and JIF. All metrics and models proposed had their relative strengths, based on the components of achievement they focused on, and their sophistication or transparency.

The review also identified and assessed new metrics and over the past few decades. Peer-review has been increasingly criticized for reliance on subjectivity and propensity for bias,(7) and there have been arguments that the use of specific metrics may be a more objective and fair approach for assessing individual research achievement. However, this review has highlighted that even seemingly objective measures have a range of shortcomings. For example, there are inadequacies in comparing researchers at different career stages, and across disciplines with different citation patterns.(86) Furthermore, the use of citation-based metrics can lead to gaming and potential ethical misconduct by contributing to a "publish or perish" culture in which researchers are under pressure to maintain or improve their publication records.(124, 125) New methods and adjustments to existing metrics have been proposed to explicitly address some of these limitations; for example, normalizing metrics with "exchange rates" to remove discipline-specific variation in citation patterns, thereby making metric scores more comparable for researchers working in disparate fields.(126, 127) Normalization techniques have also been used to assess researchers' metrics with greater recognition of their relative opportunity and career longevity.(128)

Other criticisms of traditional approaches center less on how they calculated achievement, and more on what they understood or assumed about its constituent elements. In this review, the measurement of impact or knowledge gain was often exclusively tied to citations.(129) Some articles proposed novel approaches to using citations as a measure of impact, such as giving greater weight to citations from papers that were themselves highly cited(130) or that come from outside the field in which the paper was published.(131) However, even other potential means of considering scientific contributions and achievement, such as mentoring, were still ultimately tied to citations because mentoring was measured by the publication output of mentees.(132)

A focus only on citations was widely thought to disadvantage certain types of researchers. For example, researchers who aim to publish with a focus on influencing practice may target more specialized or regional journals that do not have high JIFs, where their papers will be read by the appropriate audience and findings implemented, but they may not be well-cited.(51) In this regard, categorizing the type of journal in which an article has been published in terms of its focus (e.g., industry, clinical, regional/national) may go some way toward recognizing those publications that have a clear knowledge translation intention, and therefore prioritize real-world impact over academic impact.(124) There were only a few other approaches identified that captured broader conceptualizations of knowledge gain, such as practical impact or wealth generation for the economy, and these too were often simplistic, such as including patents and their citations(133) or altmetric data.(98) While altmetrics hold potential in this regard, their use has not been standardized,(98) and they come with their own limitations, with suggestions that they reflect popularity more so than real world impact.(107) Other methodologies have been proposed for assessing knowledge translation and real-world impact, but these can often be labor intensive.(134) For example, Sutherland et al. (2011)(135) suggested that assessing individual research outputs in light of specific policy objectives, through peer-review based scoring, may be a strategy, but this is typically not feasible in situations such as grant funding allocation, where there are time-constraints and large applicant pools to assess.

In terms of how one can make sense of the validity of many of these emerging approaches for assessing an individual's research achievements, metrics should demonstrate their legitimacy empirically, as well as having a theoretical basis for their use and clearly differentiating what aspects of quality, achievement or impact they purport to examine.(55, 67) If the recent, well-publicized(136-138) San Francisco Declaration on Research Assessment (DORA)(139) is anything to go by, internationally there is a move away from the assessment of individual researchers using the JIF and the journal in which the research has been published.

Figure 3. The Comprehensive Researcher Achievement Model (CRAM)

<Insert Figure 3>

There is momentum, instead, for assessment of researcher achievements on the basis of a wider mix of measures, hence our proposed Comprehensive Researcher Achievement Model (CRAM) (**Figure 3**). On the left-hand side of this model is the researcher to be assessed, and key characteristics that influence the assessment. Among these factors, some (i.e., field or discipline, co-authorship, career longevity) can be controlled for depending on the metric, while other components, such as gaming or the research topic (i.e., whether it is "trendy" or innovative) are less amenable to control or even prediction. Online databases, which track citations and downloads and measure other forms of impact, hold much potential and will likely be increasingly used in the future to assess both individual researchers and their outputs. Hence, assessment components (past funding, articles, citations, patents, downloads, and some media traction) included in our model are those primarily accessible online.

Strengths and Limitations

The findings of this review suggest assessment components should be used with care, and with recognition of how they can be influenced by other factors, and what aspects of achievement they reflect (i.e., productivity, quality, impact, influence). No metric or model singularly captures all aspects of achievement, and hence use of a range, such as the examples in our model, is advisable. CRAM recognizes that the configuration and weighting of assessment methods will depend on the assessors and their purpose, the resources available for the assessment process, and access to assessment components. Our results must be interpreted in light of our focus on academic literature. The limits of our focus on peer-reviewed literature were evident in the fact some new metrics were not mentioned in articles, and therefore not captured in our results. While we defined impact broadly at the outset, overwhelmingly the literature we reviewed focused on academic, citation-based impact. Furthermore, although we assessed bias in the ways documented, the study design limited our ability to apply a standardized quality assessment tool. A strength of our focus was that we set no inclusion criteria with regard to scientific discipline, because novel and useful approaches to assessing research achievement can come from diverse fields. Many of the articles we reviewed were broadly in the area of health and medical research, and our discussion is concerned with the implications for health and medical research, as this is where our interests lie.

CONCLUSION

There is no ideal model or metric by which to assess individual researcher achievement. We have proposed a generic model, designed to minimize risk of the use of any one or a smaller number of metrics, but it is not proposed as an ultimate solution. The mix of assessment components and metrics will depend on the purpose. Greater transparency in approaches used to assess achievement including their evidence-base is required.(37) Any model used to assess achievement for purposes such as promotion or funding allocation should include some quantitative components, based on robust data, and be able to be rapidly updated, presented with confidence intervals, and normalized.(37) The assessment process should be difficult to manipulate, and explicit about the components of achievement being measured. As such, no current metric suitably fulfills all these criteria. The best strategy to assess an individual's research achievement is likely to involve the use of multiple approaches(140) in order to dilute the influence and potential disadvantages of any one metric, while providing more rounded picture of a researcher's achievement;(85, 141) this is what the CRAM aims to contribute.

All-in-all, achievement in terms of impact and knowledge gain is broader than the number of articles published or their citation rates, and yet most metrics have no means of factoring in these broader issues. Altmetrics hold promise in complementing citation-based metrics and assessing more diverse notions of impact, but usage of this type of tool requires further standardization.(98) Finally, despite the limitations of peer-review, the role of expert judgement should not be discounted.(41) Metrics are perhaps best applied as a complement or check on the peer-review process, rather than the sole means of assessment of an individual's research achievements.(142)

Acknowledgements

None.

Competing Interests

The authors have declared that no competing interests exist.

Funding

The work on which this paper is based was funded by the Australian National Health and Medical Research Council (NHMRC) for work related to an assessment of its peer review processes being conducted by the Council. Staff of the Australian Institute of Health Innovation undertook this systematic review for Council as part of that assessment. Other than specifying what they would like to see from a literature review, NHMRC had no role in the conduct of the systematic review, or the decision to publish.

Data sharing statement

All data has been made available as Appendices.

Author Contributions

JB conceptualized and drafted the manuscript, revised it critically for important intellectual content, and led the study. JH, KC and JCL made substantial contributions to the design, analysis and revision of the work and critically reviewed the manuscript for important intellectual content. CP, CB, MB, RC-W, FR, PS, AH, LAE, KL, EA, RS and EM carried out the initial investigation, sourced and analyzed the data and revised the manuscript for important intellectual content. PH and JIW critically commented on the manuscript, contributed to the revision and editing of the final manuscript and reviewed the work for important intellectual content. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

REFERENCES

1. Ibrahim N, Chaibi AH, Ben Ahmed M. New scientometric indicator for the qualitative evaluation of scientific production. *New Libr World*. 2015;116(11-12):661-76. doi:10.1108/nlw-01-2015-0002
2. Aixela FJ, Rovira-Esteva S. Publishing and impact criteria, and their bearing on translation studies: in search of comparability. *Perspectives-Studies in Translatology*. 2015;23(2):265-83. doi:10.1080/0907676x.2014.972419
3. Belter CW. Bibliometric indicators: opportunities and limits. *J Med Libr Assoc*. 2015;103(4):219-21. doi:10.3163/1536-5050.103.4.014
4. Frixione E, Ruiz-Zamarripa L, Hernandez G. Assessing individual intellectual output in scientific research: Mexico's national system for evaluating scholars performance in the humanities and the behavioral sciences. *PLOS One*. 2016;11(5): doi: 10.1371/journal.pone.0155732. doi:10.1371/journal.pone.0155732
5. Marzolla M. Assessing evaluation procedures for individual researchers: the case of the Italian national scientific qualification. *J Informetr*. 2016;10(2):408-38. doi:10.1016/j.joi.2016.01.009
6. Marsh HW, Jayasinghe UW, Bond NW. Improving the peer-review process for grant applications-reliability, validity, bias, and generalizability. *Am Psychol*. 2008;63(3):160-8. doi:10.1037/0003-066x.63.3.160
7. Kaatz A, Magua W, Zimmerman DR, et al. A quantitative linguistic analysis of national institutes of health R01 application critiques from investigators at one institution. *Acad Med*. 2015;90(1):69-75. doi:10.1097/acm.0000000000000442
8. Aoun SG, Bendok BR, Rahme RJ, et al. Standardizing the evaluation of scientific and academic performance in neurosurgery-critical review of the "h" index and its variants. *World Neurosurg*. 2013;80(5):E85-E90. doi:10.1016/j.wneu.2012.01.052
9. Hicks D, Wouters P, Waltman L, et al. Bibliometrics: the Leiden Manifesto for research metrics. *Nature*. 2015;520(7548):429-31. doi:10.1038/520429a
10. King J. A review of bibliometric and other science indicators and their role in research evaluation. *J Inf Sci*. 1987;13(5):261-76. doi:10.1177/016555158701300501
11. Abramo G, Cicero T, D'Angelo CA. A sensitivity analysis of researchers' productivity rankings to the time of citation observation. *J Informetr*. 2012;6(2):192-201. doi:10.1016/j.joi.2011.12.003
12. Arimoto A. Declining symptom of academic productivity in the Japanese research university sector. *High Educ*. 2015;70(2):155-72. doi:10.1007/s10734-014-9848-4
13. Carey RM. Quantifying scientific merit is it time to transform the impact factor? *Circ Res*. 2016;119(12):1273-5. doi:10.1161/circresaha.116.309883
14. Durieux V, Gevenois PA. Bibliometric indicators: quality measurements of scientific publication. *Radiology*. 2010;255(2):342-51. doi:10.1148/radiol.09090626
15. Selvarajoo K. Measuring merit: take the risk. Science. 2015;347(6218):139-40.
16. Wildgaard L, Schneider JW, Larsen B. A review of the characteristics of 108 author-level bibliometric indicators. *Scientometrics*. 2014;101(1):125-58. doi:10.1007/s11192-014-1423-3
17. Maximin S, Green D. The science and art of measuring the impact of an article. *Radiographics*. 2014;34(1):116-8. doi:10.1148/rg.341134008
18. Callaway E. Publishing elite turns against impact factor. *Nature*. 2016;535(7611):210-1.
19. Hirsch JE. An index to quantify an individual's scientific research output. *Proc Natl Acad Sci USA*. 2005;102(46):16569-72.

20. Bollen J, Crandall D, Junk D, et al. An efficient system to fund science: from proposal review to peer-to-peer distributions. *Scientometrics.* 2017;110(1):521-8. doi:10.1007/s11192-016-2110-3
21. Finch A. Can we do better than existing author citation metrics? *Bioessays*. 2010;32(9):744-7. doi:10.1002/bies.201000053
22. EndNote. Clarivate Analytics; 2017.
23. Schlosser RW. Appraising the quality of systematic reviews. *Focus: Technical Briefs*. 2007;17:1-8.
24. Braithwaite J, Herkes J, Ludlow K, et al. Association between organisational and workplace cultures, and patient outcomes: systematic review. *BMJ Open*. 2017;7(11):e017708.
25. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33(1):159-74.
26. Shamseer L, Moher D, Clarke M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. *BMJ.* 2015;2(349):g7647.
27. Hawker S, Payne S, Kerr C, et al. Appraising the evidence: reviewing disparate data systematically. *Qual Health Res*. 2002;12(9):1284-99.
28. Thorngate W, Chowdhury W. By the numbers: track record, flawed reviews, journal space, and the fate of talented authors. In: Kaminski B, Koloch G, editors. Advances in Social Simulation: Proceedings of the 9th Conference of the European Social Simulation Association. Advances in Intelligent Systems and Computing. 229. Heidelberg, Germany: Springer Berlin; 2014. p. 177-88.
29. Sood A, Therattil PJ, Chung S, et al. Impact of subspecialty fellowship training on research productivity among academic plastic surgery faculty in the United States. *Eplasty*. 2015;15:e50.
30. Mutz R, Bornmann L, Daniel H-D. Testing for the fairness and predictive validity of research funding decisions: a multilevel multiple imputation for missing data approach using ex-ante and ex-post peer evaluation data from the Austrian science fund. *J Assoc Inf Sci Technol.* 2015;66(11):2321-39. doi:10.1002/asi.23315
31. Rezek I, McDonald RJ, Kallmes DF. Pre-residency publication rate strongly predicts future academic radiology potential. *Acad Radiol.* 2012;19(5):632-4. doi:10.1016/j.acra.2011.11.017
32. Knudson D. Kinesiology faculty citations across academic rank. *Quest.* 2015;67(4):346-51. doi:10.1080/00336297.2015.1082144
33. Wang D, Song C, Barabasi A-L. Quantifying long-term scientific impact. *Science.* 2013;342(6154):127-32. doi:10.1126/science.1237825
34. Efron N, Brennan NA. Citation analysis of Australia-trained optometrists. *Clin Exp Optom*. 2011;94(6):600-5. doi:10.1111/j.1444-0938.2011.00652.x
35. Perlin MS, Santos AAP, Imasato T, et al. The Brazilian scientific output published in journals: a study based on a large CV database. *J Informetr.* 2017;11(1):18-31. doi:10.1016/j.joi.2016.10.008
36. Stallings J, Vance E, Yang J, et al. Determining scientific impact using a collaboration index. *Proc Natl Acad Sci USA*. 2013;110(24):9680-5. doi:10.1073/pnas.1220184110
37. Kreiman G, Maunsell JHR. Nine criteria for a measure of scientific output. *Front Comput Neurosci.* 2011;5(48): doi: 10.3389/fncom.2011.00048. doi:10.3389/fncom.2011.00048
38. Mingers J. Measuring the research contribution of management academics using the Hirsch-index. *J Oper Res Soc.* 2009;60(9):1143-53. doi:10.1057/jors.2008.94

39. Halvorson MA, Finlay AK, Cronkite RC, et al. Ten-year publication trajectories of health services research career development award recipients: collaboration, awardee characteristics, and productivity correlates. *Eval Health Prof.* 2016;39(1):49-64. doi:10.1177/0163278714542848
40. Stroebe W. The graying of academia: will it reduce scientific productivity? *Am Psychol*. 2010;65(7):660-73. doi:10.1037/a0021086
41. Agarwal A, Durairajanayagam D, Tatagari S, et al. Bibliometrics: tracking research impact by selecting the appropriate metrics. *Asian J Androl*. 2016;18(2):296-309. doi:10.4103/1008-682x.171582
42. Jacob JH, Lehrl S, Henkel AW. Early recognition of high quality researchers of the German psychiatry by worldwide accessible bibliometric indicators. *Scientometrics.* 2007;73(2):117-30. doi:10.1007/s11192-006-1729-x
43. Minasny B, Hartemink AE, McBratney A, et al. Citations and the h-index of soil researchers and journals in the Web of Science, Scopus, and Google Scholar. *Peerj.* 2013;1: doi: 10.7717/peerj.183. doi:10.7717/peerj.183
44. Gorraiz J, Gumpenberger C. Going beyond citations: SERUM - a new tool provided by a network of libraries. *Liber Quarterly.* 2010;20(1):80-93.
45. van Eck NJ, Waltman L, van Raan AFJ, et al. Citation analysis may severely underestimate the impact of clinical research as compared to basic research. *PLOS One*. 2013;8(4): doi: 10.1371/journal.pone.0062395. doi:10.1371/journal.pone.0062395
46. Meho LI, Rogers Y. Citation counting, citation ranking, and h-index of human-computer interaction researchers: a comparison of Scopus and Web of Science. *J Assoc Inf Sci Technol.* 2008;59(11):1711-26. doi:10.1002/asi.20874
47. Selek S, Saleh A. Use of h index and g index for American academic psychiatry. *Scientometrics.* 2014;99(2):541-8. doi:10.1007/s11192-013-1204-4
48. Kali A. Scientific impact and altmetrics. *Indian J Pharmacol.* 2015;47(5):570-1. doi:10.4103/0253-7613.165184
49. Neylon C, Wu S. Article-level metrics and the evolution of scientific impact. *PLOS Biol.* 2009;7(11): doi: 10.1371/journal.pbio.1000242. doi:10.1371/journal.pbio.1000242
50. Sahel J-A. Quality versus quantity: assessing individual research performance. *Sci Transl Med.* 2011;3(84): doi: 10.1126/scitranslmed.3002249. doi:10.1126/scitranslmed.3002249
51. Pinnock D, Whittingham K, Hodgson LJ. Reflecting on sharing scholarship, considering clinical impact and impact factor. *Nurse Educ Today.* 2012;32(7):744-6. doi:10.1016/j.nedt.2012.05.031
52. Eyre-Walker A, Stoletzki N. The assessment of science: the relative merits of post-publication review, the impact factor, and the number of citations. *PLOS Biol.* 2013;11(10). doi:10.1371/journal.pbio.1001675
53. Ferrer-Sapena A, Sanchez-Perez EA, Peset F, et al. The Impact Factor as a measuring tool of the prestige of the journals in research assessment in mathematics. *Res Eval.* 2016;25(3):306-14. doi:10.1093/reseval/rvv041
54. Moustafa K. Aberration of the citation. *Account Res.* 2016;23(4):230-44.
55. Abramo G, D'Angelo CA. Refrain from adopting the combination of citation and journal metrics to grade publications, as used in the Italian national research assessment exercise (VQR 2011-2014). *Scientometrics*. 2016;109(3):2053-65. doi:10.1007/s11192-016-2153-5
56. Páll-Gergely B. On the confusion of quality with impact: a note on Pyke's m-index. *BioScience*. 2015;65(2):117. doi:10.1093/biosci/biu207

57. Niederkrotenthaler T, Dorner TE, Maier M. Development of a practical tool to measure the impact of publications on the society based on focus group discussions with scientists. *BMC Public Health*. 2011;11(588): doi: 10.1186/471-2458-11-588. doi:10.1186/1471-2458-11-588
58. Kreines EM, Kreines MG. Control model for the alignment of the quality assessment of scientific documents based on the analysis of content-related context. *J Comput Syst Sci.* 2016;55(6):938-47. doi:10.1134/s1064230716050099
59. DiBartola SP, Hinchcliff KW. Metrics and the scientific literature: deciding what to read. *J Vet Intern Med*. 2017;31(3):629-32. doi:10.1111/jvim.14732
60. Szymanski BK, Lluis de la Rosa J, Krishnamoorthy M. An internet measure of the value of citations. *J Inf Sci.* 2012;185(1):18-31. doi:10.1016/j.ins.2011.08.005
61. Bloching PA, Heinzl H. Assessing the scientific relevance of a single publication over time. *S Afr J Sci.* 2013;109(9/10): doi: 10.1590/sajs.2013/20130063.
62. Benchimol Barbosa PR. Comments on paper by Thomas et al: how to evaluate "quality of publication". *Arq Bras Cardiol.* 2011;97(1):88-9.
63. Benchimol-Barbosa PR, Ribeiro RL, Barbosa EC. Further comments on the paper by Thomas et al: how to evaluate "quality of publication". *Arq Bras Cardiol.* 2011;97(1):88.
64. Benchimol-Barbosa PR, Ribeiro RL, Barbosa EC. Additional comments on the paper by Thomas et al: how to evaluate "quality of publication". *Arq Bras Cardiol.* 2011;97(1):88-9.
65. Slim K, Dupre A, Le Roy B. Impact factor: an assessment tool for journals or for scientists? *Anaesth Crit Care Pain Med.* 2017;36(6):347-8. doi:10.1016/j.accpm.2017.06.004
66. Diem A, Wolter SC. The use of bliometrics to measure research performance in education sciences. *Res High Edu.* 2013;54(1):86-114. doi:10.1007/s11162-012-9264-5
67. Bornmann L, Leydesdorff L. Does quality and content matter for citedness? A comparison with para-textual factors and over time. *J Informetr.* 2015;9(3):419-29. doi:10.1016/j.joi.2015.03.001
68. Santangelo GM. Article-level assessment of influence and translation in biomedical research. *Mol Biol Cell*. 2017;28(11):1401-8. doi:10.1091/mbc.E16-01-0037
69. Ravenscroft J, Liakata M, Clare A, et al. Measuring scientific impact beyond academia: an assessment of existing impact metrics and proposed improvements. *PLOS One.* 2017;12(3). doi:10.1371/journal.pone.0173152
70. Trueger NS, Thoma B, Hsu CH, et al. The altmetric score: a new measure for article-level dissemination and impact. *Ann Emerg Med.* 2015;66(5):549-53. doi:10.1016/j.annemergmed.2015.04.022
71. Welk G, Fischman MG, Greenleaf C, et al. Editorial board position statement regarding the declaration on research assessment (DORA) - recommendations rith respect to journal impact factors. *Res Q Exerc Sport*. 2014;85(4):429-30. doi:10.1080/02701367.2014.964104
72. Taylor DR, Michael LM, II, Klimo P, Jr. Not everything that matters can be measured and not everything that can be measured matters response. *J Neurosurg.* 2015;123(3):544-5.
73. Christopher MM. Weighing the impact (factor) of publishing in veterinary journals. *J Vet Sci.* 2015;17(2):77-82. doi:10.1016/j.jvc.2015.01.002
74. Jokic M. H-index as a new scientometric indicator. Biochemia Med. 2009;19(1):5-9.
75. Bornmann L, Pudovkin AI. The journal impact factor should not be discarded. *J Korean Med Sci.* 2017;32(2):180-2.

76. Franceschini F, Galetto M, Maisano D, et al. The success-index: an alternative approach to the h-index for evaluating an individual's research output. *Scientometrics.* 2012;92(3):621-41. doi:10.1007/s11192-011-0570-z

77. Prathap G. Citation indices and dimensional homogeneity. *Curr Sci*. 2017;113(5):853-5.

78. Saad G. Applying the h-index in exploring bibliometric properties of elite marketing scholars. *Scientometrics*. 2010;83(2):423-33. doi:10.1007/s11192-009-0069-z

79. Duffy RD, Jadidian A, Webster GD, et al. The research productivity of academic psychologists: assessment, trends, and best practice recommendations. *Scientometrics.* 2011;89(1):207-27. doi:10.1007/s11192-011-0452-4

80. Prathap G. Evaluating journal performance metrics. *Scientometrics*. 2012;92(2):403-8. doi:10.1007/s11192-012-0746-1

81. Lando T, Bertoli-Barsotti L. A new bibliometric index based on the shape of the citation distribution. *PLOS One*. 2014;9(12): doi: 10.1371/journal.pone.0115962. doi:10.1371/journal.pone.0115962

82. Bornmann L, Wallon G, Ledin A. Is the h index related to (standard) bibliometric measures and to the assessments by peers? An investigation of the h index by using molecular life sciences data. *Res Eval.* 2008;17(2):149-56. doi:10.3152/095820208x319166

83. Pepe A, Kurtz MJ. A measure of total research impact independent of time and discipline. *PLOS One.* 2012;7(11):e46428. doi:10.1371/journal.pone.0046428

84. Haslam N, Laham S. Early-career scientific achievement and patterns of authorship: the mixed blessings of publication leadership and collaboration. *Res Eval.* 2009;18(5):405-10. doi:10.3152/095820209x481075

85. Ioannidis JPA, Klavans R, Boyack KW. Multiple citation indicators and their composite across scientific disciplines. *PLOS Biol*. 2016;14(7): doi: 10.1371/journal.pbio.1002501. doi:10.1371/journal.pbio.1002501

86. van Leeuwen T. Testing the validity of the Hirsch-index for research assessment purposes. *Res Eval.* 2008;17(2):157-60. doi:10.3152/095820208x319175

87. Ouimet M, Bedard P-O, Gelineau F. Are the h-index and some of its alternatives discriminatory of epistemological beliefs and methodological preferences of faculty members? The case of social scientists in Quebec. *Scientometrics.* 2011;88(1):91-106. doi:10.1007/s11192-011-0364-3

88. Kshettry VR, Benzel EC. Research productivity and fellowship training in neurosurgery. World Neurosurg. 2013;80(6):787-8. doi:10.1016/j.wneu.2013.10.005

89. Biswal AK. An absolute index (Ab-index) to measure a researcher's useful contributions and productivity. *PLOS One*. 2013;8(12): doi: 10.1371/journal.pone.0084334. doi:10.1371/journal.pone.0084334

90. Tschudy MM, Rowe TL, Dover GJ, et al. Pediatric academic productivity: pediatric benchmarks for the h- and g-indices. *J Pediatr*. 2016;169:272-6. doi:10.1016/j.jpeds.2015.10.030

91. Azer SA, Azer S. Bibliometric analysis of the top-cited gastroenterology and hepatology articles. *BMJ Open.* 2016;6(2): doi: 10.1136/bmjopen-2015-009889. doi:10.1136/bmjopen-2015-009889

92. Joshi MA. Bibliometric indicators for evaluating the quality of scientifc publications. *J Contemp Dent Pract*. 2014;15(2):258-62.

93. Danielson J, McElroy S. Quantifying published scholarly works of experiential education directors. *Am J Pharm Edu*. 2013;77(8):167.

94. Ion D, Andronic O, Bolocan A, et al. Tendencies on traditional metrics. C*hirurgia (Bucur)*. 2017;112(2):117-23. doi:10.21614/chirurgia.112.2.117

95. Suiter AM, Moulaison HL. Supporting scholars: an analysis of academic library websites' documentation on metrics and impact. *J Acad Librariansh*. 2015;41(6):814-20. doi:10.1016/j.acalib.2015.09.004

96. Butler JS, Kaye ID, Sebastian AS, et al. The evolution of current research impact metrics from bibliometrics to altmetrics? *Clin Spine Surg*. 2017;30(5):226-8.

97. Krapivin M, Marchese M, Casati F. Exploring and understanding scientific metrics in citation networks. In: Zhou J, editor. Complex Sciences, Pt 2. Lecture Notes of the Institute for Computer Sciences Social Informatics and Telecommunications Engineering. 52009. p. 1550-63.

98. Carpenter TA. Comparing digital apples to digital apples: background on niso's effort to build an infrastructure for new forms of scholarly assessment. *Inf Serv Use.* 2014;34(1-2):103-6. doi:10.3233/isu-140739

99. Gasparyan AY, Nurmashev B, Yessirkepov M, et al. The journal impact factor: moving toward an alternative and combined scientometric approach. *J Korean Med Sci* 2017;32(2):173-9. doi:10.3346/jkms.2017.32.2.173

100. Moed HF, Halevi G. Multidimensional assessment of scholarly research impact. *J Assoc Inf Sci Technol.* 2015;66(10):1988-2002. doi:10.1002/asi.23314

101. Chuang K-Y, Olaiya MT, Ho Y-S. Bibliometric analysis of the Polish Journal of Environmental Studies (2000-11). *Pol J Environ Stud.* 2012;21(5):1175-83.

102. Vinyard M. Altmetrics: an overhyped fad or an important tool for evaluating scholarly output? Computers in Libraries. 2016;36(10):26-9.

103. van Noorden R. A profusion of measures. *Nature.* 2010;465(7300):864-6. doi:10.1038/465864a

104. van Noorden R. Love thy lab neighbour. *Nature.* 2010;468(7327):1011. doi:10.1038/4681011a

105. Dinsmore A, Allen L, Dolby K. Alternative perspectives on impact: the potential of ALMs and altmetrics to inform funders about research impact. *PLOS Biol.* 2014;12(11):e1002003. doi:10.1371/journal.pbio.1002003

106. Cress PE. Using altmetrics and social media to supplement impact factor: maximizing your article's academic and societal impact. *Aesthet Surg J.* 2014;34(7):1123-6. doi:10.1177/1090820x14542973

107. Moreira JAG, Zeng XHT, Amaral LAN. The distribution of the asymptotic number of citations to sets of publications by a researcher or from an academic department are consistent with a discrete lognormal model. *PLOS One.* 2015;10(11): doi: 10.1371/journal.pone.0143108. doi:10.1371/journal.pone.0143108

108. Waljee JF. Discussion: are quantitative measures of academic productivity correlated with academic rank in plastic surgery? A national study. *Plast Reconstr Surg.* 2015;136(3):622-3. doi:10.1097/prs.0000000000001566

109. Fazel S, Wolf A. What is the impact of a research publication? Evid Based Ment Health. 2017;20(2):33-4. doi:10.1136/eb-2017-102668

110. Eysenbach G. Can tweets predict citations? Metrics of social impact based on Twitter and correlation with traditional metrics of scientific impact. *J Med Internet Res.* 2011;13(4): doi: 10.2196/jmir.012. doi:10.2196/jmir.2012

111. Hoffmann CP, Lutz C, Meckel M. Impact factor 2.0: applying social network analysis to scientific impact assessment. In: Sprague RH, editor. 2014 47th Hawaii International Conference on System Sciences. Proceedings of the Annual Hawaii International Conference on System Sciences 2014. p. 1576-85.

112. Maggio LA, Meyer HS, Artino AR. Beyond citation rates: a real-time impact analysis of health professions education research using altmetrics. *Acad Med.* 2017;92(10):1449-55. doi:10.1097/acm.0000000000001897

113. Raj A, Carr PL, Kaplan SE, et al. Longitudinal analysis of gender differences in academic productivity among medical faculty across 24 medical schools in the United States. *Acad Med.* 2016;91(8):1074-9. doi:10.1097/acm.0000000000001251

114. Markel TA, Valsangkar NP, Bell TM, et al. Endangered academia: preserving the pediatric surgeon scientist. *J Pediatr Surg.* 2017;52(7):1079-83. doi:10.1016/j.jpedsurg.2016.12.006

115. Mirnezami SR, Beaudry C, Lariviere V. What determines researchers' scientific impact? A case study of Quebec researchers. *Sci Public Policy.* 2016;43(2):262-74. doi:10.1093/scipol/scv038

116. Napolitano LM. Scholarly activity requirements for critical care fellowship program directors: what should it be? How should we measure it? *Crit Care Med.* 2016;44(12):2293-6. doi:10.1097/ccm.0000000000002120

117. Bai X, Xia F, Lee I, et al. Identifying anomalous citations for objective evaluation of scholarly article impact. *PLOS One.* 2016;11(9): doi: 10.1371/journal.pone.0162364. doi:10.1371/journal.pone.0162364

118. Gao C, Wang Z, Li X, et al. PR-Index: using the h-Index and PageRank for determining true impact. *PLOS One.* 2016;11(9): doi: 10.1371/journal.pone.0161755. doi:10.1371/journal.pone.0161755

119. Assimakis N, Adam M. A new author's productivity index: p-index. *Scientometrics.* 2010;85(2):415-27. doi:10.1007/s11192-010-0255-z

120. Petersen AM, Succi S. The Z-index: a geometric representation of productivity and impact which accounts for information in the entire rank-citation profile. *J Informetr.* 2013;7(4):823-32. doi:https://doi.org/10.1016/j.joi.2013.07.003

121. Claro J, Costa CAV. A made-to-measure indicator for cross-disciplinary bibliometric ranking of researchers performance. *Scientometrics.* 2011;86(1):113-23. doi:10.1007/s11192-010-0241-5

122. Sahoo BK, Singh R, Mishra B, et al. Research productivity in management schools of India during 1968-2015: a directional benefit-of-doubt model analysis. *Omega Int J Manage S.* 2017;66:118-39. doi:10.1016/j.omega.2016.02.004

123. Aragon AM. A measure for the impact of research. *Sci Rep.* 2013;3: doi: 10.1038/srep01649. doi:10.1038/srep01649

124. Shibayama S, Baba Y. Impact-oriented science policies and scientific publication practices: the case of life sciences in Japan. *Res Policy.* 2015;44(4):936-50. doi:10.1016/j.respol.2015.01.012

125. Tijdink JK, Schipper K, Bouter LM, et al. How do scientists perceive the current publication culture? A qualitative focus group interview study among Dutch biomedical researchers. *BMJ Open.* 2016;6(2): doi: 10.1136/bmjopen-2015-008681. doi:10.1136/bmjopen-2015-008681

126. Crespo JA, Li Y, Ruiz-Castillo J. The measurement of the effect on citation inequality of differences in citation practices across scientific fields. *PLOS One*. 2013;8(3): doi: 10.1371/journal.pone.0058727. doi:10.1371/journal.pone.0058727

127. da Silva JAT. Does China need to rethink its metrics- and citation-based research rewards policies? *Scientometrics.* 2017;112(3):1853-7. doi:10.1007/s11192-017-2430-y

128. Devos P. Research and bibliometrics: a long history. *Clin Res Hepatol Gastroenterol.* 2011;35(5):336-7. doi:10.1016/j.clinre.2011.04.008

129. Slyder JB, Stein BR, Sams BS, et al. Citation pattern and lifespan: a comparison of discipline, institution, and individual. *Scientometrics.* 2011;89(3):955-66. doi:10.1007/s11192-011-0467-x

130. Zhou Y-B, Lu L, Li M. Quantifying the influence of scientists and their publications: distinguishing between prestige and popularity. *New J Phys*. 2012;14: doi: 10.1088/367-2630/14/3/033033. doi:10.1088/1367-2630/14/3/033033

131. Sorensen AA, Weedon D. Productivity and impact of the top 100 cited Parkinson's disease investigators since 1985. *J Parkinsons Dis*. 2011;1(1):3-13. doi:10.3233/jpd-2011-10021

132. Jeang K-T. H-index, mentoring-index, highly-cited and highly-accessed: how to evaluate scientists? *Retrovirology*. 2008;5(106). doi:10.1186/1742-4690-5-106

133. Franceschini F, Maisano D. Publication and patent analysis of European researchers in the field of production technology and manufacturing systems. *Scientometrics*. 2012;93(1):89-100. doi:10.1007/s11192-012-0648-2

134. Sibbald SL, MacGregor JCD, Surmacz M, et al. Into the gray: a modified approach to citation analysis to better understand research impact. *J Med Libr Assoc*. 2015;103(1):49-54. doi:10.3163/1536-5050.103.1.010

135. Sutherland WJ, Goulson D, Potts SG, et al. Quantifying the impact and relevance of scientific research. *PLOS One*. 2011;6(11):e27537. doi:10.1371/journal.pone.0027537

136. Nature Editorial Team. Announcement: Nature journals support the San Francisco Declaration on Research Assessment. *Nature*. 2017;544(7651):394. doi:10.1038/nature.2017.21882

137. Pugh EN, Jr., Gordon SE. Embracing the principles of the San Francisco Declaration of Research Assessment: Robert Balaban's editorial. *J Gen Physiol*. 2013;142(3):175. doi:10.1085/jgp.201311077

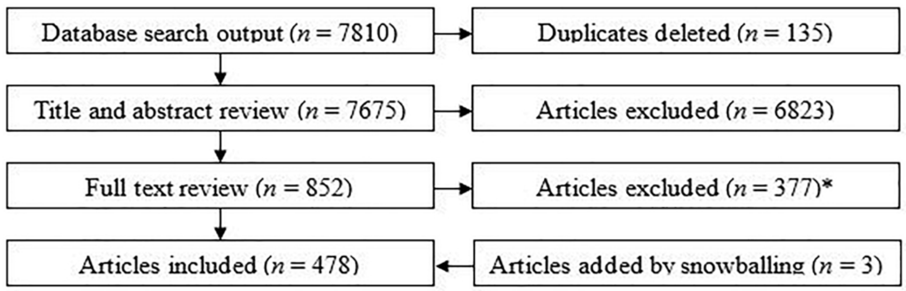
138. Zhang L, Rousseau R, Sivertsen G. Science deserves to be judged by its contents, not by its wrapping: revisiting Seglen's work on journal impact and research evaluation. *PLOS One*. 2017;12(3): doi: 10.1371/journal.pone.0174205. doi:10.1371/journal.pone.0174205

139. San Francisco Declaration on Research Assessment (DORA). DORA—ASCB San Francisco, US2016 [Available from: http://www.ascb.org/dora/.

140. Cabezas-Clavijo A, Delgado-Lopez-Cozar E. Google Scholar and the h-index in biomedicine: the popularization of bibliometric assessment. *Med Intensiva*. 2013;37(5):343-54. doi:10.1016/j.medin.2013.01.008

141. Iyengar R, Wang Y, Chow J, et al. An integrated approach to evaluate faculty members' research performance. *Acad Med*. 2009;84(11):1610-6. doi:10.1097/ACM.0b013e3181bb2364

142. Jacso P. Eigenfactor and article influence scores in the journal citation reports. *Online Inform Rev*. 2010;34(2):339-48. doi:10.1108/14684521011037034

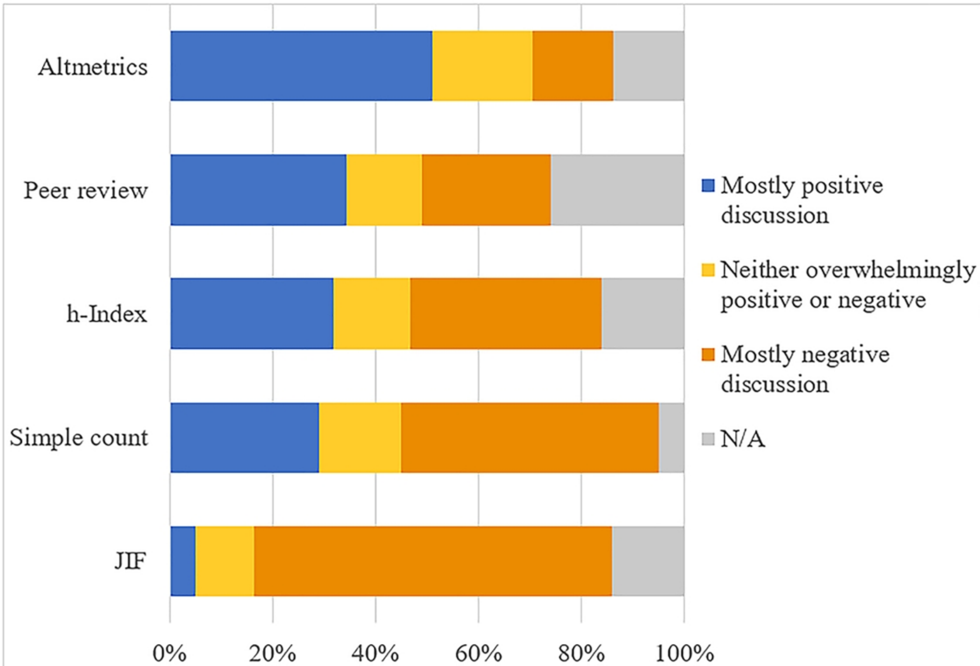


***Reasons for exclusion are noted below**

Reason for exclusion at the full text level	**Number of articles excluded**
Not in English language	47
Full text not available	62
Does not discuss assessment of an individual researcher	268
Total	**377**

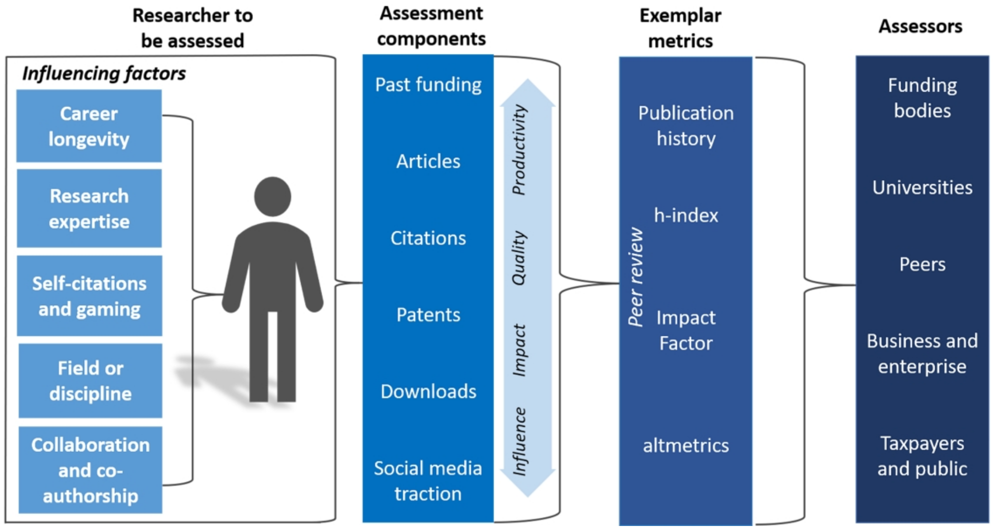
Data screening and extraction process for academic articles

279x188mm (300 x 300 DPI)



Percentages of positive and negative discussion regarding selected commonly used metrics for assessing individual researchers (n=478 articles)

279x191mm (300 x 300 DPI)



The Comprehensive Researcher Achievement Model (CRAM)

279x148mm (300 x 300 DPI)

Appendix 1: Full Search Strategy

Name of database	Web of Science Core Collection, BIOSIS Citation Index, Medline	
Platform	Web of Science [Clarivate Analytics]	
Database coverage	2007-2017	
Date exported to Reference Management Software (EndNote)	19th October 2017	
Search strategy	Model OR framework OR assess* OR evaluat*OR *metric*OR measur* OR criteri*OR citation*OR unconscious bias OR rank*	Results: 13,282,151
	AND	
	researcher excellence OR track record OR researcher funding OR researcher perform* OR relative to opportunity OR researcher potential OR research* career pathway OR academic career pathway OR funding system OR funding body OR researcher impact OR scientific* productivity OR academic productivity OR top researcher OR researcher ranking OR grant application OR researcher output OR h*index OR i*index OR impact factor OR individual researcher	Results: 11,616
	Combined sets [Auto select language based on search language]	Results: 7,530

Appendix 2: Summary table of included articles and the metrics or models they discuss

Publication Details				Metric or Model Assessing an Individual's Research Achievement						
First author	**Year**	**Journal name**	**Format^**	**Peer-review**	**Simple Counts**	**h-index**	**JIF**	**Other**	**Alt-metrics**	**New**
Abramo	2016	Scientometrics	ED					Y		
Agarwal	2016	Asian Journal of Andrology	ED		Y	Y	Y	Y	Y	
Ahmad	2013	Anesthesia and Analgesia	EM		Y					
Aixela	2015	Perspectives: Studies in Translatology	ED	Y		Y	Y	Y		
Akl	2012	Canadian Medical Association Journal	EM	Y						
Albion	2012	Australian Educational Researcher	EM			Y	Y	Y		
Alguliyev	2016	Journal of Scientometric Research	EM				Y	Y		
Allen	2010	ScienceAsia	ED			Y	Y			
Anderson	2008	Scientometrics	ED			Y				Y
Anderson	2017	Applied Economics	EM	Y		Y	Y			
Anfossi	2015	International Journal of Dermatology	EM				Y			
Antunes	2015	Revista do Colegio Brasileiro de Cirurgioes	EM	Y		Y				
Aoun	2013	World Neurosurgery	RE	Y		Y	Y			
Aragon	2013	Nature Scientific Reports	EM							Y
Armado	2017	Transinformação	EM			Y		Y		
Assimakis	2010	Scientometrics	EM							Y
Azer	2016	Education Forum				Y	Y	Y		
Babineau	2014	The Western Journal of Emergency Medicine	EM			Y				

Baccini	2014	Scientometrics	EM			Y	Y	Y		
Badar	2016	Aslib Journal of Information Management	EM	Y			Y			
Bai	2016	PLOS One	EM		Y	Y	Y	Y		Y
Bala	2013	Journal of Clinical Epidemiology	EM				Y			
Balaban	2013	Journal of General Physiology	ED	Y						
Balandin	2009	Augmentative and Alternative Communication	ED			Y	Y			
Barczynski	2009	Journal of Human Kinetics	ED				Y	Y		
Bastian	2017	Journal of Bone and Joint Surgery-American Volume	EM			Y				
Baum	2011	SAGE	EM	Y			Y			
Beck	2017	Research Evaluation	EM	Y						
Beirlant	2010	Scandinavian Journal of Statistics	EM			Y				
Belikov	2015	f1000 Research	EM			Y				Y
Bellini	2012	The Lancet	ED		Y	Y	Y			
Belter	2015	Journal of The Medical Library Association	ED	Y		Y				
Benchimol-Barbosa	2011	Arquivos Brasileiros de Cardiologia	ED				Y			
Benway	2009	Urology	ED	Y	Y	Y				
Bertuzzi	2013	Molecular Biology of the Cell	ED				Y			
Bharathi	2013	PLOS One	ED			Y				
Bini	2008	Electronic Transactions on Numerical Analysis	EM							Y
Birks	2014	Health Services Research & Policy	EM	Y		Y				
Biswal	2013	PLOS One	ED			Y		Y		
Bloch	2016	Research Evaluation	EM					Y		

Bloching	2013	South African Journal of Science	EM	Y						Y
Bollen	2016	Scientometrics	ED	Y						Y
Bolli	2014	Circulation Research	ED							
Bornmann	2009	EMBO Reports	ED			Y	Y			
Bornmann	2015	Journal of Informetrics	EM	Y	Y	Y	Y			
Bornmann	2016	EMBO Reports	ED		Y	Y	Y			
Bornmann	2014	Scientometrics	EM		Y	Y				
Bornmann	2008	Research Evaluation	EM	Y	Y	Y	Y	Y		
Bornmann	2017	Journal of Informetrics	EM		Y	Y	Y	Y		
Bornmann	2017	Journal of Korean Medical Science	ED				Y	Y		
Bould	2011	British Journal of Anaesthesia	EM			Y				
Bradshaw	2016	PLOS One	EM		Y	Y	Y	Y		
Brown	2011	American Journal of Occupational Therapy	ED			Y	Y	Y		
Buela-Casal	2012	Scientometrics	EM				Y			
Buela-Casal	2010	Revista de Psicodidáctica	ED		Y	Y	Y	Y	Y	
Butler	2017	Clinical Spine Surgery	ED						Y	
Cabazas Clavijo	2013	Medicina Intensiva (English edition)	RE		Y	Y	Y			
Cagan	2013	Disease Models & Mechanisms	ED				Y			
Callaway	2016	Nature	ED				Y			
Calver	2013	Grumpy Scientists	ED		Y	Y	Y	Y		
Calver	2015	Australian Universities Review	ED					Y		
Caminiti	2015	BMC Health Services Research	RE							Y

Cantin	2015	International Journal of Morphology	EM			Y				
Carpenter	2014	Academic Emergency Medicine	ED			Y	Y	Y	Y	
Carpenter	2014	Information Service and Use	ED				Y		Y	
Castelnuovo	2010	Clinical Practice & Epidemiology in Mental Health	RE			Y	Y		Y	Y
Castillo	2010	American Journal of Neuroradiology	ED			Y		Y		
Chiari	2016	Nurse Education Today	EM	Y						
Choi	2014	Journal of Radiation Oncology	EM	Y		Y		Y		Y
Choi	2009	International Journal of Radiation Oncology, Biology, Physics	EM		Y	Y				
Chopra	2016	Aesthetic Surgery Journal	EM			Y				
Choudhri	2015	Radiographics	ED		Y	Y	Y			
Chowdhury	2015	PLOS One	EM	Y		Y				
Christopher	2015	Journal of Veterinary Cardiology	ED				Y			
Chung	2012	Scientometrics	EM						Y	
Ciriminna	2013	Chemistry Central Journal	ED		Y	Y	Y	Y		
Claro	2011	Scientometrics	EM							
Cleary	2010	International Journal of Mental Health Nursing	ED			Y				
Cone	2013	Academic Emergency Medicine	ED			Y				
Cone	2012	Academic Emergency Medicine	ED				Y			
Cordero-Villafafila	2015	Revista de Psiquiatría y Salud Mental (English Edition)	ED			Y	Y	Y		Y
Costas	2011	Scientometrics	EM		Y			Y		
Costas	2009	Journal of the American Society for Information Science and Technology	EM		Y		Y			

Crespo	2013	PLOS One	EM		Y	Y				Y
Cress	2014	Aesthetic Surgery Journal	ED				Y		Y	
Crotty		European Heart Journal	ED			Y				
Culley	2014	Anesthesia & Analgesia	EM		Y	Y		Y		
Cynical Geographers Collective	2011	Antipode	ED		Y		Y			
Czarnecki	2013	Bulletin of the Polish Academy of Sciences	EM			Y				
da Silva	2017	Scientometrics	ED				Y	Y	Y	
Danell	2011	Journal of the American Society for Information Science and Technology	EM		Y					
Danielson	2013	American Journal of Pharmaceutical Education	EM		Y	Y		Y		
de Granda-Orive	2014	Archivos de Bronconeumología	ED		Y			Y		
De Gregori	2016	Journal of Pain Research	EM						Y	
De la Flor-Martínez M	2017	Medicina Oral Patologia Oral Y Cirugia Bucal	EM	Y		Y				
De Marchi	2016	Scientometrics	EM				Y			
De Witte	2010	Scientometrics	EM	Y						Y
Delgadillo	2016	Family & Consumer Sciences research journal	RE			Y				Y
DeLuca	2013	Academic Emergency Medicine	EM	Y		Y				
Devos	2011	Clinics and Research in Hepatology and Gastroenterology	ED			Y				
Diamandis	2017	BMC Medicine	ED				Y			
DiBartola	2017	Journal of Veterinary Internal Medicine	ED			Y	Y	Y		
Diem	2013	Research in Higher Education	EM				Y			
Ding	2011	Information Processing and Management	EM		Y	Y	Y	Y	Y	

Ding	2011	Journal of the American Society for Information Science and Technology	EM			Y	Y		Y	
Diniz-Filho	2016	Journal of Informetrics	EM	Y	Y		Y			
Dinsmore	2014	PLOS Biology	ED						Y	
Dodson	2012	Biochemical and Biophysical Research Communications	EM	Y		Y	Y			Y
Donato	2014	Revista Portuguesa De Pneumologia	ED				Y			
Doyle	2015	Molecular Psychiatry	EM	Y						
Duffy	2011	Scientometrics	EM		Y	Y		Y		
Duffy	2008	Journal of Counseling Psychology	EM		Y	Y		Y		Y
Durieux	2010	Radiology	RE			Y	Y	Y	Y	
Ebadi	2016	Scientometrics	EM					Y		Y
Eblen	2016	PLOS One	EM	Y						
Efron	2011	Clinical and Experimental Optometry	EM		Y	Y		Y		
Ekpo	2016	Journal of Medical Imaging and Radiation Sciences	EM			Y	Y	Y		Y
El Emam	2012	Journal of Medical Internet Research	EM		Y	Y	Y			
Ellson	2009	Journal of Business Research	ED							
Eloy	2014	Otolaryngology–Head and Neck Surgery	EM	Y		Y	Y	Y		
Eloy	2013	Laryngoscope	EM			Y				
Esposito	2010	European Journal of Oral Implantology.	ED			Y				
Eyre-Walker	2013	PLOS Biology	EM	Y	Y		Y			
Eysenbach	2011	Journal of Medical Internet Research	EM		Y	Y	Y		Y	
Fabry	2017	GMS Journal for Medical Education	ED	Y			Y		Y	

Fang	2016	eLIFE	EM	Y						
Fazel	2017	Evidence-based Mental Health	EM	Y				Y	Y	
Fedderke	2015	Research Policy	EM		Y	Y				
Feethman	2015	Veterinary Record	ED				Y			
Ferrer-Sapena	2016	Research Evaluation	ED		Y		Y	Y	Y	Y
Filler	2014	Academic Medicine	EM					Y		
Finch	2010	Bioessays	ED			Y	Y	Y		
Flaatten	2016	Acta Anaesthesiologica Scandinavica	ED			Y	Y			
Franceschet	2010	Journal of Informetrics	EM				Y	Y		
Franceschini	2012	Scientometrics	EM					Y		Y
Franceschini	2012	Scientometrics	EM			Y	Y	Y		Y
Franceschini	2012	Scientometrics	EM		Y	Y		Y		
Frittelli	2016	Journal of the Association for Information Science and Technology	EM			Y	Y			Y
Frixione	2016	PLOS One	EM	Y					Y	
Fujita	2017	IEEE 41st Annual Computer Software and Applications Conference (COMPSAC)	EM	Y	Y					
Gambadauro	2007	European Journal of Obstetrics & Gynecology and Reproductive Biology	ED				Y			
Gao	2016	PLOS One	ED			Y				Y
Garcia-Perez	2015	Scientometrics	EM		Y			Y		
Garcia-Perez	2009	Spanish Journal of Psychology	EM		Y	Y				
Garner	2017	Journal of Neurointerventional Surgery	RE		Y	Y				

Gasparyan	2017	Journal of Korean Medical Science	ED				Y	Y	Y	
Gast	2014	Plastic and Reconstructive Surgery	EM		Y	Y				
Gast	2014	Plastic & Reconstructive Surgery	EM			Y		Y		
Gaughan	2008	Research Evaluation	EM					Y		
Gefen	2011	Journal of Biomechanics	LE	Y		Y				
Giminez-Toledo	2016	Scientometrics	EM					Y		
Glänzel	2014	Transinformação	ED			Y		Y		
Good	2015	Research Evaluation	ED					Y		
Gorraiz	2010	LIBER Quarterly	ED		Y		Y		Y	
Gracza	2008	Library Collections Acquisitions & Technical Services	ED			Y	Y			
Grisso	2017	Journal of Women's Health	EM	Y						
Grzybowski	2017	Clinics in Dermatology	ED				Y			
Gumpenberger	2016	Scientometrics.	ED	Y		Y	Y		Y	
Haddad	2014	The Bone and Joint Journal	ED				Y			
Haddow	2015	Research Evaluation	EM							
Haeffner-Cavaillon	2009	Archivum Immunologiae et Therapiae Experimentalis	ED	Y		Y	Y	Y		
Halbach	2011	Annals of Anatomy	EM		Y	Y		Y		
Hall	2015	Tourism Management	ED				Y			
Halvorson	2016	Implications for Training in the Health Professions	EM		Y	Y				
Hamidreza	2013	Acta Informatica Medica	EM			Y				
Hammarfelt	2017	Research Evaluation	EM	Y		Y	Y			
Han	2013	ISSI	EM	Y			Y			Y

Han	2010	Journal of Animal and Veterinary Advances	EM			Y	Y			
Haslam	2009	Research Evaluation	EM		Y	Y	Y			
Haslam	2010	European Journal of Social Psychology	EM			Y	Y	Y	Y	
Healy	2011	Breast Cancer Research and Treatment	EM			Y				
Heinzl	2012	AIP Conference Proceedings	ED			Y	Y	Y		
Henrekson	2011	The Manchester School	EM		Y	Y	Y	Y		
Herteliu	2017	Publications	EM			Y				
Hew	2017	Telematics and Informatics	EM		Y	Y	Y			
Hicks	2015	Nature	ED			Y	Y			
Hicks	2015	Nature	ED			Y	Y			
Hoffman	2014	47th Hawaii International Conference on System Sciences	O			Y	Y		Y	
Holliday	2010	International Journal of General Medicine	EM	Y			Y			Y
Houser	2017	Leukos	ED			Y	Y			
Hughes	2015	International Journal of Radiation Oncology Biology Physics NB Conference supplement	EM		Y	Y				
Hunt	2011	Acta Neuropsychiatrica	ED			Y	Y			
Hutchins	2016	PLOS Biology	EM							Y
Hyman	2014	Molecular Biology of the Cell	ED							
Ibrahim	2015	New Library World	EM	Y	Y	Y				Y
Ioannidis	2016	PLOS Biology	EM		Y	Y				Y
Ion	2017	Chirurgia	RE			Y	Y	Y		
Iyendar	2009	Academic Medicine	EM				Y			Y

Jackson	2015	Medical Journal of Australia	ED	Y						
Jackson	2011	PLOS One	EM					Y		
Jacob	2007	Scientometrics	EM		Y		Y			
Jacso	2010	Online Information Review	EM				Y	Y		
Jacso	2008	Online Information Review	ED			Y				
Jalil	2013	IEEE International Conference on Teaching, Assessment and Learning for Engineering (TALE)	EM				Y			
Jamjoom	2015	Neurosciences	EM			Y				
Jamjoom	2016	World Neurosurgery	EM			Y				
Jan	2016	Journal of Scientometric Research	EM			Y		Y		
Javey	2012	American Chemical Society	ED			Y	Y			
Jeang	2008	Retrovirology	ED			Y				Y
Jokic	2009	Biochemia Medica	ED		Y	Y	Y			
Joshi	2014	The Journal of Contemporary Dental Practice	ED			Y		Y		
Joynson	2015	f1000 Research	EM							
Kaatz	2015	Academic Medicine	EM	Y						
Kaatz	2016	Academic Medicine	EM	Y						
Kali	2015	Indian Journal of Pharmacology	ED		Y				Y	
Kalra	2013	Journal of Neurosurgery-Pediatrics	EM			Y		Y		
Kaltman	2014	Circulation Research	EM		Y					
Kapoor	2013	The Annals of Medical and Health Sciences Research	ED				Y			
Kellner	2008	Anais Da Academia Brasileira De Ciencias	EM			Y				

Khan	2013	World Neurology	EM			Y				
Knudson	2015	Quest	EM		Y					
Kosmulski	2012	Research Evaluation	ED		Y		Y			
Krapivin	2009	Complex Sciences	EM		Y	Y			Y	Y
Kreiman	2011	Frontiers in Computational Neuroscience	ED	Y	Y		Y		Y	
Kreines	2016	Journal of Computer and Systems Sciences International	EM							Y
Kshettry	2013	World Neurosurgery	ED			Y		Y		
Kulasagareh	2010	European Archives of Oto-Rhino-Laryngology	EM			Y				
Kulczycki	2017	Journal of Informetrics	ED			Y				
Kumar	2009	Iete Technical Review	ED		Y	Y	Y			
Kuo	2017	Computers in Human Behavior	EM						Y	
Lando	2014	PLOS One	EM		Y	Y				Y
Lariviere	2010	Journal of the American Society for Information Science and Technology	EM				Y			
Lariviere	2016	PLOS One	EM		Y					
Lariviere	2011	Journal of Informetrics	EM					Y		
Lauer	2015	The New England Journal of Medicine	ED	Y						
Law	2013	Asia Pacific Journal of Tourism Research	EM	Y	Y		Y			
Lee	2009	Journal of neurosurgery	EM			Y				
Leff	2009	International Journal of COPD	ED				Y			
Leydesdorff	2016	Scientometrics	ED			Y	Y	Y		
Li	2015	Science	EM	Y						

Li	2016	In: Nah FFH, Tan CH, eds. Hci in Business, Government, and Organizations: Ecommerce and Innovation, Pt I. Vol 97512016:61-71.	EM	Y						
Liang	2015	IEEE International Conference on Smart City/SocialCom/SustainCom	EM							Y
Liao	2011	Decision Support Systems	EM		Y		Y			
Lindner	2015	PLOS One	EM	Y	Y					
Lindner	2016	American Journal of Evaluation	EM	Y						
Lippi	2009	Clinical Chemistry and Laboratory Medicine	ED			Y	Y			
Lippi	2013	Clinica Chimica Acta	EM			Y	Y			
Lippi	2017	Annals of Translational Medicine	EM			Y	Y			Y
Lissoni	2011	Industrial and Corporate Change	EM				Y			
Littman	2017	Medical Education Online	EM		Y	Y	Y			
Liu	2011	Management Information Systems	EM		Y			Y	Y	
Lopez	2015	Journal of Surgical Education	EM	Y		Y				
Lopez	2015	Journal of Hand Surgery America	EM		Y	Y				
Lortie	2013	Scientometrics	EM		Y		Y			
Lovegrove	2008	BioScience	EM	Y		Y		Y		
Lozano	2017	Current Science	ED		Y	Y		Y		
MacMasters	2017	Academic Psychiatry	EM		Y	Y				
Maggio	2017	Academic Medicine	EM			Y			Y	
Mali	2017	Science & Public Policy	EM							
Markel	2017	Journal of Pediatric Surgery	EM		Y	Y		Y		

Markpin	2008	Scientometrics	EM				Y			Y
Marsh	2008	American Psychologist	EM	Y						
Marshall	2017	Otolaryngology—Head and Neck Surgery	EM				Y			
Marzolla	2016	Journal of Informetrics	EM	Y		Y		Y		
Mas-Bleder	2013	Scientometrics	EM		Y			Y		
Matsas	2012	Brazilian Journal of Physics	EM							Y
Maunder	2007	La Revue Canadienne de Psychiatrie	EM				Y	Y		Y
Maximin	2014	RadioGraphics	ED	Y	Y		Y		Y	
Mazloumian	2011	PLOS One	EM							Y
Mazmanian	2014	Evaluation & the Health Professions	RE					Y		
McAlister	2011	American Heart Association Journals	ED		Y		Y			
McGovern	2013	Academic Medicine	EM	Y	Y			Y		
Medo	2016	Physical Review	EM			Y		Y		
Meho	2008	Journal of the American Society for Information Science and Technology	EM		Y	Y				
Mester	2016	Interdisciplinary Description of Complex Systems	ED		Y	Y	Y			
Metcalf	2010	Radiologic Technology	EM							
Milone	2016	American Journal of Orthopedics	EM	Y		Y				Y
Minasny	2013	PeerJ	EM		Y	Y				
Mingers	2015	European Journal of Operational Research	ED		Y	Y		Y		
Mingers	2009	Journal of the Operational Research Society	EM		Y	Y				
Mingers	2017	Scientometrics	EM		Y					

Mirnezami	2016	Science and Public Policy	EM		Y			Y		
Misteli	2013	The Journal of Cell Biology	ED				Y			
Moed	2015	Journal of the Association for Information Science and Technology	RE						Y	
Moed	2009	Archivum Immunologiae et Therapia Experimentalis	ED			Y	Y	Y		
Mooij	2014	Scientometrics	EM					Y		Y
Moppett	2011	British Journal of Anaesthesia	EM	Y	Y	Y		Y	Y	
Moreira	2015	PLOS One	EM			Y	Y		Y	Y
Morel	2009	PLOS Neglected Tropic Diseases	EM			Y				Y
Moustafa	2016	Accountability in Research-Policies and Quality Assurance	ED		Y					
Murphy	2011	Irish Journal of Medical Science	EM		Y		Y			
Murphy	2017	Nature	ED					Y		
Mutz	2015	Journal of the Association for Information Science and Technology	EM	Y						
Mutz	2012	Zeitschrift fur Psychologie	EM	Y						
Nah	2009	Journal of The American Society for Information Science and Technology	EM				Y	Y		
Napolitano	2016	Critical Care Medicine	ED		Y			Y		
Nature Editorial Office	2013	Nature Letters	ED		Y		Y			
Nature Editorial Office	2017	Nature	ED				Y			
Neufeld	2011	Research Evaluation	EM	Y		Y				
Neylon	2009	PLOS Biology	ED		Y		Y			

Nicol	2007	Medical Journal of Australia	EM	Y	Y		Y			
Nicolini	2008	Scientometrics	EM				Y	Y		
Niederkrotenthaler	2011	BMC Public Health	EM							Y
Nielsen	2017	Studies in Higher Education	EM				Y	Y		
Nigam	2012	Indian Journal of Dermatology, Venerology and Leprology	ED			Y				
Nightingale	2013	Nurse Education in Practice	EM		Y	Y	Y		Y	
Nosek	2010	Personality and Social Psychology Bulletin	EM			Y				Y
Nykl	2015	Journal of Informetrics	EM	Y		Y	Y			
O'Brien	2012	Oikos	ED							
O'Connor	2010	European Journal of Cancer Care	ED				Y	Y		
Okhovati	2016	Global Journal of Health Science	EM	Y	Y	Y	Y	Y		
Oliveira	2013	Revista Paulista de Pediatria	EM		Y	Y	Y	Y		
Oliveira	2011	Arquivos Brasileiros de Cardiologia	EM		Y	Y	Y			
Oliveira	2013	Scientometrics	EM		Y	Y	Y	Y		
Opthof	2009	Netherlands Heart Journal	EM			Y	Y			
Orduna-Malea	2015	El Profesional de la Información	ED	Y	Y	Y	Y		Y	Y
Osterloh	2015	Evaluation Review	EM	Y	Y		Y			
Ouimet	2011	Scientometrics	EM			Y		Y		
Pagani	2015	Scientometrics	RE		Y		Y			Y
Pagel	2011	British Journal of Anaesthesia	EM			Y				
Pagel	2011	Anaesthesia	EM			Y		Y		
Pagel	2015	Original Investigations in Education	EM		Y	Y		Y		

Paik	2014	Surgical Education	EM			Y				
Pan	2014	Science Reports	EM			Y	Y			Y
Pandit	2011	Anaesthesia	ED		Y	Y		Y		
Patel	2013	Journal of the Royal Society of Medicine	EM	Y	Y	Y	Y	Y		Y
Patel	2011	Journal of the Royal Society of Medicine	RE		Y	Y	Y	Y		
Patrow	2011	Journal of Postgraduate Medicine	ED			Y				
Pepe	2012	PLOS One	EM			Y				Y
Pereyra-Rojas	2017	Frontiers in Psychology	EM	Y		Y		Y		
Perlin	2017	Journal of Informetrics	EM		Y		Y			
Persson	2014	Acta Physiologica	ED						Y	
Peters	2017	Journal of Infometrics	ED				Y			
Petersen	2013	Journal of Informetrics	EM							Y
Petersen	2010	Physical Review	EM							
Pinnock	2012	Nurse Education Today	ED		Y		Y			
Põder	2017	Trames-Journal of the Humanities and Social Sciences	EM			Y				Y
Prabhu	2017	World Neurosurgery	ED			Y	Y	Y	Y	
Prathap	2016	Scientometrics	EM		Y		Y			
Prathap	2012	Scientometrics	EM			Y	Y	Y		
Prathap	2014	Scientometrics	EM			Y				Y
Prathap	2017	Current Science	ED		Y	Y	Y			Y
Pringle	2008	Learned Publishing	ED		Y	Y	Y	Y		
Pshetizky	2009	Journal of the American Board of Family Medicine	EM		Y		Y			

Pugh Jr	2013	Journal of General Physiology	ED				Y			
Pulina	2007	Italian Journal of Animal Science	EM		Y	Y	Y	Y		
Pyke	2015	BioScience	ED							Y
Qi	2016	Scientometrics	EM		Y					
Quigley	2012	Journal of Cancer Education	EM			Y				
Rad	2012	Academic Radiology	EM			Y				
Radicchi	2008	Proceedings of the National Academy of Sciences of the United States of America	EM		Y	Y		Y		Y
Radicchi	2012	Journal of Informetrics	EM		Y			Y		
Raj	2016	Academic Medicine	EM		Y	Y		Y		
Ramasesha	2011	Current Science	ED		Y	Y	Y	Y		
Rana	2013	Journal of Cancer Education	EM		Y	Y				
Ravenscroft	2017	PLOS One	EM			Y	Y	Y	Y	
Rey-Rocha	2015	Scientometrics	EM		Y					
Rezek	2011	Academic Radiology	EM							
Ribas	2015	Proceedings of the 24th International Conference on World Wide Web	O	Y	Y	Y				Y
Ribas	2015	arXiv	ED							Y
Ricker	2009	Interciencia	ED	Y			Y			Y
Rieder	2010	Langenbeck's Archives of Surgery	ED			Y		Y		
Robinson	2011	Journal of School Psychology	ED				Y			
Rodriguez-Navarro	2011	PLOS One	EM							Y
Ronai	2012	Pigment Cell and Melanoma research	ED	Y	Y					

Rons	2009	Research Evaluation	EM							
Rosati	2016	Journal of Cardiac Surgery	EM			Y				
Ruane	2009	Scientometrics	EM		Y	Y				Y
Saad	2010	Scientometrics	EM			Y				
Safdar	2015	Society for Academic Emergency Medicine (SAEM)	EM	Y						
Sahel	2011	Science Translational Medicine	ED		Y	Y	Y			
Sahoo	2017	Omega	EM		Y	Y	Y			Y
Saleem	2011	Internal Archives of Medicine	ED			Y	Y			
Sangam	2008	Current Science	ED			Y	Y			
Santangelo	2017	Molecular Biology of the Cell	ED				Y	Y		
Saraykar	2017	Academic Psychiatry	EM			Y				
Sarli	2016	Missouri Medicine	ED				Y	Y	Y	
Satyanarayana	2008	Indian Journal of Medical Research	ED			Y	Y			
Saxena	2013	Journal of Pharmacology Pharmacotherapeutics	EM			Y	Y	Y		Y
Sebire	2008	Ultrasound in Obstetrics and Gynaecology	ED			Y		Y	Y	
Selek	2014	Scientometrics	EM		Y	Y		Y		
Seo	2017	Management Decision	EM				Y			
Shanta	2013	Journal of Medical Physics	ED		Y	Y	Y			
Shibayama	2015	Research Policy	EM		Y		Y			
Sibbald	2015	Journal of the Medical Library Association	ED							Y
Simons	2008	Science	ED				Y			
Sittig	2015	MEDINFO 2015: eHealth-enabled Health	EM		Y	Y				Y

Slim	2017	Anaesthesia, Critical Care & Pain Medicine	ED			Y	Y		Y	
Slyder	2011	Scientometrics	EM		Y					
Smeyers	2011	Journal of Philosophy of Education	ED		Y		Y			
Smith	2008	Bone & Joint Journal	ED				Y			
Soares de Araujo	2011	Revista Brasileira de Medicina do Esporte	EM			Y	Y	Y		
Sobhy	2016	Embo Reports	ED				Y			
Sobkowicz	2015	Journal of Artificial Societies and Social Simulation	EM	Y						
Solarino	2012	Annals of Geophysics	RE		Y	Y	Y			Y
Sood	2015	Eplasty	EM			Y				
Sorenson	2011	Journal of Parkinson's Disease	EM		Y	Y				Y
Spaan	2009	Medical & Biological Engineering & Computing	ED			Y	Y			
Spearman	2010	Journal of Neurosurgery	EM			Y				
Spreckelsen	2011	BMC Medical Informatics and Decision Making	EM			Y	Y	Y		
Staller	2017	Qualitative Social Work	ED		Y	Y			Y	
Stallings	2013	Proceedings of the National Academy of Sciences of the United States of America	EM		Y	Y				Y
Street	2009	Health Research Policy and System	EM	Y						
Stroebe	2010	American Psychologist	ED		Y			Y		
Stroobants	2013	Nature	ED							
Sturmer	2013	Revista Brasileira De Fisioterapia	EM		Y	Y				
Suiter	2015	The Journal of Academic Librarianship	EM			Y	Y	Y	Y	
Suminski	2012	The Journal of the American Osteopathic Association	EM		Y		Y	Y		

Surla	2017	The Electronic Library	ED		Y		Y			Y
Susarla	2015	Plastic and Reconstructive surgery	EM		Y	Y				
Susarla	2015	Journal of Dental Education	EM	Y		Y				
Sutherland	2011	PLOS One	EM	Y			Y			
Svider	2013	Laryngoscope	EM			Y				
Svider	2014	Ophthalmology	EM	Y		Y				
Svider	2013	Laryngoscope	EM	Y		Y				
Svider	2013	Laryngoscope	EM			Y		Y		
Swanson	2016	Annals of Plastic Surgery	EM			Y				
Szklo	2008	Epidemiology	ED				Y			
Szymanski	2012	Information Sciences	EM			Y	Y	Y		Y
Taborsky	2007	International Journal of Behavioural Biology	ED	Y						
Tan	2016	The Annals of Applied Statistics	EM		Y	Y	Y		Y	Y
Tandon	2015	National Academy Science Letters-India	ED				Y			
Taylor	2015	Poultry Science	ED			Y	Y		Y	
Teixeira	2013	PLOS One	EM			Y				
Tenreiro Machado	2017	Entropy	EM	Y				Y		
Thelwall	2017	Aslib Journal of Information Management	EM						Y	
Therattil	2016	Annals of Plastic Surgery	EM			Y				
Thomaz	2011	Arquivos Brasileiros De Cardiologia	ED			Y	Y	Y		
Thorngate	2014	Advances in Social Simulation	EM	Y						
Tijdink	2016	BMJ Open	EM							

Timothy	2015	Tourism Management	ED				Y			
Torrisi	2014	Scientometrics	EM	Y		Y	Y	Y		
Tricco	2017	PLOS One	RE	Y						
Trueger	2015	Annals of Emergency Medicine	ED			Y	Y		Y	
Tschudy	2016	Journal of Pediatrics	EM			Y		Y		
Tse	2008	Nature	ED			Y	Y			Y
Tuitt	2011	Canadian Journal of Gastroenterology	EM			Y	Y	Y		
Usmani	2011	Sudanese Journal of Paediatrics	ED			Y	Y			
Valsangkar	2016	Surgery	EM		Y	Y		Y		
van Arensbergen	2012	Higher Education Policy	EM	Y						
van den Besselaar	2009	Research Evaluation	EM	Y	Y					
van Eck	2013	PLOS One	EM		Y					
van Leeuwen	2008	Research Evaluation	EM			Y				
van Leeuwen	2012	Research Evaluation	EM	Y						
van Noorden	2010	Nature	ED			Y	Y	Y	Y	
van Wesel	2016	Science and Engineering Ethics	EM							
Vaughan	2017	Scientometrics	EM						Y	
Verma	2015	Proceedings of the National Academy of Sciences of the United States of America	ED	Y			Y			
Vico	2015	Prometheus	EM	Y						
Vieira	2011	Scientometrics	EM							Y
Vinkler	2012	Journal of Informetrics	ED					Y		

Vinyard	2016	Computers in libraries	ED			Y	Y		Y	
von Bartheld	2015	PeerJ	EM			Y	Y	Y		
Wacogne	2016	Archives of Disease in Childhood-Education and Practice Edition	ED			Y	Y	Y	Y	
Wagner	2012	Research Evaluation	ED		Y					Y
Waisbren	2008	Journal of Women's Health	EM							
Walijee	2015	Plastic and Reconstructive Surgery	ED						Y	
Walker	2010	BMC Medical Education	EM		Y		Y	Y		
Wallace	2012	PLOS One	EM	Y	Y					
Walters	2011	Journal of the American Society for Information Science and Technology	EM	Y	Y		Y			
Waltman	2013	In: Gorraiz J, Schiebel E, Gumpenberger C, Horlesberger M, Moed H, eds. 14th International Society of Scientometrics and Informetrics Conference	EM		Y	Y				Y
Waltman	2013	Journal of Informetrics	EM		Y					
Wang	2013	Science	EM			Y	Y	Y		Y
Ward	2012	Anaesthesia	ED							
Watson	2015	Journal of Pediatric Surgery	EM		Y	Y				
Welk	2014	Research Quarterly for Exercise and Sport	ED				Y			
Wieczorek	2016	Financial Environment and Business Development	ED		Y	Y	Y			
Wildgaard	2014	Scientometrics	RE		Y	Y	Y	Y		
Williamson	2008	Family Medicine	EM							Y
Wootton	2013	Health Research Policy and Systems	EM	Y			Y			Y
Würtz	2016	Annals of Epidemiology	RE			Y				

Wykes	2013	Journal of Mental Health	ED			Y	Y			
Yaminfirooz	2015	The Electronic Library	EM			Y				Y
Yang	2013	Journal of Informetrics	EM	Y		Y				Y
Yates	2015	Source Code for Biology and Medicine	EM	Y						
Yu	2016	Computers in Human Behaviour	EM						Y	
Ze	2012	International Conference on Intelligent Computing	EM		Y	Y				
Zhang	2012	Scientometrics	EM							Y
Zhang	2017	PLOS One	EM		Y		Y			
Zhang	2012	Scientometrics	EM		Y	Y		Y		
Zhao	2014	Scientometrics	EM	Y			Y	Y		
Zhou	2012	New Journal of Physics	EM			Y				Y
Zhu	2015	arXiv	EM							Y
Zhuo	2008	Molecular Pain	EM	Y		Y				Y
Zima	2008	Biochemia Medica	ED			Y	Y			
Zou	2016	Scientometrics	EM		Y	Y				Y
Zupetic	2017	Academic Radiology	EM		Y					
Zycxkowski	2010	Scientometrics	ED							Y

^Empirical (EM); Editorial/Opinion (ED); Review (RE); Other (O).

Appendix 3: New models and metrics for assessing an individual researcher's achievement (2007-2017)

First author	Year	Journal name	Level	Metric or Model	Name	Basis	Description
Anderson	2008	Scientometrics	Researcher	Metric	Tapered h-index	h-index	It accounts for the tapered distribution of citations.
Aragon	2013	Nature Scientific Reports	Both	Metric	Scientist impact (Φ)	Author contributions and citation counts	Instead of the total number of citations, the proposed measure Φ (Scientist Impact) aims at discerning the genuine number of people (specifically lead authors) the paper (or first author) has had an impact upon by removing self-citation. In other words, Φ aims at measuring the papers reach.
Assimakis	2010	Scientometrics	Researcher	Metric	The Golden Productivity Index	Author contribution and publication count	A rank dependent index that measures the productivity of an individual researcher by evaluating the number of papers as well as the rank of co-authorship. It emphasizes the first author's contribution.
Bai	2016	PLOS One	Researcher	Metric	COIRank algorithm	Network analysis	Quantifies scientific impact by reproducing the accumulated COI relationship in the scientific community. COIRank focuses on improving PageRank though setting a weight for PageRank algorithm and promotes the performance in identifying influential articles. It therefore accounts for self-citation and citation by others at the same institution.
Belikov	2015	f1000 Research	Researcher	Metric	L-index	h-index and author contribution	Accounts for co-author contribution by designating citations to each individual author according to their order on a paper. It also considers the age of publications, favoring newer ones. However, if a scientist has made a significant scientific breakthrough and ceases publications, his or her L-index will remain high regardless. It ranges from 0.0-9.9.
Bini	2008	Electronic Transactions on Numerical Analysis	Both	Metric	Information not available	Citation count	Proposes to integrate models for evaluating papers, authors, and journals based on citations, co-authorship and publications. After the one-class model for ranking scientific publications, they introduced the two-class model which ranks papers and authors, and the three-class model for ranking papers, authors, and journals.

Bloching	2013	South African Journal of Science	Article	Metric	TAPSIF-temporally averaged paper-specific impact factor	Citation count and IF	Calculated from a paper's average number of citations per year (including the publication year) combined with bonus cites for the publishing journal's prestige–which is taken as the journal impact factor from the publication year. Annual TAPSIF values of all the papers by an author can be combined to measure the overall scientific relevance of that author (temporally averaged author-specific impact factor-TASIF).
Bollen	2016	Scientometrics	Researcher	Model	Equal Allocation Model	Peer-review	A novel model in which each researcher is allocated funding and is required to donate a proportion of that funding to other researchers--hence uses crowd wisdom to fund scientists.
Caminiti	2015	BMC Health Services Research	Researcher	Metric	Information not available	Citation count	This work in progress suggests a mixture of 12 easily retrievable indicators (bibliometric and citation parameters, as well as "hidden" activities such as teaching, mentoring etc). The weighting system was constructed considering the hypothesized effort for all indicators. The chosen indicators and attributed scores still remain to be validated. Modified from Wooton, Health Res Policy Syst. 2013;11:2; Smith, Br Med J. 2001;323(7312):528–8.; and Mezrich J Am Coll Radiol. 2007;4(7):471–8.
Castelnuovo	2010	Clinical Practice & Epidemiology in Mental Health	Researcher	Metric	Single Researcher Impact Factor	IF	This metric takes into account publications (journal articles, books, oral and poster presentations in scientific meetings); products (e.g., software, CD-ROM, videos, databases); and activities (reported scientific activities such as scientific positions or positions in conferences organization, participation in journal editorial boards, activities on human resources education, and participation in international funding projects). Minimum and maximum values are assigned to each task for national and international impact.
Claro	2011	Scientometrics	Researcher	Metric	The x-index	IF and author contribution	Aims to enable cross-disciplinary comparison and uses indicators of both quality and quantity, taking into account the number of publications a researcher has published, and then calculating a publication score for each. This considers number of authors on the paper and the journal's 5-year impact factor; it is also normalized by the journals in which the author tends to publish (rather than top-down classification of a field). Also uses a co-authorship share coefficient. Therefore, aims to determine relative contribution to a paper and normalize by field. While requiring only modest data extraction and processing efforts, it is not based on individual article citations but that of the journal (JIF), which can have limitations.

Cordero-Villafafila	2015	Revista de Psiquiatría y Salud Mental (English Edition)	Both	Metric	RC Algorithim	IF	The first English-language publication of this metric, it quantitatively evaluates the personal impact factor of the scientific production of isolated researchers. It also an individual form (RCγ) and group form (RCγG), and is able to assess personal impact of individual publications, or or a group of them. It also provides a procedure to classify research centers of different types based on the impact (FRCγG) made by their results amongst researchers of the same field. One of the limitations of the RC algorithm is, precisely, its dependence on said bibliographic databases, which have a strong pre-eminence of studies published in English.
Crespo	2015	PLOS One	Other	Metric	Exchange Rate	Citation count	This is an average-based indicator that is used to explore differential citation rates between disciplines by using it as a normalization factor. It is not suitable for assessing individual researchers but provides insight into comparison across disciplines.
De Witte	2010	Scientometrics	Researcher	Metric	RES-score - Research Evaluation Score	Data Envelopment Analysis	Authors present a methodology to aggregate multidimensional research output, using a tailored version of the non-parametric Data Envelopment Analysis model. This they claim is a more accurate representation of a research performance.
Delgadillo	2016	Family & Consumer Sciences Research Journal	Both	Metric	HLA-index	h-index	This index, actually originally published in a book by Harzing (2011), normalizes the h-index to take into account career stage and discipline.
Dodson	2012	Biochemical and Biophysical Research Communications	Researcher	Metric	SP-index	IF	This metric is said to quantify the scientific production of researchers, representing the product of the annual citation number by the accumulated impact factors of the journals in which the papers are published, divided by the annual number of published papers.
Duffy	2008	Journal of Counseling Psychology	Both	Metric	IRPI - Integrated Research Productivity Index	Citation count	This metric statistically combines an individual's author-weighted publications (AWS), average times cited by other publications (MC), and years since first publication (Y) into a comprehensive score, calculated as (AWS x MC)/Y. It thereby accounts for differences in career length.
Ebadi	2016	Scientometrics	Researcher	Model	iSEER	Machine learning	An intelligent machine learning framework for scientific evaluation of researchers (iSEER) considers various "influencing factors of different types" (e.g., funding, collaboration pattern, performance such as quantity and impact of papers, efficiency). It can be used as a complementary tool to overcome limitations in peer-review.

Ekpo	2016	Journal of Medical Imaging and Radiation Sciences	Researcher	Metric	TotalImpact	Author contribution, publication count and citation count	For each of the authors, the total number of publications in peer-reviewed journals (P), total number of citations (C), international collaboration metrics, number of citations per publication (CPP), h-index, and i10-index are extracted (using SciVal). This metric assessed whether authors were leading the research or coauthoring by judging their position in the list of authors for each article. Authors listed as first, second, or last (FSL) were classified as lead researchers, and those listed in-between as coauthors. Each author's total impact was then quantified by: TotalImpact=P×C×FSL.
Franceschini	2012	Scientometrics	Both	Metric	Information not available	Citation counts and h-index	A study specific measurement that includes the number of publications/patents and their citations and also quantifies average number of co-authors relating to publications/patents of one researcher (an indicator of tendency for co-authorship). It also uses the minimum and maximum years: the oldest publication/patent and the year relating to their latest one. This provide an indication of the temporal extension of the publishing or patenting activity of a researcher. They also use the most-cited is publication/patent of a researcher, representing the "jewel in the crown" in terms of impact/diffusion. These metrics are also scalable to teams though, where the h-spectrum is h-values to a group of researchers (including average and medium), and the h-group is the h-index of the union of publications patents associated with publications/patents.
Franceschini	2012	Scientometrics	Researcher	Metric	The Success-Index	Citation counts, NSP-index by Komulski (2011)	This metric is based on Komulski's (2011) NSP (number of successful papers) index with the exception that for each publication the comparison term is sometimes replaced by a more appropriate indicator of propensity to cite, determined on the basis of a representative sample of publications. While it is more complicated than the original, it is insensitive to differential propensity to cite and therefore suitable for comparisons between authors of different fields.

Frittelli	2016	Journal of the Association for Information Science and Technology	Researcher	Metric	SRM - Scientific Research Measures	h-index and calculus	Proposes a novel class of measures (SRM) based on calculus principles that rank a scientist's research performance by taking into account the whole citation curve of a researcher (their performance curve = number of citations of each publication, in decreasing order of citations). The performance cures can be chosen flexibly (e.g., to reflect seniority, characteristics of a field). They extend this idea by proposing Dual SRMs, which are based on theories of risk-measures. It better distinguishes researchers with the same citation curve.
Gao	2016	PLOS One	Both	Metric	PR-index - PageRank Index	Network analysis and h-index	This metric uses PageRank score calculation combined with h-index calculation to measure author impact. It considers publication and citation quantity but also takes a publication’s citation network into consideration. This means the index will rank majority authors higher by applying PageRank based on the publication citation relationship (distinguishing higher quality citations from lower ones).
Han	2013	Institute of Strategic Studies Islamabad	Both	Metric	New Evaluation Index	Network analysis	The new evaluation index takes into account direct and indirect references, direct and indirect citations, and citation network.
Holliday	2010	International Journal of General Medicine	Article	Model	Modified Delphi technique of peer-review	Peer-review	This paper reports using the modified Delphi process to appraise and rank research applications, with experts rating each application's scientific merit, originality, the adequacy of the study design to achieve the research goals, and whether the potential impact of the study would warrant its funding. While its ease of administration, reproducibility, and accessibility makes this a useful adjunct to the traditional processes of grant selection, it does not directly assess individual researcher's but their work.
Hutchins	2016	PLOS Biology	Both	Metric	iCite	Citation count	This is used for individual articles and normalizes their citation score by adding in co-citation metrics.
Ibrahim	2015	New Library World	Both	Metric	Hx	h-index and author contribution	This metric is a hybridization of two indicators based on the individual h-index (weighted by the average number of co-authors for each paper) and h-index contemporary weighted by qualitative factors (conferences and journal in which a researcher participated or published). It accounts for the period of citations and number of authors on a paper, is applicable at all levels and for any discipline of research, takes conferences into consideration, and is thought to reduce unscientific practices such as integration of authors who have not genuinely contributed.

Ioannidis	2016	PLOS Biology	Researcher	Metric	Composite	Citation count, h-index and author contribution	A study-specific composite metric based: on total number of citations in, for example, 2013 (NC), total number of citations received in 2013 to papers for which the researcher is single author (NS), total number of citations received in 2013 to papers for which the author is single or first author (NSF), total number of citations received in 2013 to papers for which the researcher is single, first, or last author (NSFL). Added to these are the h-index and modified h-index. The indicators are standardized (NC, H, Hm, NS, NSF, NSFL), giving each a standardized value from 0 to 1, where 1 is given to the researcher with the highest raw value for the respective indicator. The six standardized indicators are then summed to generate the composite index C. Well-tested and validated using factor analysis, which yielded two factors: bulk impact (NC and H), author order and co-authorship-adjusted impact (Hm, NS, NSF, and NSFL).
Iyendar	2009	Academic Medicine	Researcher	Model	RD - Research Density and Individual Impact Factor	IF	RD measures the ability to obtain grants at a point in time, while IFF reflects the quality of research. The adopted methodology compares the impact factor of an investigator's articles with those of the top journals within their own field. Each investigator identified the top three journals in his or her field. The average impact factor of these three journals was used as the benchmark for that investigator. Each faculty member was then asked to calculate his or her own individual impact factor (IIF) for two consecutive years, using 75% of their benchmark as target. This benchmark was selected after reviewing results of comparisons of investigators' IIFs with their self-defined benchmarks at several multiples (50%, 75%, and 100%). We used 75% of the self-defined benchmark as the target, because it is unlikely for every paper to be published in the best journal in the field, and yet 75% reflects the reasonably high standard of the research quality that MSSM strives for. The data were collated and the IIF of each faculty member was computed as the ratio of his or her impact factor to 75% of his or her self-defined benchmark, expressed as a percentage.
Jeang	2008	Retrovirology	Researcher	Metric	Mentoring Index	h-index	Argues that good mentoring should be a significant consideration of one's contribution to science. It focuses on using the h-index of previous trainees in evaluating established researchers. It is thought this index could encourage the development of long-lasting mentoring relationships.

Krapivin	2009	Complex Sciences	Both	Metric	PaperRank and PR-hirsch	Network analysis and h-index	Based on PageRank, which has been very successful in ranking web pages, essentially considering the reputation of the web page referring to a given page, and the outgoing link density (i.e., pages P linked by pages L where L has few outgoing links are considered more important than pages P cited by pages L where L has many outgoing links). PaperRank (PR) applies page rank to papers by considering papers as web pages and citations as links, and hence trying to consider not only citations when ranking papers, but also taking into account the rank of the citing paper and the density of outgoing citations from the citing paper. The PR-Hirsch is a modification of the H-index based on the same PageRank approach. PR and PR-Hirsch are complementary to citation-based metrics, capable of capturing information present in the whole citation network, namely the "weight" (the reputation or authority) of a citing paper.
Kreines	2016	Journal of Computer and Systems Sciences International	Article	Model	Information not available	Citation count and IF	Proposes a model for assessing quality in the content of individual articles using computational analysis with bibliometric and scientometric data (number of citations and the journal's IF).
Lando	2014	PLOS One	Article	Metric	l-index	h-index	This index considers the most elite papers and rewards papers of high impact and based on the form of the citation distribution. It is thought to outperform the h-index in terms of accuracy and sensitivity to the form of the citation distribution, while being strongly correlated with other important h-type indices. It rewards the more regular and reliable researchers.
Liang	2015	IEEE International Conference on Smart City/SocialCom/ SustainCom	Both	Model	Temporal tracking model		The temporal research evolution model takes into account individual output, researcher profile and experiences

Lippi	2017	Annals of Translational Medicine	Researcher	Metric	SIF-Scientist Impact Factor	IF	This metric is calculated as all citations of articles published in the two years following the publication year of the articles, divided by the overall number of articles published in that year. For example, the SIF for the year 2017 would be obtained by dividing all citations in the years 2015–2016 to articles published in the year 2014, divided by the overall number of articles published in the year 2014. The total number of recent citations is normalized according to the number of recently published articles, limiting the bias emerging from publishing a large number of scarcely cited articles; and the output measure reliably reflects the recent scientific impact of the scientist, so complementing an overall career indicator, such as the h-index.
Markpin	2008	Scientometrics	Other	Metric	ACIF - Article-Count Impact Factor	IF	This is proposed as a journal-level metric that is calculated as the total number of articles cited in the current year divided by the number of articles published in 1st and 2nd year. Note that is based on the number of articles that were cited, rather than the times cited of the cited articles. However, it could be used for individual researchers.
Matsas	2012	Brazilian Journal of Physics	Both	Metric	NIF - Normalized Impact Factor	IF	Introduces a normalized impact factor that looks at the researchers influence on their scientific community by assessing the degree to which they have been influenced by their community. Looks each of an author's publications, the number of co-authors, references in the article and citations it has received. From the way it is calculated: "in a closed community of identical individuals (i.e., who publish, reference and are cited by each other at the same rate), all members have NIF = 1." Leaders in a field are then those with a NIF greater than or equal to 1 i.e., they influence their peers at least as much as they are influenced by them.
Maunder	2007	La Revue Canadienne de Psychiatrie	Article	Metric	Citation Ratio	Citation count	This metric is designed to overcome systematic differences amongst niche fields by comparing the impact of a particular paper to the average impact of a paper in its journal. A ratio above 1 indicates relatively greater success.
Mazloumian	2011	PLOS One	Article	Metric	Boost Factor	Citation count	This metric calculates when a particular research gains scientific authority, that is, they publish some groundbreaking work that then leads to an upswing in citations of their earlier papers. It is able to model the trend of the "rich get richer", a cascade of citations and is too improve the "signal-to-noise" ratio in citation rates by detecting sudden changes in citations.

Milone	2016	American Journal of Orthopedics	Article	Metric	Information not available	Publication count	A study specific measurement simply calculated by taking the mean of first and last authored publications.
Mooji	2014	Scientometrics	Both	Model	Information not available	Peer-review, altmetrics, citation count	This paper proposes a comprehensive and new framework for assessing research quality assessment which utilizes intrinsic (i.e., the internal quality of a publication) and extrinsic indicators (i.e., citation counts, web-based influence). It uses peer-review ratings for the former and bibliometric and altmetric data at the individual article and author levels for the latter. One limit includes that the assessment of extrinsic factors is still biased in terms of multi-author papers. This framework builds in a quality check on peer-review.
Moreira	2015	PLOS One	Researcher	Metric	µ	Information not available	Suggests accumulated citations from an author's aggregated publications follow an asymptotic number, and then use a lognormal model. Creates µ as a scale of expected citability of a researcher's publication. It is able to be used at all career stages and indicates more of quality over quantity.
Morel	2009	PLOS Neglected Tropic Diseases	Researcher	Metric	Information not available	Network Analysis	Co-citation networks generated using SNA of publications, to identify groups and individuals with high collaboration rates.
Niederkroten thaler	2011	BMC Public Health	Article	Model	Information not available	Information not available	A tool designed to measure the societal impact of research publications. It consists of three quantitative dimensions: (1) the aim of a publication, (2) the efforts of the authors to translate their research results, and, if translation was accomplished, (3) (a) the size of the area where translation was accomplished (regional, national or international), (b) its status (preliminary versus permanent) and (c) the target group of the translation (individuals, subgroup of population, total population).
Nosek	2010	Personality and Social Psychology Bulletin	Researcher	Metric	Ics- Individual researcher career-stage impact	Citation count	Produces career-stage metric of scientific impact based on citation counts. Its development was based on extensive data collection to produce a regression of expected growth of impact over time. It, therefore, reflects the distance from one's expected impact at a given career stage.
Pagani	2015	Scientometrics	Article	Metric	Methodi Ordinatio	IF	Based on IF, number of citations and year of publication in a normalized, weighted mathematical equation. It is a potential way to define scientific relevance.

Pan	2014	Science Reports	Researcher	Metric	Author Impact Factor (AIF)		Defined as the AIF of an author A in year t is the average number of citations given by papers published in year t to papers published by A in a period of Δt years before year t. Uses a time window of years for calculation.
Patel	2013	Journal of the Royal Society of Medicine	Researcher	Model	sRM - statistical Regression Model	Citation count	Used to estimate the number of high visibility (based on citation count) publications of each researcher.
Pepe	2012	PLOS One	Researcher	Metric	TORI - Total Research Impact	Citation count	Includes non-self-citations accrued by the researcher, number of authors on cited paper and number of bibliographic references to generate the cumulative output of a scholar by summing the impact of every external citation accrued in his/her career. This removes biases associated with citation counts.
Petersen	2013	Journal of Informetrics	Researcher	Metric	Z	h-index	Z is aimed at correcting the h-index's penalty (which in some cases neglects 75% of an author's body of work) by including the total number of citations for their work in the metric.
Põder	2017	Trames-Journal of the Humanities and Social Sciences	Researcher	Metric	(Current or predicted) impact rate of researcher	Citation count	Based on the citations per year squared, this metric provides a means of assessing acceleration/impact and is based on time series data. This is more sensitive to productivity overtime and can go down unlike the h-index.
Prathap	2014	Scientometrics	Researcher	Metric	Z-index	h-index	Purporting to include quality, quantity and consistency, it accounts for the high-end of research performance, while compensating for the skewness of citation-publication distributions.
Radicchi	2008	Proceedings of the National Academy of Sciences of the United States of America	Article	Metric	Relative Indicator - cf	Citation count	The relative indicator is used to deal with the fact that different fields have different citation patterns and allows for comparisons of the success of articles in different fields.
Ribas	2015	Proceedings of the 24th International Conference on World Wide Web	Both	Metric	P-score	Citation count	It associates a reputation with publication venues based on the publication patterns of reference groups, composed by researchers, in a given area of knowledge. Although the choice of reference groups can be made by using available citation data, the P-score metric itself does not depend on citation data. It uses just publication records of researchers and research groups; that is, the papers and the venues where they published in.

Ricker	2009	Interciencia	Researcher	Model	Rule-based peer-review	Peer-review	Computer generated peer-review, which is positive as researchers get peer-review feedback. Can also measure evaluators select certain criteria of interest, important journals of interest based on field.
Ruane	2009	Scientometrics	Both	Metric	h1-index	h-index	A measure of supervision quality, it gives the supervisor h1 index calculated by the h-indexes of their PhD students.
Sahoo	2017	Omega	Researcher	Model	Composite indicator	h-index, IF, citation counts	Calculated based on the relative weight of the six indicators of journal tier, total citations, author h-index, number of papers, impact factor, and journal h-index.
Saxena	2013	Journal of Pharmacology Pharmacotherapeutics	Researcher	Metric	ORPI - Original Research Publication Index	Citation count	Indicates originality, productivity, and visibility, by including total number of original articles, citations, accounting for self-citations, and the total number of citable articles (i.e., including reviews and case reports). Also accounts for author order and career length.
Sibbald	2015	Journal of the Medical Library Association	Both	Model	Modified approach to citation analysis	Citation count	Includes grey literature in the citation analysis search process and involves quantitative and qualitative methods of analysis to gain a better understanding of how a research paper was used. However, this is more expensive and time consuming than traditional metrics.
Sittig	2015	MEDINFO 2015: eHealth-enabled Health	Researcher	Model	The Biomedical Informatics Researchers ranking website	Information not available	This new system was developed to overcome previous scientific productivity ranking strategies. However, it is limited to biomedical informatics.
Sorenson	2011	Journal of Parkinson's Disease	Both	Metric	"Broad impact" citations	Citation count	Citations from those outside the field are used as a measure of broader impact.
Surla	2017	The Electronic Library	Researcher	Metric	Research Impact Factor	IF	Allows a measure of scientific influence of a researcher in their relative scientific area.
Szymanski	2012	Information Sciences	Both	Metric	CENTs - sCientific currENcy Tokens and the I-index	Citation count and h-index	An accumulation of "cents" based on the number of non-self-citations. This is also the premise behind the i-index, whereby papers a ranked according to CENTs rather than just all citations.

Tan	2016	The Annals of Applied Statistics	Article	Model	Information not available	Citation count	Proposes to use two established models in the creation of a third. The proposed model provides a structural understanding of the field variation in citation behavior and a measure of visibility for individual articles adjusted for citation probabilities within/between topics.
Vieira	2011	Scientometrics	Researcher	Metric	hnf-index	h-index	Considers the different cultures of citation of each field and the number of authors per publication, and hence can be used to measure researcher performance.
Wagner	2012	Research Evaluation	Researcher	Metric	I3 - Integrated impact indicator	Citation count	A framework for integrating citations and non-parametric statistics of percentiles, which allow highly cited papers to be weighted more than less-cited ones.
Waltman	2013		Article	Metric	HCP – Highly cited publications index	Citation count	A simple model in which the number of citations of a publication depends not only on the scientific impact of the publication but also on other 'random' factors. Does not account for productivity.
Wang	2013	Science	Article	Model	Mechanistic model for citation dynamics	Citation count	Authors demonstrate a predictable course for citations of single articles over time, purporting, therefore, to create more reliable predictive index of individual impact.
Williamson	2008	Family Medicine	Researcher	Metric	Information not available	Too broad to classify	Quantifies activities within three domains: teaching, service and research and scholarly activity. A time intensive- process that is suitable for promotion within institutions, but not grant funding or more macro-scale assessments.
Wootton	2013	Health Research Policy and Systems	Researcher	Metric	R - Simple indicator of researcher output		Formula is R=g+p+s and comprises grant income (g), publications (peer-reviewed and weighted by JIF; p) and numbers of PhD students supervised (no credit for submission after the due date of submission; s).
Yaminfirooz	2015	The Electronic Library	Both	Metric	mh-index	h-index	Use to identify differences in the impact of authors with the same h-index, and differences between the outputs of influential researchers working in a certain field and the ones publishing only a few papers during a year, can track the impact of highly cited papers.
Yang	2013	Journal of Informetrics	Researcher	Metric	A-index - Axiomatic approach	Citation count and author contribution	Allows for evaluation of individual researcher in the team context (i.e., co-authorship networks).

Zhang	2012	Scientometrics	Both	Model	Scientometric age pyramid	Information not available	Accounts for the different ages of academics, different fields, co-authorship patterns and analysis of journals. The pyramid represents the number of publications on one side and number of citations on the other side.
Zhou	2012	New Journal of Physics	Both	Metric	AP Algorithm	Citation count	Considers the prestige of the scientists citing the article but assumes equal contribution of each author to the paper.
Zhu	2015	arXiv	Researcher	Metric	The hip index - Influence-primed h-index	h-index	The hip-index weights citations by how many times a reference is mentioned, which is thought to make it a better indicator of researcher performance.
Zhuo	2008	Omega	Other	Metric	Z factor	IF	Uses both the number of publications and the impact factors of the journals in which they were published.
Zou	2016	Scientometrics	Researcher	Metric	S-ZP index	IF	Metric based on journal impact factor of publications and author order.
Zycxkowski	2010	Scientometrics	Both	Metric	C - Citation matrix	h-index	A scheme based on weighing the citation based on previous scientific achievements and authors citing the paper.

Reporting checklist for systematic review and meta-analysis.

Based on the PRISMA guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

Upload your completed checklist as an extra file when you submit to a journal.

In your methods section, say that you used the PRISMA reporting guidelines, and cite them as:

Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement

		Reporting Item	Page Number
	#1	Identify the report as a systematic review, meta-analysis, or both.	Title page
Structured summary	#2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis	2-3

		methods; results; limitations; conclusions and implications of key findings; systematic review registration number	
Rationale	#3	Describe the rationale for the review in the context of what is already known.	4-5
Objectives	#4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	5-7
Protocol and registration	#5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address) and, if available, provide registration information including the registration number.	Review protocol exists but is unpublished
Eligibility criteria	#6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rational	5-7
Information sources	#7	Describe all information sources in the search (e.g., databases with dates of coverage, contact with study authors to identify additional studies) and date last searched.	5-7
Search	#8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	4-7, Appendix 1

Study selection	#9	State the process for selecting studies (i.e., for screening, for determining eligibility, for inclusion in the systematic review, and, if applicable, for inclusion in the meta-analysis).	4-7
Data collection process	#10	Describe the method of data extraction from reports (e.g., piloted forms, independently by two reviewers) and any processes for obtaining and confirming data from investigators.	5-7 and Appendix 2
Data items	#11	List and define all variables for which data were sought (e.g., PICOS, funding sources), and any assumptions and simplifications made.	Page 6-7 and Appendix 2
Risk of bias in individual studies	#12	Describe methods used for assessing risk of bias in individual studies (including specification of whether this was done at the study or outcome level, or both), and how this information is to be used in any data synthesis.	5-7
Summary measures	#13	State the principal summary measures (e.g., risk ratio, difference in means).	The primary outcome measure was methods to assess research achievement.
Planned methods of analyis	#14	Describe the methods of handling data and combining results of studies, if done, including	6-7

		measures of consistency (e.g., I2) for each meta-analysis.	
Risk of bias across studies	#15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	5-6
Additional analyses	#16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	8-12
Study selection	#17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	7-8
Study characteristics	#18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citation.	8-12
Risk of bias within studies	#19	Present data on risk of bias of each study and, if available, any outcome-level assessment (see Item 12).	6
Results of individual studies	#20	For all outcomes considered (benefits and harms), present, for each study: (a) simple summary data for each intervention group and (b) effect estimates and confidence intervals, ideally with a forest plot.	7-11

Synthesis of results	#21	Present the main results of the review. If meta-analyses are done, include for each, confidence intervals and measures of consistency.	Not applicable to this review.
Risk of bias across studies	#22	Present results of any assessment of risk of bias across studies (see Item 15).	4-5
Additional analysis	#23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	Not applicable to this review.
Summary of Evidence	#24	Summarize the main findings, including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., health care providers, users, and policy makers	13-17
Limitations	#25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review level (e.g., incomplete retrieval of identified research, reporting bias).	15-16
Conclusions	#26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	16-17
Funding	#27	Describe sources of funding or other support (e.g., supply of data) for the systematic review; role of funders for the systematic review.	18