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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

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2 **a framework for measuring researcher achievement, impact and influence derived from**

3 **a systematic literature review of metrics and models**

4

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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)

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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

3

78   **INTRODUCTION**

79   Judging researchers' achievements and impact continues to be an important means of

80   allocating scarce research funds and assessing candidates for promotion or tenure. It has

81   historically been carried out through some form of expert peer judgement, including numbers

82   and quality of outputs, and in more recent decades, citations to them. This approach requires

83   judgements regarding the weight which should be assigned to the number of publications,

84   their quality, where they were published, and their downstream influence or impact. There are

85   significant questions about the extent to which human judgement based on these criteria is an

86   effective mechanism for making these complex assessments in a consistent and unbiased

87   way.[1-3] Criticisms of peer assessment, even when underpinned by relatively impartial

88   productivity data, include the propensity for bias, inconsistency among reviewers, nepotism,

89   group-think and subjectivity.[4-7]

90   To compensate for these limitations, approaches have been proposed that rely less on

91   subjective judgement and more on objective indicators.[3, 8-10] Indicators of achievement

92   focus on one or a combination of four aspects: quantity of researcher outputs (*productivity*);

93   value of outputs (*quality*); outcomes of research outputs (*impact*); and relations between

94   publications or authors and the wider world (*influence*).[11-15] Online publishing of journal

95   articles has provided the opportunity to easily track citations and user interactions (e.g.,

96   number of article downloads) and thus has provided a new set of indices against which

97   individual researchers, journals and articles can be compared and the relative worth of

98   contributions assessed and valued.[14] These relatively new metrics have been collectively

99   termed *bibliometrics*[16] when based on citations and numbers of publications, or

100   *altmetrics*[17] when calculated by alternative online measures of impact such as number of

101   downloads or social media mentions.[16]

102   The most established metrics for inferring researcher achievement are the h-index and

103   the Journal Impact Factor (JIF). The JIF measures the average number of citations of an

104   article in the journal over the previous year, and hence is a good indication of journal quality

105   but is increasingly regarded as a primitive measure of quality for individual researchers.[18]

106   The h-index, proposed by Hirsch in 2005,[19] attempts to portray a researcher's productivity

107   and impact in one data point. The h-index is defined as the number (*h*) of articles published

108   by a researcher that have received a citation count of at least *h*. Use of the h-index has

109   become widespread, reflected in its inclusion in author profiles on online databases such as

110   Google Scholar and Scopus.

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111   Also influenced by the advent of online databases, there has been a proliferation of

112   other assessment models and metrics,[16] many of which purport to improve upon existing

113   approaches.[20, 21] These include methods that assess the impact of articles measured by:

114   downloads or online views received; practice change related to specific research: take-up by

115   the scientific community; or mentions in social media.

116   Against the backdrop of growth in metrics and models for assessing researchers'

117   achievements, there is a lack of guidance on the relative strengths and limitations of these

118   different approaches. Understanding them is of fundamental importance to funding bodies

119   that drive the future of research, tenure and promotion committees, and more broadly for

120   providing insights into how we recognize and value the work of medical science and

121   scientists. This review identifies approaches to assessing researchers' achievements published

122   in the academic literature over the last 10 years, considering their relative strengths and

123   limitations.

124

125   **METHOD**

126   **Search Strategy**

127   Web of Science databases (including Web of Science Core Collection, MEDLINE, and

128   BIOSIS Citation Index) were searched using terms related to researcher achievement

129   (*researcher excellence, track record, researcher funding, researcher perform*, relative to*

130   *opportunity, researcher potential, research* career pathway, academic career pathway,*

131   *funding system, funding body, researcher impact, scientific* productivity, academic*

132   *productivity, top researcher, researcher ranking, grant application, researcher output,*

133   *h*index, i*index, impact factor, individual researcher*) and approaches to its assessment

134   (*model, framework, assess*, evaluat*, *metric*, measur*, criteri*, citation*, unconscious*

135   *bias, rank**) with "***" used as an unlimited truncation to capture variation in search terms.

136   These two searches were combined (using "*and*") and results were downloaded into

137   EndNote, the reference management software.

138   **Study Selection**

139   After removing duplicate references in EndNote,[22] articles were allocated amongst pairs of

140   reviewers (MB-JCL, CP-CB, KL-JH, KC-LAE) for screening against inclusion criteria.

141   Following established procedures,[23, 24] each pair was randomly assigned 5% of their

142   allocation to review concurrently against inclusion criteria, with inter-rater reliability

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143 assessed using Cohen's Kappa (κ). The κ statistic was calculated for pairs of researchers, with

144 agreement ranging from moderate to almost perfect (0.4848-0.9039).[25] Following the

145 abstract and title screen, selected articles underwent full text review. Reasons for exclusion

146 were recorded.

Inclusion Criteria

148 The following inclusion criteria were operationalized: (1) English language, (2) published in

149 the last 10 years (2007-2017), (3) full text for the article was available, and (4) the article

150 discussed an approach to the assessment of an individual researcher's achievements (at the

151 researcher or singular output-level). The research followed the Preferred Reporting Items for

152 Systematic Review and Meta-Analysis Protocols (PRISMA-P) framework.[26] Empirical and

153 non-empirical articles were included, because many articles proposing new approaches to

154 assessment, or discussing the limitations of existing ones, are not level one evidence or

155 research-based.

Data Extraction

157 Data from the included articles were extracted, including: the country of article origin, the

158 characteristics of the models or metrics discussed, the perspective the article presented on the

159 metric or model (positive, negative, indeterminable) including any potential benefits or

160 limitations of the assessment model (and if these were perceived or based on some form of

161 evidence). A custom data extraction sheet was developed in Microsoft Excel, trialed among

162 members of the research team and subsequently refined. This information was synthesized

163 for each model and metric identified through narrative techniques. The publication details

164 and classification of each paper are contained in **Appendix 1**.

Appraisal of the Literature

166 Due to the prevalence of non-empirical articles in this field (e.g., editorial contributions,

167 commentaries), it was determined that a risk of bias tool such as the Quality Assessment Tool

168 could not be applied.[27] Rather, assessors were trained in multiple meetings (October 24,

169 October 30, November 13, 2017) to critically assess the quality of articles. Given the nature

170 of the topic (in relation to the publication process) the type of models and metrics identified

171 (i.e., more metrics that use publication metrics) may influence the cumulative evidence and

172 subsequently create a risk of bias. In addition, three researchers (JH, EM, CB) reviewed every

173 included article, to extract documented conflicts of interests of authors.

6

174   **RESULTS**

175   The final dataset consisted of 478 academic articles. The data screening process is presented

176   in **Figure 1**.

177   **Figure 1. Data screening and extraction process for academic articles**

178

Database search output (*n* = 7810)	→	Duplicates deleted (*n* = 135)
Title and abstract review (*n* = 7675)	→	Articles excluded (*n* = 6823)
Full text review (*n* = 852)	→	Articles excluded (*n* = 377)*
Articles included (*n* = 478)	←	Articles added by snowballing (*n* = 3)

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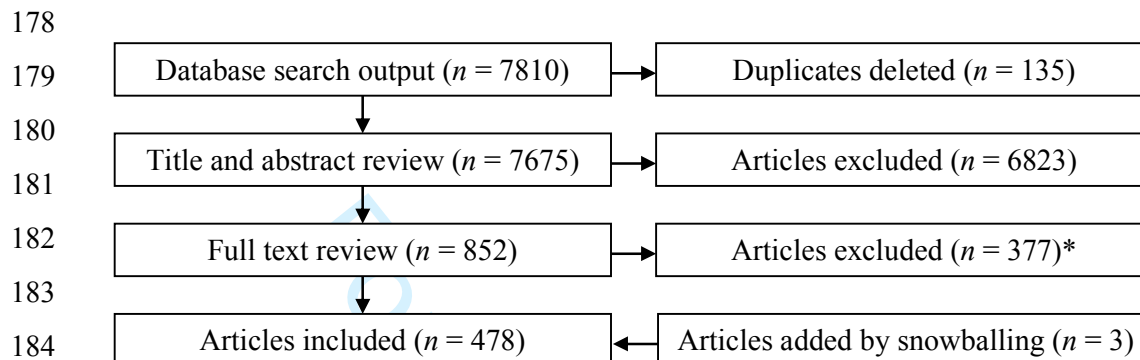
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186   ***Reasons for exclusion are noted below**

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**

187

188   Of the 478 included papers (see **Appendix 1** for a summary), 295 (61.7%) had an

189   empirical component, which ranged from interventional studies that assessed researcher

190   achievement as an outcome measure (e.g., a study measuring the outcomes of a training

191   program),[28] as a predictor[29-31] (e.g., a study that demonstrated the association between

192   number of citations early in one's career and later career productivity), or reported a

193   descriptive analysis of a new metric.[32, 33] One hundred and sixty-six (34.7%) papers were

194   not empirical, including editorial/opinion contributions that discussed the assessment of

195   research achievement, or proposed models for assessing researcher achievement. Seventeen

196   papers (3.6%) were reviews that considered one or more elements of assessing researcher

197   achievements. The quality of these contributions ranged in terms of the risk of bias in the

198   viewpoint expressed. Only for 19 papers (4.0%) did the authors declare a potential conflict of

199   interest.

7

200   Across the study period, 78 articles (16.3%) involved authors purporting to propose

201   new models or metrics. Most articles described or cited pre-existing metrics and largely

202   discussed their perceived strengths and limitations. **Figure 2** shows the proportion of positive

203   or negative discussions of five of the most common approaches to assessing an individual's

204   research achievement (altmetrics, peer-review, h-index, simple counts, and JIF). The

205   approach with most support was altmetrics (51.0% of articles mentioning altmetrics). The JIF

206   was discussed with mostly negative sentiments in relevant articles (69.4%).

207

208   **Figure 2. Percentages of positive and negative discussion regarding selected commonly**

209   **used metrics for assessing individual researchers (n=478 articles)**

210   [Insert Figure 2 here]

211

212   **Citation-Based Metrics**

213   *Publication and Citation Counts*

214   One hundred and fifty-three papers (32.0%) discussed the use of publication and citation

215   counts for purposes of assessing researcher achievement, with papers describing them as a

216   simple "traditional but somewhat crude measure",[34] as well as the building blocks for other

217   metrics.[35] A researcher's number of publications, commonly termed an n-index,[36] was

218   suggested by some to indicate researcher productivity,[14] rather than quality or influence of

219   these papers.[37] On the other hand, the literature suggested that numbers of citations

220   indicated the influence of an individual publication or at researcher-level, as an author's

221   cumulative number received across their body of work or mean citations per article.[38]

222   Some studies found support for the validity of citation counts and publications in that they

223   were correlated with other indications of a researcher's achievement, such as awards and

224   grant funding,[39, 40] and predictive of long term success in a field.[41] For example, one

225   paper argued that having larger numbers of publications and being highly cited early in one's

226   career predicted later high quality research.[42]

227   A number of limitations of using citation or publication counts was observed. For

228   example, Minasny et al. (2013) highlighted discrepancies between publications and citations

229   counts in different databases because of their differential structures and inputs.[43] Other

230   authors[38, 44, 45] noted that citation patterns vary by discipline, which they suggested can

231   make them inappropriate for comparing researchers from different fields. Average citations

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232 per publication were reported as highly sensitive to change or could be skewed if, for

233 example, a researcher has one heavily-cited article.[46, 47] A further disadvantage is the lag-

234 effect of citations,[48, 49] and that in most models citations and publications count equally

235 for all co-authors, despite potential differential contributions.[50] Some also questioned the

236 extent to which citations actually indicated quality or impact, noting that a paper may

237 influence clinical practice more than academic thinking.[51] Indeed, a paper may be highly

238 cited because it is useful (e.g., a review), controversial, or even by chance, making citations a

239 limited indication of quality or impact.[40, 50, 52] In addition to limitations, numerous

240 authors made the point that focusing on citation and publication counts can have unintended,

241 negative consequences for the assessment of researcher achievement, potentially leading to

242 gaming and manipulation, including self-citations and gratuitous authorship.[53, 54]

243 ***Singular Output-Level Approaches***

244 Forty-one papers (8.6%) discussed models and metrics at the singular output or article-level

245 that could be used to infer researcher achievement. The components of achievement they

246 reported assessing were typically quality or impact.[55, 56] For example, some papers

247 reported attempts to examine the quality of a single article by assessing its content.[57, 58]

248 Among the metrics identified in the literature, the immediacy index (II) focused on impact by

249 measuring the average number of cites an article received in the year it was published.[59]

250 Similarly, Finch suggested adapting the Source Normalized Impact per Publication (SNIP; a

251 metric used for journal-level calculations across different fields of research) to an article-

252 level.[21]

253 Many of the article-level metrics identified could also be upscaled to produce

254 researcher-level indications of achievement. For example, the sCientific currENcy Tokens

255 (CENTs), proposed by Szymanski et al. (2012), involved giving a "cent" for each new non-

256 self-citation a publication received; CENTs are then used as the basis for the researcher-level

257 i-index, which follows a similar approach as the h-index, but removes self-citations.[60] The

258 TAPSIF (Temporally-Averaged Paper-Specific Impact Factor) calculates an article's average

259 number of citations per year combined with bonus cites for the publishing journal's prestige,

260 and can be aggregated to measure the overall relevance of a researcher (Temporally

261 Averaged Author-Specific Impact Factor; TAASIF).[61]

262 *Journal impact factor*

9

263 The JIF, commonly recognized as a journal-level measure of quality,[59, 62-64] was

264 discussed in 211 (44.1%) of the papers reviewed in relation to assessing singular outputs or

265 individual researchers. A number of papers described the JIF being used informally to assess

266 an individual's research achievement at the singular output-level, and formally in countries

267 such as France and China.[65] It implies article quality because it is typically a more

268 competitive process to publish in journals with high impact factors.[66] Indeed, the JIF was

269 found to be the best predictor of a paper's propensity to receive citations.[67]

270 The JIF has a range of limitations when used to indicate journal quality,[68] including

271 that it is disproportionally affected by highly cited, outlier articles,[41, 69] and is susceptible

272 to "gaming" by editors.[17, 70] Other criticisms focused on using the JIF to assess individual

273 articles or the researchers who author them.[71] Some critics claimed that using the JIF to

274 measure an individual's achievement encourages researchers to publish in higher-impact but

275 less-appropriate journals for their field—which ultimately means their article may not be read

276 by relevant researchers.[72, 73] Furthermore, the popularity of a journal was argued to be a

277 poor indication of the quality of any one article, with the citation distributions for calculating

278 JIF found to be heavily skewed (i.e., a small subset of papers receive the bulk of the citations

279 while some may receive none).[18] Ultimately, many commentators argued that the JIF is an

280 inappropriate metric to assess individual researchers because it is an aggregate metric of a

281 journal's publication, and expresses nothing about any individual paper.[21, 49, 50, 74]

282 However, Bornmann et al. (2017) suggested one case in which it would be appropriate to use

283 JIF for assessing individual researchers: in relation to their recently published papers that had

284 not had the opportunity to accumulate citations.[75]

Researcher-Level Approaches

h-index

287 The h-index was among the most commonly discussed metrics in the literature (254 [53.1%]

288 of the papers reviewed); in many of these papers, it was described by authors as more

289 sophisticated than citation and publication counts, but still straightforward, logical and

290 intuitive.[76-78] Authors noted its combination of productivity (h publications) and impact

291 indicators (h citations) as being more reliable[79, 80] and stable than average citations per

292 publications[41] because it is not skewed by the influence of one popular article.[81] One

293 study found that the h-index correlated with other metrics more difficult to obtain.[78] It also

10

294 showed convergent validity with peer-reviewed assessments[82] and was found to be a good

295 predictor of future achievement.[41]

296   However because of the lag-effect with citations and publications, the h-index

297 increases with a researcher's years of activity in the field, and cannot decrease, even if

298 productivity later declines.[83] Hence, numerous authors suggested it was inappropriate for

299 comparing researchers at different career stages,[84] or those early in their career.[70] The h-

300 index was also noted as being susceptible to many of the critiques leveled against citation

301 counts, including potential for gaming, and inability to reflect differential contributions by

302 co-authors.[85] Because disciplines differ in citation patterns[86] some studies noted

303 variations in author h-indices between different methodologies[87] and within medical

304 subspecialities.[88] Some therefore argued that the h-index should not be used as the sole

305 measure of a researcher's achievement.[88]

306 *h-index variants*

307 A number of modified versions of the h-index were identified; these purported to draw on its

308 basic strengths of balancing productivity with impact while redressing perceived limitations.

309 For example, the g-index measures global citation performance,[89] and was defined

310 similarly to the h-index but with more weight given to highly cited articles by assuming the

311 top g articles have received at least g^2 citations.[90] Azer and Azer (2016) argued it was a

312 more useful measure of researcher productivity.[91] Another variant of the h-index identified,

313 the m-quotient, was suggested to minimize the potential to favor senior academics by

314 accounting for the time passed since a researcher has begun publishing papers.[92, 93] Other

315 h-index variations reported in the articles reviewed attempted to account for author

316 contributions, such as the h-maj index, which includes only articles in which the researcher

317 played a core role (based on author order); and the weighted h-index, which assigns credit

318 points according to author order.[89, 94]

319 **Recurring Issues with Citation-Based Metrics**

320 The literature review results suggested that no one citation-based metric was ideal for all

321 purposes. All of the common metrics examined focused on one aspect of an individual's

322 achievement, and thus failed to account for other aspects of achievement. The limitations

323 with some of the frequently used citation-based metrics are listed in **Box 1**.

324

> 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

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347 suggested no correlation between attention on Twitter and expert analysis of an article's

348 originality, significance or rigour.[108] Another showed that Tweets predict citations.[109]

349 Overall, further work needs to assess the value of altmetric scores in terms of their

350 association with other traditional indicators of achievement.[110] Notwithstanding this, there

351 were increasing calls to consider altmetrics alongside more conventional metrics in assessing

352 researchers and their work.[111]

353

354 *Past Funding*

355 A past record of being funded by national agencies was identified as a common measurement

356 of individual academic achievement in a number of papers, and has been argued to be a

357 reliable method that is consistent across medical research.[112-114] For example, the NIH's

358 (National Institute of Health's) RePORT (Research Portfolio Online Reporting Tools) system

359 encourages public accountability for funding by providing online access to reports, data and

360 NIH-funded research projects.[112, 115]

361

362 **New Metrics and Models identified**

363 The review also identified and assessed new metrics and models that were proposed during

364 the review period, many of which had not gained widespread acceptance or use. While there

365 was considerable heterogeneity and varying degrees of complexity among the 78 new

366 approaches identified, there were also many areas of overlap in their methods and purposes.

367 For example, some papers reported on metrics that used a PageRank algorithm,[116, 117] a

368 form of network analysis based on structural characteristics of publications (e.g., co-

369 authorship or citation patterns).[14] Metrics based on PageRank purported to measure both

370 the direct and indirect impact of a publication or researcher. Other approaches considered the

371 relative contributions of authors to a paper in calculating productivity.[118] Numerous

372 metrics and models that built upon existing approaches were also reported.[119] For example,

373 some developed composite metrics that included a publication's JIF alongside an author

374 contribution measure[120] or other existing metrics.[121] However, each of these approaches

375 reported limitations, in addition to their strengths or improvements upon other methods. For

376 example, in focusing on productivity, a metric necessarily often neglected impact.[122]

377 **Appendix 2** provides a summary of these new or re-fashioned metrics and models, with

378 details of their basis and purpose.

379

380

381 **DISCUSSION**

382 This systematic review identified a large number of diverse metrics and models for assessing

383 an individual's research achievement that have been developed in the last 10 years (2007-

384 2017), as evidenced in **Appendix 2.** At the same time, other approaches that pre-dated our

385 study time period were also discussed frequently in the literature reviewed, including the h-

386 index and JIF. All metrics and models proposed had their relative strengths, based on the

387 components of achievement they focused on, and their sophistication or transparency.

388

389 **Strengths and limitations**

390 The review also identified and assessed new metrics and Over the past few decades,

391 peer-review has been increasingly criticized for reliance on subjectivity and propensity for

392 bias,[7] and there have been arguments that the use of specific metrics may be a more

393 objective and fair approach for assessing individual research achievement. However, this

394 review has highlighted that even seemingly objective measures have a range of shortcomings.

395 For example, there are inadequacies in comparing researchers at different career stages, and

396 across disciplines with different citation patterns.[86] Furthermore, the use of citation-based

397 metrics can lead to gaming and potential ethical misconduct by contributing to a "publish or

398 perish" culture in which researchers are under pressure to maintain or improve their

399 publication records.[123, 124] New methods and adjustments to existing metrics have been

400 proposed to explicitly address some of these limitations; for example, normalizing metrics

401 with "exchange rates" to remove discipline-specific variation in citation patterns, thereby

402 making metric scores more comparable for researchers working in disparate fields.[125, 126]

403 Normalization techniques have also been used to assess researchers' metrics with greater

404 recognition of their relative opportunity and career longevity.[127]

405 Other criticisms of traditional approaches center less on how they calculated

406 achievement, and more on what they understood or assumed about its constituent elements.

407 In this review, the measurement of impact or knowledge gain was often exclusively tied to

408 citations.[128] Some articles proposed novel approaches to using citations as a measure of

409 impact, such as giving greater weight to citations from papers that were themselves highly

410 cited[129] or that come from outside the field in which the paper was published.[130]

411 However, even other potential means of considering scientific contributions and achievement,

14

412   such as mentoring, were still ultimately tied to citations because mentoring was measured by

413   the publication output of mentees.[131]

414   A focus only on citations was widely thought to disadvantage certain types of

415   researchers. For example, researchers who aim to publish with a focus on influencing practice

416   may target "lower-impact", more specialized or regional journals that are not necessarily

417   highly cited, where their papers will be read by the appropriate audience and findings

418   implemented.[51] In this regard, categorizing the type of journal in which an article has been

419   published, in terms of its focus (e.g., industry, clinical, regional/national), may go some way

420   toward recognizing those publications that have a clear knowledge translation intention.[123]

421   There were only a few other approaches identified that captured broader conceptualizations

422   of knowledge gain, such as practical impact or wealth generation for the economy, and these

423   too were often simplistic, such as including patents and their citations[132] or altmetric

424   data.[98] While altmetrics hold potential in this regard, their use has not been

425   standardized,[98] and they come with their own limitations, with suggestions that they reflect

426   popularity more so than real world impact.[106] Other methodologies have been proposed for

427   assessing knowledge translation, but these can often be labor intensive.[133] For example,

428   Sutherland et al. (2011)[134] suggested that assessing individual research outputs in light of

429   specific policy objectives, through peer-review based scoring, may be a strategy, but this is

430   typically not feasible in situations such as grant funding allocation, where there are time-

431   constraints and large applicant pools to assess.

432   In terms of how one can make sense of the validity of many of these emerging

433   approaches for assessing an individual's research achievements, metrics should demonstrate

434   their legitimacy empirically, as well as having a theoretical basis for their use and clearly

435   differentiating what aspects of quality, achievement or impact they purport to examine.[55,

436   67] If the recent, well-publicized[135-137] San Francisco Declaration on Research

437   Assessment (DORA)[138] is anything to go by, internationally there is a move away from the

438   assessment of individual researchers using the JIF and the journal in which the research has

439   been published.

440

441   **Figure 3. The Comprehensive Researcher Achievement Model (CRAM)**

442   [Insert Figure 3 Here]

443

444   There is momentum, instead, for assessment of researcher achievements on the basis

445   of a wider mix of measures, hence our proposed Comprehensive Researcher Achievement

15

446 Model (CRAM) (**Figure 3**). On the left-hand side of this model is the researcher to be

447 assessed, and key characteristics that influence the assessment. Among these factors, some

448 (i.e., field or discipline, co-authorship, career longevity) can be controlled for depending on

449 the metric, while other components, such as gaming or the research topic (i.e., whether it is

450 "trendy" or innovative) are less amenable to control or even prediction. Online databases,

451 which track citations and downloads and measure other forms of impact, hold much potential

452 and will likely be increasingly used in the future to assess both individual researchers and

453 their outputs. Hence, assessment components (past funding, articles, citations, patents,

454 downloads, and some media traction) included in our model are those primarily accessible

455 online.

456   The findings of this review suggest assessment components should be used with care,

457 and with recognition of how they can be influenced by other factors, and what aspects of

458 achievement they reflect (i.e., productivity, quality, impact, influence). No metric or model

459 singularly captures all aspects of achievement, and hence use of a range, such as the

460 examples in our model, is advisable. Finally, this model recognizes that the configuration and

461 weighting of assessment methods will depend on the assessors and their purpose, the

462 resources available for the assessment process, and access to assessment components.

463 However, these results must be interpreted in light of our focus only on academic literature in

464 the review; this may have led to a more publication concentrated model.

465

466 **CONCLUSION**

467 There is no ideal model or metric by which to assess individual researcher achievement. We

468 have proposed a generic model, designed to minimize risk of the use of any one or a smaller

469 number of metrics, but it is not proposed as an ultimate solution. The mix of assessment

470 components and metrics will depend on the purpose. Greater transparency in approaches used

471 to assess achievement including their evidence-base is required.[37] Any model used to

472 assess achievement for purposes such as promotion or funding allocation should include

473 some quantitative components, based on robust data, and be able to be rapidly updated,

474 presented with confidence intervals, and normalized.[37] The assessment process should be

475 difficult to manipulate, and explicit about the components of achievement being measured.

476 As such, no current metric suitably fulfills all these criteria. The best strategy to assess an

477 individual's research achievement is likely to involve the use of multiple approaches[139] in

478 order to dilute the influence and potential disadvantages of any one metric, while providing

16

479 more rounded picture of a researcher's achievement;[85, 140] this is what the CRAM aims to
480 contribute.
481   All-in-all, achievement in terms of impact and knowledge gain is broader than the
482 number of articles published or their citation rates, and yet most metrics have no means of
483 factoring in these broader issues. Altmetrics hold promise in complementing citation-based
484 metrics and assessing more diverse notions of impact, but usage of this type of tool requires
485 further standardization.[98] Finally, despite the limitations of peer-review, the role of expert
486 judgement should not be discounted.[41] Metrics are perhaps best applied as a complement or
487 check on the peer-review process, rather than the sole means of assessment of an individual's
488 research achievements.[141]

17

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Competing Interests

The authors have declared that no competing interests exist.

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.

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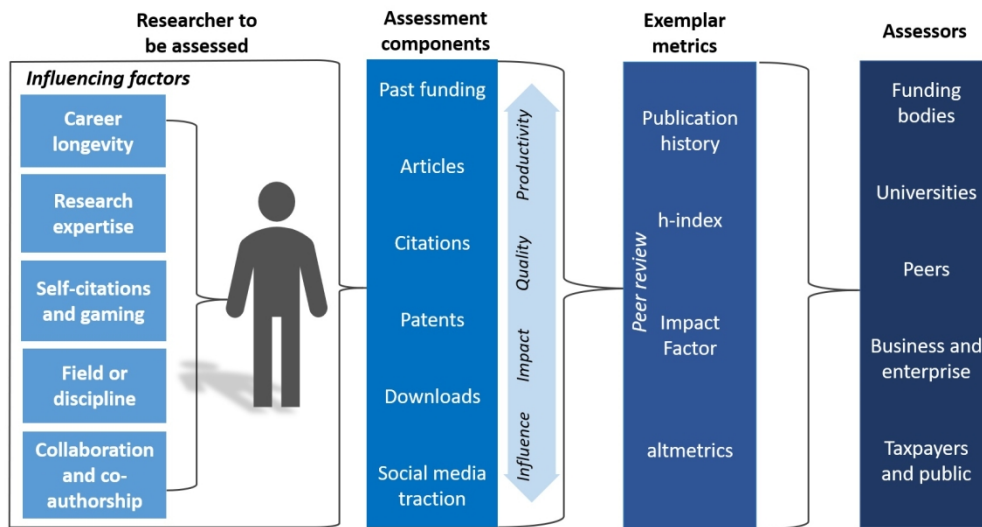
Appendix 1: Summary table of included articles and the metrics or models they discuss

		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				

Author	Year	Journal	Type	C1	C2	C3	C4	C5	C6
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

Author	Year	Journal								
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			

Author	Year	Journal	Type								
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

Author	Year	Source	Type						
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

Author	Year	Journal	Type						
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			

Name	Year	Journal									
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							

Author	Year	Source	Type						
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		

Author	Year	Journal	Type	C1	C2	C3	C4	C5	C6
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				

Author	Year	Journal	Type							
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			

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	Year	Journal		C1	C2	C3	C4	C5	C6	C7
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		

	Year	Journal	Type								
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				

Author	Year	Journal	Type						
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				

Author	Year	Journal	Type						
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							

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Name	Year	Journal	Type										
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			

Name	Year	Journal	Type								
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					

Author	Year	Journal	Type^							
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	*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 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](#25)   Discuss limitations at study and outcome level (e.g.,   16
                            risk of bias), and at review level (e.g., incomplete
                            retrieval of identified research, reporting bias).

Conclusions   [#26](#26)   Provide a general interpretation of the results in the   16-17
                            context of other evidence, and implications for future
                            research.

Funding   [#27](#27)   Describe sources of funding or other support (e.g.,   18
                            supply of data) for the systematic review; role of
                            funders for the systematic review.

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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

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1 **The Comprehensive Researcher Achievement Model (CRAM):**

2 **a framework for measuring researcher achievement, impact and influence derived from**

3 **a systematic literature review of metrics and models**

4

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34 **ABSTRACT**

35 **Objectives** Effective researcher assessment is key to decisions about funding allocations,

36 promotion and tenure. We aimed to identify what is known about methods for assessing

37 researcher achievements, leading to a new composite assessment model.

38 **Design** We systematically reviewed the literature via the Preferred Reporting Items for

39 Systematic Review and Meta-Analysis Protocols (PRISMA-P) framework.

40 **Data sources** All Web of Science databases (including Core Collection, MEDLINE, and

41 BIOSIS Citation Index) to the end of 2017.

42 **Eligibility criteria** (1) English language, (2) published in the last 10 years (2007-2017), (3)

43 full text was available, and (4) the article discussed an approach to the assessment of an

44 individual researcher's achievements.

45 **Data extraction and synthesis** Articles were allocated amongst four pairs of reviewers for

46 screening, with each pair was randomly assigned 5% of their allocation to review

47 concurrently against inclusion criteria, with inter-rater reliability assessed using Cohen's

48 Kappa (κ). The κ statistic showed agreement ranged from moderate to almost perfect

49 (0.4848-0.9039). Following screening, selected articles underwent full text review and bias

50 assessed.

51 **Results** Four hundred and seventy-eight articles were included in the final review.

52 Established approaches developed prior to our inclusion period (e.g., citations and outputs, h-

53 index, journal impact factor), remained dominant in the literature and in practice. New

54 bibliometric methods and models emerged in the last 10 years including: measures based on

55 PageRank algorithms or "altmetric" data, methods to apply peer judgement, and techniques to

56 assign values to publication quantity and quality. Each assessment method tended to

57 prioritize certain aspects of achievement over others.

58 **Conclusions** All metrics and models focus on an element or elements, at the expense of

59 others. A new composite design, the Comprehensive Researcher Achievement Model

60 (CRAM) is presented which supersedes past anachronistic models. The CRAM is modifiable

61 to a range of applications.

62 **Keywords:** Researcher assessment; Research metrics; h-index; Journal impact factor;

63 citations; outputs; Comprehensive Researcher Achievement Model (CRAM)

64

65 **Article Summary**

66 **Strengths and limitations of this study**

2

67 • A large, diverse dataset of over 478 articles, containing many ideas for assessing
68   researcher performance, was analyzed

69 • Strengths of the review include executing a wide-ranging search strategy, and the
70   consequent high number of included articles for review; the results are limited by the
71   literature itself, e.g., new metrics were not mentioned in the articles, and therefore not
72   captured in the results

73 • A new model combining multiple factors to assess researcher performance is now
74   available

75 • Its strengths include combining quantitative and qualitative components in the one
76   model

77 • The CRAM model, despite being evidence-oriented, is a generic one and now needs
78   to be applied in the field

3

79 **INTRODUCTION**

80 Judging researchers' achievements and academic impact continues to be an important means

81 of allocating scarce research funds and assessing candidates for promotion or tenure. It has

82 historically been carried out through some form of expert peer judgement, to assess the

83 number and quality of outputs, and in more recent decades, citations to them. This approach

84 requires judgements regarding the weight which should be assigned to the number of

85 publications, their quality, where they were published, and their downstream influence or

86 impact. There are significant questions about the extent to which human judgement based on

87 these criteria is an effective mechanism for making these complex assessments in a consistent

88 and unbiased way.(1-3) Criticisms of peer assessment, even when underpinned by relatively

89 impartial productivity data, include the propensity for bias, inconsistency among reviewers,

90 nepotism, group-think and subjectivity.(4-7)

91   To compensate for these limitations, approaches have been proposed that rely less on

92 subjective judgement and more on objective indicators.(3, 8-10) Indicators of achievement

93 focus on one or a combination of four aspects: quantity of researcher outputs (*productivity*);

94 value of outputs (*quality*); outcomes of research outputs (*impact*); and relations between

95 publications or authors and the wider world (*influence*).(11-15) Online publishing of journal

96 articles has provided the opportunity to easily track citations and user interactions (e.g.,

97 number of article downloads) and thus has provided a new set of indices against which

98 individual researchers, journals and articles can be compared and the relative worth of

99 contributions assessed and valued.(14) These relatively new metrics have been collectively

100 termed *bibliometrics*(16) when based on citations and numbers of publications, or

101 *altmetrics*(17) when calculated by alternative online measures of impact such as number of

102 downloads or social media mentions.(16)

103   The most established metrics for inferring researcher achievement are the h-index and

104 the Journal Impact Factor (JIF). The JIF measures the average number of citations of an

105 article in the journal over the previous year, and hence is a good indication of journal quality

106 but is increasingly regarded as a primitive measure of quality for individual researchers.(18)

107 The h-index, proposed by Hirsch in 2005,(19) attempts to portray a researcher's productivity

108 and impact in one data point. The h-index is defined as the number (*h*) of articles published

109 by a researcher that have received a citation count of at least *h*. Use of the h-index has

110 become widespread, reflected in its inclusion in author profiles on online databases such as

111 Google Scholar and Scopus.

4

112   Also influenced by the advent of online databases, there has been a proliferation of

113 other assessment models and metrics,(16) many of which purport to improve upon existing

114 approaches.(20, 21) These include methods that assess the impact of articles measured by:

115 downloads or online views received; practice change related to specific research; take-up by

116 the scientific community; or mentions in social media.

117   Against the backdrop of growth in metrics and models for assessing researchers'

118 achievements, there is a lack of guidance on the relative strengths and limitations of these

119 different approaches. Understanding them is of fundamental importance to funding bodies

120 that drive the future of research, tenure and promotion committees, and more broadly for

121 providing insights into how we recognize and value the work of science and scientists,

122 particularly those researching in medicine and healthcare. This review aimed to identify

123 approaches to assessing researchers' achievements published in the academic literature over

124 the last 10 years, considering their relative strengths and limitations and drawing on this to

125 propose a new composite assessment model.

126

127 **METHOD**

128 **Search Strategy**

129 All Web of Science databases (eight in total, including Web of Science Core Collection,

130 MEDLINE, and BIOSIS Citation Index) were searched using terms related to researcher

131 achievement (*researcher excellence, track record, researcher funding, researcher perform*,*

132 *relative to opportunity, researcher potential, research* career pathway, academic career*

133 *pathway, funding system, funding body, researcher impact, scientific* productivity, academic*

134 *productivity, top researcher, researcher ranking, grant application, researcher output,*

135 *h*index, i*index, impact factor, individual researcher*) and approaches to its assessment

136 (*model, framework, assess*, evaluat*, *metric*, measur*, criteri*, citation*, unconscious*

137 *bias, rank**) with "*" used as an unlimited truncation to capture variation in search terms, as

138 seen in **Appendix 1**. These two searches were combined (using "*and*") and results were

139 downloaded into EndNote, the reference management software.

140 **Study Selection**

141 After removing duplicate references in EndNote,(22) articles were allocated amongst pairs of

142 reviewers (MB-JCL, CP-CB, KL-JH, KC-LAE) for screening against inclusion criteria.

143 Following established procedures,(23, 24) each pair was randomly assigned 5% of their

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144 allocation to review concurrently against inclusion criteria, with inter-rater reliability

145 assessed using Cohen's Kappa (κ). The κ statistic was calculated for pairs of researchers, with

146 agreement ranging from moderate to almost perfect (0.4848-0.9039).(25) Following the

147 abstract and title screen, selected articles underwent full text review. Reasons for exclusion

148 were recorded.

Inclusion Criteria

150 The following inclusion criteria were operationalized: (1) English language, (2) published in

151 the last 10 years (2007-2017), (3) full text for the article was available, and (4) the article

152 discussed an approach to the assessment of an individual researcher's achievements (at the

153 researcher or singular output-level). The research followed the Preferred Reporting Items for

154 Systematic Review and Meta-Analysis Protocols (PRISMA-P) framework.(26) Empirical and

155 non-empirical articles were included, because many articles proposing new approaches to

156 assessment, or discussing the limitations of existing ones, are not level one evidence or

157 research-based.

Data Extraction

159 Data from the included articles were extracted, including: the country of article origin, the

160 characteristics of the models or metrics discussed, the perspective the article presented on the

161 metric or model (positive, negative, indeterminable) including any potential benefits or

162 limitations of the assessment model (and if these were perceived or based on some form of

163 evidence). A customised data extraction sheet was developed in Microsoft Excel, trialed

164 among members of the research team and subsequently refined. This information was

165 synthesized for each model and metric identified through narrative techniques. The

166 publication details and classification of each paper are contained in **Appendix 2**.

Appraisal of the Literature

168 Due to the prevalence of non-empirical articles in this field (e.g., editorial contributions,

169 commentaries), it was determined that a risk of bias tool such as the Quality Assessment Tool

170 could not be applied.(27) Rather, assessors were trained in multiple meetings (October 24,

171 October 30, November 13, 2017) to critically assess the quality of articles. Given the topic of

172 the review (focusing on the publication process), the type of models and metrics identified

173 (i.e., more metrics that use publication metrics) may influence the cumulative evidence and

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174 subsequently create a risk of bias. In addition, three researchers (JH, EM, CB) reviewed every

175 included article, to extract documented conflicts of interests of authors.

176 **Patient and public involvement**

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

178 **RESULTS**

179 The final dataset consisted of 478 academic articles. The data screening process is presented

180 in **Figure 1**.

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

183 Of the 478 included papers (see **Appendix 2** for a summary), 295 (61.7%) had an

184 empirical component, which ranged from interventional studies that assessed researcher

185 achievement as an outcome measure (e.g., a study measuring the outcomes of a training

186 program),(28) as a predictor(29-31) (e.g., a study that demonstrated the association between

187 number of citations early in one's career and later career productivity), or reported a

188 descriptive analysis of a new metric.(32, 33) One hundred and sixty-six (34.7%) papers were

189 not empirical, including editorial or opinion contributions that discussed the assessment of

190 research achievement, or proposed models for assessing researcher achievement. Seventeen

191 papers (3.6%) were reviews that considered one or more elements of assessing researcher

192 achievements. The quality of these contributions ranged in terms of the risk of bias in the

193 viewpoint expressed. Only for 19 papers (4.0%) did the authors declare a potential conflict of

194 interest.

195 Across the study period, 78 articles (16.3%) involved authors purporting to propose

196 new models or metrics. Most articles described or cited pre-existing metrics and largely

197 discussed their perceived strengths and limitations. **Figure 2** shows the proportion of positive

198 or negative discussions of five of the most common approaches to assessing an individual's

199 research achievement (altmetrics, peer-review, h-index, simple counts, and JIF). The

200 approach with most support was altmetrics (51.0% of articles mentioning altmetrics). The JIF

201 was discussed with mostly negative sentiments in relevant articles (69.4%).

202

203 **Figure 2. Percentages of positive and negative discussion regarding selected commonly**

204 **used metrics for assessing individual researchers (n=478 articles)**

205 **<Insert Figure 2>**

7

206   Legend: Positive discussion refers to articles that discuss the metric in a favorable light or focus on the strengths

207   of the metric; negative discussion refers to articles that focus on the limitations or shortcomings of the metric.

208   **Citation-Based Metrics**

209   *Publication and Citation Counts*

210   One hundred and fifty-three papers (32.0%) discussed the use of publication and citation

211   counts for purposes of assessing researcher achievement, with papers describing them as a

212   simple "traditional but somewhat crude measure",(34) as well as the building blocks for other

213   metrics.(35) A researcher's number of publications, commonly termed an n-index,(36) was

214   suggested by some to indicate researcher productivity,(14) rather than quality, impact or

215   influence of these papers.(37) On the other hand, the literature suggested that numbers of

216   citations indicated the academic impact of an individual publication or researcher's body of

217   work, calculated as an author's cumulative or mean citations per article.(38) Some studies

218   found support for the validity of citation counts and publications in that they were correlated

219   with other indications of a researcher's achievement, such as awards and grant funding,(39,

220   40) and predictive of long term success in a field.(41) For example, one paper argued that

221   having larger numbers of publications and being highly cited early in one's career predicted

222   later high quality research.(42)

223   A number of limitations of using citation or publication counts was observed. For

224   example, Minasny et al. (2013) highlighted discrepancies between publications and citations

225   counts in different databases because of their differential structures and inputs.(43) Other

226   authors(38, 44, 45) noted that citation patterns vary by discipline, which they suggested can

227   make them inappropriate for comparing researchers from different fields. Average citations

228   per publication were reported as highly sensitive to change or could be skewed if, for

229   example, a researcher has one heavily-cited article.(46, 47) A further disadvantage is the lag-

230   effect of citations,(48, 49) and that in most models citations and publications count equally

231   for all co-authors, despite potential differential contributions.(50) Some also questioned the

232   extent to which citations actually indicated quality or impact, noting that a paper may

233   influence clinical practice more than academic thinking.(51) Indeed, a paper may be highly

234   cited because it is useful (e.g., a review), controversial, or even by chance, making citations a

235   limited indication of quality or impact.(40, 50, 52) In addition to limitations, numerous

236   authors made the point that focusing on citation and publication counts can have unintended,

237   negative consequences for the assessment of researcher achievement, potentially leading to

238   gaming and manipulation, including self-citations and gratuitous authorship.(53, 54)

8

Singular Output-Level Approaches

239

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

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

Journal impact factor

258

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

266   The JIF has a range of limitations when used to indicate journal quality,(68) including
267 that it is disproportionally affected by highly cited, outlier articles,(41, 69) and is susceptible
268 to "gaming" by editors.(17, 70) Other criticisms focused on using the JIF to assess individual
269 articles or the researchers who author them.(71) Some critics claimed that using the JIF to
270 measure an individual's achievement encourages researchers to publish in higher-impact but

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271 less-appropriate journals for their field—which ultimately means their article may not be read

272 by relevant researchers.(72, 73) Furthermore, the popularity of a journal was argued to be a

273 poor indication of the quality of any one article, with the citation distributions for calculating

274 JIF found to be heavily skewed (i.e., a small subset of papers receive the bulk of the citations

275 while some may receive none).(18) Ultimately, many commentators argued that the JIF is an

276 inappropriate metric to assess individual researchers because it is an aggregate metric of a

277 journal's publication, and expresses nothing about any individual paper.(21, 49, 50, 74)

278 However, Bornmann et al. (2017) suggested one case in which it would be appropriate to use

279 JIF for assessing individual researchers: in relation to their recently published papers that had

280 not had the opportunity to accumulate citations.(75)

281 ***Researcher-Level Approaches***

282 *h-index*

283 The h-index was among the most commonly discussed metrics in the literature (254 [53.1%]

284 of the papers reviewed); in many of these papers, it was described by authors as more

285 sophisticated than citation and publication counts, but still straightforward, logical and

286 intuitive.(76-78) Authors noted its combination of productivity (h publications) and impact

287 indicators (h citations) as being more reliable(79, 80) and stable than average citations per

288 publications(41) because it is not skewed by the influence of one popular article.(81) One

289 study found that the h-index correlated with other metrics more difficult to obtain.(78) It also

290 showed convergent validity with peer-reviewed assessments(82) and was found to be a good

291 predictor of future achievement.(41)

292   However because of the lag-effect with citations and publications, the h-index

293 increases with a researcher's years of activity in the field, and cannot decrease, even if

294 productivity later declines.(83) Hence, numerous authors suggested it was inappropriate for

295 comparing researchers at different career stages,(84) or those early in their career.(70) The h-

296 index was also noted as being susceptible to many of the critiques leveled against citation

297 counts, including potential for gaming, and inability to reflect differential contributions by

298 co-authors.(85) Because disciplines differ in citation patterns(86) some studies noted

299 variations in author h-indices between different methodologies(87) and within medical

300 subspecialties.(88) Some therefore argued that the h-index should not be used as the sole

301 measure of a researcher's achievement.(88)

302 *h-index variants*

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303   A number of modified versions of the h-index were identified; these purported to draw on its

304   basic strengths of balancing productivity with impact while redressing perceived limitations.

305   For example, the g-index measures global citation performance,(89) and was defined

306   similarly to the h-index but with more weight given to highly cited articles by assuming the

307   top g articles have received at least g^2 citations.(90) Azer and Azer (2016) argued it was a

308   more useful measure of researcher productivity.(91) Another variant of the h-index identified,

309   the m-quotient, was suggested to minimize the potential to favor senior academics by

310   accounting for the time passed since a researcher has begun publishing papers.(92, 93) Other

311   h-index variations reported in the articles reviewed attempted to account for author

312   contributions, such as the h-maj index, which includes only articles in which the researcher

313   played a core role (based on author order); and the weighted h-index, which assigns credit

314   points according to author order.(89, 94)

315   *Recurring Issues with Citation-Based Metrics*

316   The literature review results suggested that no one citation-based metric was ideal for all

317   purposes. All of the common metrics examined focused on one aspect of an individual's

318   achievement, and thus failed to account for other aspects of achievement. The limitations

319   with some of the frequently used citation-based metrics are listed in **Box 1**.

320

321   **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

322

323   **Non-Citation Based Approaches**

324   *altmetrics*

11

325 In contradistinction with the metrics discussed above, fifty-four papers (11.3%) discussed

326 altmetrics (or "alternative metrics"), which included a wide range of techniques to measure

327 non-traditional, non-citation based usage of articles, that is, influence.(17) Altmetric

328 measures included the number of online article views,(95) bookmarks,(96) downloads,(41)

329 PageRank algorithms(97) and attention by mainstream news,(65) in books(98) and social

330 media, for example, in blogs, commentaries, online topic reviews or tweets.(99, 100) These

331 metrics typically measure the "web visibility" of an output.(101) A notable example is the

332 social networking site for researchers and scientists, ResearchGate, which uses an algorithm

333 to score researchers based on the use of their outputs, including citations, reads, and

334 recommendations.(102)

335   A strength of altmetrics lies in providing a measure of influence promptly after

336 publication.(70, 103, 104) 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),(105) 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,(106) 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 influence or even popularity,(107) instead of quality or productivity.(108) Hence, one study

347 suggested no correlation between attention on Twitter and expert analysis of an article's

348 originality, significance or rigour.(109) Another showed that Tweets predict citations.(110)

349 Overall, further work needs to assess the value of altmetric scores in terms of their

350 association with other traditional indicators of achievement.(111) Notwithstanding this, there

351 were increasing calls to consider altmetrics alongside more conventional metrics in assessing

352 researchers and their work.(112)

353

354 ***Past Funding***

355 A past record of being funded by national agencies was identified as a common measurement

356 of individual academic achievement (particularly productivity, quality and impact) in a

357 number of papers, and has been argued to be a reliable method that is consistent across

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358 medical research.(113-115) For example, the NIH's (National Institute of Health's) RePORT

359 (Research Portfolio Online Reporting Tools) system encourages public accountability for

360 funding by providing online access to reports, data and NIH-funded research projects.(113,

361 116)

362

363 **New Metrics and Models Identified**

364 The review also identified and assessed new metrics and models that were proposed during

365 the review period, many of which had not gained widespread acceptance or use. While there

366 was considerable heterogeneity and varying degrees of complexity among the 78 new

367 approaches identified, there were also many areas of overlap in their methods and purposes.

368 For example, some papers reported on metrics that used a PageRank algorithm,(117, 118) a

369 form of network analysis based on structural characteristics of publications (e.g., co-

370 authorship or citation patterns).(14) Metrics based on PageRank purported to measure both

371 the direct and indirect impact of a publication or researcher. Other approaches considered the

372 relative contributions of authors to a paper in calculating productivity.(119) Numerous

373 metrics and models that built upon existing approaches were also reported.(120) For example,

374 some developed composite metrics that included a publication's JIF alongside an author

375 contribution measure(121) or other existing metrics.(122) However, each of these approaches

376 reported limitations, in addition to their strengths or improvements upon other methods. For

377 example, in focusing on productivity, a metric necessarily often neglected impact.(123)

378 **Appendix 3** provides a summary of these new or re-fashioned metrics and models, with

379 details of their basis and purpose.

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381

382 **DISCUSSION**

383 This systematic review identified a large number of diverse metrics and models for assessing

384 an individual's research achievement that have been developed in the last 10 years (2007-

385 2017), as evidenced in **Appendix 3.** At the same time, other approaches that pre-dated our

386 study time period of 2007-2017 were also discussed frequently in the literature reviewed,

387 including the h-index and JIF. All metrics and models proposed had their relative strengths,

388 based on the components of achievement they focused on, and their sophistication or

389 transparency.

13

390   The review also identified and assessed new metrics and over the past few decades.

391 Peer-review has been increasingly criticized for reliance on subjectivity and propensity for

392 bias,(7) and there have been arguments that the use of specific metrics may be a more

393 objective and fair approach for assessing individual research achievement. However, this

394 review has highlighted that even seemingly objective measures have a range of shortcomings.

395 For example, there are inadequacies in comparing researchers at different career stages, and

396 across disciplines with different citation patterns.(86) Furthermore, the use of citation-based

397 metrics can lead to gaming and potential ethical misconduct by contributing to a "publish or

398 perish" culture in which researchers are under pressure to maintain or improve their

399 publication records.(124, 125) New methods and adjustments to existing metrics have been

400 proposed to explicitly address some of these limitations; for example, normalizing metrics

401 with "exchange rates" to remove discipline-specific variation in citation patterns, thereby

402 making metric scores more comparable for researchers working in disparate fields.(126, 127)

403 Normalization techniques have also been used to assess researchers' metrics with greater

404 recognition of their relative opportunity and career longevity.(128)

405   Other criticisms of traditional approaches center less on how they calculated

406 achievement, and more on what they understood or assumed about its constituent elements.

407 In this review, the measurement of impact or knowledge gain was often exclusively tied to

408 citations.(129) Some articles proposed novel approaches to using citations as a measure of

409 impact, such as giving greater weight to citations from papers that were themselves highly

410 cited(130) or that come from outside the field in which the paper was published.(131)

411 However, even other potential means of considering scientific contributions and achievement,

412 such as mentoring, were still ultimately tied to citations because mentoring was measured by

413 the publication output of mentees.(132)

414   A focus only on citations was widely thought to disadvantage certain types of

415 researchers. For example, researchers who aim to publish with a focus on influencing practice

416 may target more specialized or regional journals that do not have high JIFs, where their

417 papers will be read by the appropriate audience and findings implemented, but they may not

418 be well-cited.(51) In this regard, categorizing the type of journal in which an article has been

419 published in terms of its focus (e.g., industry, clinical, regional/national) may go some way

420 toward recognizing those publications that have a clear knowledge translation intention, and

421 therefore prioritize real-world impact over academic impact.(124) There were only a few

422 other approaches identified that captured broader conceptualizations of knowledge gain, such

423 as practical impact or wealth generation for the economy, and these too were often simplistic,

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424 such as including patents and their citations(133) or altmetric data.(98) While altmetrics hold

425 potential in this regard, their use has not been standardized,(98) and they come with their own

426 limitations, with suggestions that they reflect popularity more so than real world impact.(107)

427 Other methodologies have been proposed for assessing knowledge translation and real-world

428 impact, but these can often be labor intensive.(134) For example, Sutherland et al.

429 (2011)(135) suggested that assessing individual research outputs in light of specific policy

430 objectives, through peer-review based scoring, may be a strategy, but this is typically not

431 feasible in situations such as grant funding allocation, where there are time-constraints and

432 large applicant pools to assess.

433   In terms of how one can make sense of the validity of many of these emerging

434 approaches for assessing an individual's research achievements, metrics should demonstrate

435 their legitimacy empirically, as well as having a theoretical basis for their use and clearly

436 differentiating what aspects of quality, achievement or impact they purport to examine.(55,

437 67) If the recent, well-publicized(136-138) San Francisco Declaration on Research

438 Assessment (DORA)(139) is anything to go by, internationally there is a move away from the

439 assessment of individual researchers using the JIF and the journal in which the research has

440 been published.

441

442 **Figure 3. The Comprehensive Researcher Achievement Model (CRAM)**

443 **<Insert Figure 3>**

444   There is momentum, instead, for assessment of researcher achievements on the basis

445 of a wider mix of measures, hence our proposed Comprehensive Researcher Achievement

446 Model (CRAM) (**Figure 3**). On the left-hand side of this model is the researcher to be

447 assessed, and key characteristics that influence the assessment. Among these factors, some

448 (i.e., field or discipline, co-authorship, career longevity) can be controlled for depending on

449 the metric, while other components, such as gaming or the research topic (i.e., whether it is

450 "trendy" or innovative) are less amenable to control or even prediction. Online databases,

451 which track citations and downloads and measure other forms of impact, hold much potential

452 and will likely be increasingly used in the future to assess both individual researchers and

453 their outputs. Hence, assessment components (past funding, articles, citations, patents,

454 downloads, and some media traction) included in our model are those primarily accessible

455 online.

456 **Strengths and Limitations**

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457 The findings of this review suggest assessment components should be used with care, and

458 with recognition of how they can be influenced by other factors, and what aspects of

459 achievement they reflect (i.e., productivity, quality, impact, influence). No metric or model

460 singularly captures all aspects of achievement, and hence use of a range, such as the

461 examples in our model, is advisable. CRAM recognizes that the configuration and weighting

462 of assessment methods will depend on the assessors and their purpose, the resources available

463 for the assessment process, and access to assessment components. Our results must be

464 interpreted in light of our focus on academic literature. The limits of our focus on peer-

465 reviewed literature were evident in the fact some new metrics were not mentioned in articles,

466 and therefore not captured in our results. While we defined impact broadly at the outset,

467 overwhelmingly the literature we reviewed focused on academic, citation-based impact.

468 Furthermore, although we assessed bias in the ways documented, the study design limited our

469 ability to apply a standardized quality assessment tool.

470

471 **CONCLUSION**

472 There is no ideal model or metric by which to assess individual researcher achievement. We

473 have proposed a generic model, designed to minimize risk of the use of any one or a smaller

474 number of metrics, but it is not proposed as an ultimate solution. The mix of assessment

475 components and metrics will depend on the purpose. Greater transparency in approaches used

476 to assess achievement including their evidence-base is required.(37) Any model used to

477 assess achievement for purposes such as promotion or funding allocation should include

478 some quantitative components, based on robust data, and be able to be rapidly updated,

479 presented with confidence intervals, and normalized.(37) The assessment process should be

480 difficult to manipulate, and explicit about the components of achievement being measured.

481 As such, no current metric suitably fulfills all these criteria. The best strategy to assess an

482 individual's research achievement is likely to involve the use of multiple approaches(140) in

483 order to dilute the influence and potential disadvantages of any one metric, while providing

484 more rounded picture of a researcher's achievement;(85, 141) this is what the CRAM aims to

485 contribute.

486 All-in-all, achievement in terms of impact and knowledge gain is broader than the

487 number of articles published or their citation rates, and yet most metrics have no means of

488 factoring in these broader issues. Altmetrics hold promise in complementing citation-based

489 metrics and assessing more diverse notions of impact, but usage of this type of tool requires

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490   further standardization.(98) Finally, despite the limitations of peer-review, the role of expert

491   judgement should not be discounted.(41) Metrics are perhaps best applied as a complement or

492   check on the peer-review process, rather than the sole means of assessment of an individual's

493   research achievements.(142)

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496

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506 the conduct of the systematic review, or the decision to publish.

507

508 **Data sharing statement**

509 All data has been made available as Appendices.

510

511 **Author Contributions**

512 JB conceptualized and drafted the manuscript, revised it critically for important intellectual

513 content, and led the study. JH, KC and JCL made substantial contributions to the design,

514 analysis and revision of the work and critically reviewed the manuscript for important

515 intellectual content. CP, CB, MB, RC-W, FR, PS, AH, LAE, KL, EA, RS and EM carried out

516 the initial investigation, sourced and analyzed the data and revised the manuscript for

517 important intellectual content. PH and JIW critically commented on the manuscript,

518 contributed to the revision and editing of the final manuscript and reviewed the work for

519 important intellectual content. All authors approved the final manuscript as submitted and

520 agree to be accountable for all aspects of the work.

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Database search output ($n = 7810$)	→	Duplicates deleted ($n = 135$)
Title and abstract review ($n = 7675$)	→	Articles excluded ($n = 6823$)
Full text review ($n = 852$)	→	Articles excluded ($n = 377$)*
Articles included ($n = 478$)	←	Articles added by snowballing ($n = 3$)

*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

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

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The Comprehensive Researcher Achievement Model (CRAM)

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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	

Author	Year	Journal	Type							
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

Author	Year	Journal	Type							
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			

Author	Year	Journal	Type							
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	

Author	Year	Journal	Type							
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	

Author	Year	Journal	Type								
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					

Author	Year	Journal	Type							
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

Author	Year	Journal	Type							
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

Author	Year	Journal	Type						
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			

Author	Year	Journal	Type							
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						

Author	Year	Source	Type							
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		

Name	Year	Journal	Type									
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							

Author	Year	Journal	Type									
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		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			

Author	Year	Journal	Type							
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			

Author	Year	Journal	Type							
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					

Name	Year	Journal	Type						
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						
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

Note: Safdar 2015 has a Y in the first data column.

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Author	Year	Journal	Type										
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					

Name	Year	Journal	Type							
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							

Name	Year	Journal	Type							
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			

Author	Year	Journal	Type							
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		

Author	Year	Journal	Type						
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 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.

Author	Year	Journal		Type	Metric	Base	Description
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: $TotalImpact = P \times C \times FSL$.
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).

Author	Year	Journal		Type	Name	Based on	Description
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.

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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](#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](#22)	Present results of any assessment of risk of bias across studies (see Item 15).	4-5
Additional analysis	[#23](#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](#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](#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](#26)	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	16-17
Funding	[#27](#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

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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

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\<b\>Primary Subject Heading\</b\>:	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

1   **The Comprehensive Researcher Achievement Model (CRAM):**

2   **a framework for measuring researcher achievement, impact and influence derived from**

3   **a systematic literature review of metrics and models**

4

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34   **ABSTRACT**

35   **Objectives** Effective researcher assessment is key to decisions about funding allocations,

36   promotion and tenure. We aimed to identify what is known about methods for assessing

37   researcher achievements, leading to a new composite assessment model.

38   **Design** We systematically reviewed the literature via the Preferred Reporting Items for

39   Systematic Review and Meta-Analysis Protocols (PRISMA-P) framework.

40   **Data sources** All Web of Science databases (including Core Collection, MEDLINE, and

41   BIOSIS Citation Index) to the end of 2017.

42   **Eligibility criteria** (1) English language, (2) published in the last 10 years (2007-2017), (3)

43   full text was available, and (4) the article discussed an approach to the assessment of an

44   individual researcher's achievements.

45   **Data extraction and synthesis** Articles were allocated amongst four pairs of reviewers for

46   screening, with each pair was randomly assigned 5% of their allocation to review

47   concurrently against inclusion criteria, with inter-rater reliability assessed using Cohen's

48   Kappa (κ). The κ statistic showed agreement ranged from moderate to almost perfect

49   (0.4848-0.9039). Following screening, selected articles underwent full text review and bias

50   assessed.

51   **Results** Four hundred and seventy-eight articles were included in the final review.

52   Established approaches developed prior to our inclusion period (e.g., citations and outputs, h-

53   index, journal impact factor), remained dominant in the literature and in practice. New

54   bibliometric methods and models emerged in the last 10 years including: measures based on

55   PageRank algorithms or "altmetric" data, methods to apply peer judgement, and techniques to

56   assign values to publication quantity and quality. Each assessment method tended to

57   prioritize certain aspects of achievement over others.

58   **Conclusions** All metrics and models focus on an element or elements, at the expense of

59   others. A new composite design, the Comprehensive Researcher Achievement Model

60   (CRAM) is presented which supersedes past anachronistic models. The CRAM is modifiable

61   to a range of applications.

62   **Keywords:** Researcher assessment; Research metrics; h-index; Journal impact factor;

63   citations; outputs; Comprehensive Researcher Achievement Model (CRAM)

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65   **Article Summary**

66   **Strengths and limitations of this study**

2

- 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

3

79   **INTRODUCTION**

80   Judging researchers' achievements and academic impact continues to be an important means

81   of allocating scarce research funds and assessing candidates for promotion or tenure. It has

82   historically been carried out through some form of expert peer judgement, to assess the

83   number and quality of outputs, and in more recent decades, citations to them. This approach

84   requires judgements regarding the weight which should be assigned to the number of

85   publications, their quality, where they were published, and their downstream influence or

86   impact. There are significant questions about the extent to which human judgement based on

87   these criteria is an effective mechanism for making these complex assessments in a consistent

88   and unbiased way.(1-3) Criticisms of peer assessment, even when underpinned by relatively

89   impartial productivity data, include the propensity for bias, inconsistency among reviewers,

90   nepotism, group-think and subjectivity.(4-7)

91   To compensate for these limitations, approaches have been proposed that rely less on

92   subjective judgement and more on objective indicators.(3, 8-10) Indicators of achievement

93   focus on one or a combination of four aspects: quantity of researcher outputs (*productivity*);

94   value of outputs (*quality*); outcomes of research outputs (*impact*); and relations between

95   publications or authors and the wider world (*influence*).(11-15) Online publishing of journal

96   articles has provided the opportunity to easily track citations and user interactions (e.g.,

97   number of article downloads) and thus has provided a new set of indices against which

98   individual researchers, journals and articles can be compared and the relative worth of

99   contributions assessed and valued.(14) These relatively new metrics have been collectively

100 termed *bibliometrics*(16) when based on citations and numbers of publications, or

101 *altmetrics*(17) when calculated by alternative online measures of impact such as number of

102 downloads or social media mentions.(16)

103   The most established metrics for inferring researcher achievement are the h-index and

104 the Journal Impact Factor (JIF). The JIF measures the average number of citations of an

105 article in the journal over the previous year, and hence is a good indication of journal quality

106 but is increasingly regarded as a primitive measure of quality for individual researchers.(18)

107 The h-index, proposed by Hirsch in 2005,(19) attempts to portray a researcher's productivity

108 and impact in one data point. The h-index is defined as the number (*h*) of articles published

109 by a researcher that have received a citation count of at least *h*. Use of the h-index has

110 become widespread, reflected in its inclusion in author profiles on online databases such as

111 Google Scholar and Scopus.

4

112   Also influenced by the advent of online databases, there has been a proliferation of

113   other assessment models and metrics,(16) many of which purport to improve upon existing

114   approaches.(20, 21) These include methods that assess the impact of articles measured by:

115   downloads or online views received; practice change related to specific research; take-up by

116   the scientific community; or mentions in social media.

117   Against the backdrop of growth in metrics and models for assessing researchers'

118   achievements, there is a lack of guidance on the relative strengths and limitations of these

119   different approaches. Understanding them is of fundamental importance to funding bodies

120   that drive the future of research, tenure and promotion committees, and more broadly for

121   providing insights into how we recognize and value the work of science and scientists,

122   particularly those researching in medicine and healthcare. This review aimed to identify

123   approaches to assessing researchers' achievements published in the academic literature over

124   the last 10 years, considering their relative strengths and limitations and drawing on this to

125   propose a new composite assessment model.

126

127   **METHOD**

128   **Search Strategy**

129   All Web of Science databases (eight in total, including Web of Science Core Collection,

130   MEDLINE, and BIOSIS Citation Index) were searched using terms related to researcher

131   achievement (*researcher excellence, track record, researcher funding, researcher perform*,*

132   *relative to opportunity, researcher potential, research* career pathway, academic career*

133   *pathway, funding system, funding body, researcher impact, scientific* productivity, academic*

134   *productivity, top researcher, researcher ranking, grant application, researcher output,*

135   *h*index, i*index, impact factor, individual researcher*) and approaches to its assessment

136   (*model, framework, assess*, evaluat*, *metric*, measur*, criteri*, citation*, unconscious*

137   *bias, rank**) with "***" used as an unlimited truncation to capture variation in search terms, as

138   seen in **Appendix 1**. These two searches were combined (using "*and*") and results were

139   downloaded into EndNote, the reference management software.

140   **Study Selection**

141   After removing duplicate references in EndNote,(22) articles were allocated amongst pairs of

142   reviewers (MB-JCL, CP-CB, KL-JH, KC-LAE) for screening against inclusion criteria.

143   Following established procedures,(23, 24) each pair was randomly assigned 5% of their

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144 allocation to review concurrently against inclusion criteria, with inter-rater reliability

145 assessed using Cohen's Kappa (κ). The κ statistic was calculated for pairs of researchers, with

146 agreement ranging from moderate to almost perfect (0.4848-0.9039).(25) Following the

147 abstract and title screen, selected articles underwent full text review. Reasons for exclusion

148 were recorded.

149 **Inclusion Criteria**

150 The following inclusion criteria were operationalized: (1) English language, (2) published in

151 the last 10 years (2007-2017), (3) full text for the article was available, and (4) the article

152 discussed an approach to the assessment of an individual researcher's achievements (at the

153 researcher or singular output-level). The research followed the Preferred Reporting Items for

154 Systematic Review and Meta-Analysis Protocols (PRISMA-P) framework.(26) Empirical and

155 non-empirical articles were included, because many articles proposing new approaches to

156 assessment, or discussing the limitations of existing ones, are not level one evidence or

157 research-based. Both quantitative and qualitative studies were included.

158 **Data Extraction**

159 Data from the included articles were extracted, including: the country of article origin, the

160 characteristics of the models or metrics discussed, the perspective the article presented on the

161 metric or model (positive, negative, indeterminable) including any potential benefits or

162 limitations of the assessment model (and if these were perceived or based on some form of

163 evidence). A customised data extraction sheet was developed in Microsoft Excel, trialed

164 among members of the research team and subsequently refined. This information was

165 synthesized for each model and metric identified through narrative techniques. The

166 publication details and classification of each paper are contained in **Appendix 2**.

167 **Appraisal of the Literature**

168 Due to the prevalence of non-empirical articles in this field (e.g., editorial contributions,

169 commentaries), it was determined that a risk of bias tool such as the Quality Assessment Tool

170 could not be applied.(27) Rather, assessors were trained in multiple meetings (October 24,

171 October 30, November 13, 2017) to critically assess the quality of articles. Given the topic of

172 the review (focusing on the publication process), the type of models and metrics identified

173 (i.e., more metrics that use publication metrics) may influence the cumulative evidence and

6

174 subsequently create a risk of bias. In addition, three researchers (JH, EM, CB) reviewed every

175 included article, to extract documented conflicts of interests of authors.

176 **Patient and public involvement**

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

178 **RESULTS**

179 The final dataset consisted of 478 academic articles. The data screening process is presented

180 in **Figure 1**.

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

183 Of the 478 included papers (see **Appendix 2** for a summary), 295 (61.7%) had an

184 empirical component, which ranged from interventional studies that assessed researcher

185 achievement as an outcome measure (e.g., a study measuring the outcomes of a training

186 program),(28) as a predictor(29-31) (e.g., a study that demonstrated the association between

187 number of citations early in one's career and later career productivity), or reported a

188 descriptive analysis of a new metric.(32, 33) One hundred and sixty-six (34.7%) papers were

189 not empirical, including editorial or opinion contributions that discussed the assessment of

190 research achievement, or proposed models for assessing researcher achievement. Seventeen

191 papers (3.6%) were reviews that considered one or more elements of assessing researcher

192 achievements. The quality of these contributions ranged in terms of the risk of bias in the

193 viewpoint expressed. Only for 19 papers (4.0%) did the authors declare a potential conflict of

194 interest.

195 Across the study period, 78 articles (16.3%) involved authors purporting to propose

196 new models or metrics. Most articles described or cited pre-existing metrics and largely

197 discussed their perceived strengths and limitations. **Figure 2** shows the proportion of positive

198 or negative discussions of five of the most common approaches to assessing an individual's

199 research achievement (altmetrics, peer-review, h-index, simple counts, and JIF). The

200 approach with most support was altmetrics (51.0% of articles mentioning altmetrics). The JIF

201 was discussed with mostly negative sentiments in relevant articles (69.4%).

202

203 **Figure 2. Percentages of positive and negative discussion regarding selected commonly**

204 **used metrics for assessing individual researchers (n=478 articles)**

205 **<Insert Figure 2>**

7

206   Legend: Positive discussion refers to articles that discuss the metric in a favorable light or focus on the strengths

207   of the metric; negative discussion refers to articles that focus on the limitations or shortcomings of the metric.

208   **Citation-Based Metrics**

209   *Publication and Citation Counts*

210   One hundred and fifty-three papers (32.0%) discussed the use of publication and citation

211   counts for purposes of assessing researcher achievement, with papers describing them as a

212   simple "traditional but somewhat crude measure",(34) as well as the building blocks for other

213   metrics.(35) A researcher's number of publications, commonly termed an n-index,(36) was

214   suggested by some to indicate researcher productivity,(14) rather than quality, impact or

215   influence of these papers.(37) On the other hand, the literature suggested that numbers of

216   citations indicated the academic impact of an individual publication or researcher's body of

217   work, calculated as an author's cumulative or mean citations per article.(38) Some studies

218   found support for the validity of citation counts and publications in that they were correlated

219   with other indications of a researcher's achievement, such as awards and grant funding,(39,

220   40) and predictive of long term success in a field.(41) For example, one paper argued that

221   having larger numbers of publications and being highly cited early in one's career predicted

222   later high quality research.(42)

223   A number of limitations of using citation or publication counts was observed. For

224   example, Minasny et al. (2013) highlighted discrepancies between publications and citations

225   counts in different databases because of their differential structures and inputs.(43) Other

226   authors(38, 44, 45) noted that citation patterns vary by discipline, which they suggested can

227   make them inappropriate for comparing researchers from different fields. Average citations

228   per publication were reported as highly sensitive to change or could be skewed if, for

229   example, a researcher has one heavily-cited article.(46, 47) A further disadvantage is the lag-

230   effect of citations,(48, 49) and that in most models citations and publications count equally

231   for all co-authors, despite potential differential contributions.(50) Some also questioned the

232   extent to which citations actually indicated quality or impact, noting that a paper may

233   influence clinical practice more than academic thinking.(51) Indeed, a paper may be highly

234   cited because it is useful (e.g., a review), controversial, or even by chance, making citations a

235   limited indication of quality or impact.(40, 50, 52) In addition to limitations, numerous

236   authors made the point that focusing on citation and publication counts can have unintended,

237   negative consequences for the assessment of researcher achievement, potentially leading to

238   gaming and manipulation, including self-citations and gratuitous authorship.(53, 54)

8

Singular Output-Level Approaches

239 Forty-one papers (8.6%) discussed models and metrics at the singular output or article-level

240 that could be used to infer researcher achievement. The components of achievement they

241 reported assessing were typically quality or impact.(55, 56) For example, some papers

242 reported attempts to examine the quality of a single article by assessing its content.(57, 58)

243 Among the metrics identified in the literature, the immediacy index (II) focused on impact by

244 measuring the average number of cites an article received in the year it was published.(59)

245 Similarly, Finch suggested adapting the Source Normalized Impact per Publication (SNIP; a

246 metric used for journal-level calculations across different fields of research) to the article-

247 level.(21)

249 Many of the article-level metrics identified could also be upscaled to produce

250 researcher-level indications of academic impact. For example, the sCientific currENcy

251 Tokens (CENTs), proposed by Szymanski et al. (2012), involved giving a "cent" for each

252 new non-self-citation a publication received; CENTs are then used as the basis for the

253 researcher-level i-index, which follows a similar approach as the h-index, but removes self-

254 citations.(60) The TAPSIF (Temporally-Averaged Paper-Specific Impact Factor) calculates an

255 article's average number of citations per year combined with bonus cites for the publishing

256 journal's prestige, and can be aggregated to measure the overall relevance of a researcher

257 (Temporally Averaged Author-Specific Impact Factor; TAASIF).(61)

Journal impact factor

259 The JIF, commonly recognized as a journal-level measure of quality,(59, 62-64) was

260 discussed in 211 (44.1%) of the papers reviewed in relation to assessing singular outputs or

261 individual researchers. A number of papers described the JIF being used informally to assess

262 an individual's research achievement at the singular output-level, and formally in countries

263 such as France and China.(65) It implies article quality because it is typically a more

264 competitive process to publish in journals with high impact factors.(66) Indeed, the JIF was

265 found to be the best predictor of a paper's propensity to receive citations.(67)

266 The JIF has a range of limitations when used to indicate journal quality,(68) including

267 that it is disproportionally affected by highly cited, outlier articles,(41, 69) and is susceptible

268 to "gaming" by editors.(17, 70) Other criticisms focused on using the JIF to assess individual

269 articles or the researchers who author them.(71) Some critics claimed that using the JIF to

270 measure an individual's achievement encourages researchers to publish in higher-impact but

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271 less-appropriate journals for their field—which ultimately means their article may not be read

272 by relevant researchers.(72, 73) Furthermore, the popularity of a journal was argued to be a

273 poor indication of the quality of any one article, with the citation distributions for calculating

274 JIF found to be heavily skewed (i.e., a small subset of papers receive the bulk of the citations

275 while some may receive none).(18) Ultimately, many commentators argued that the JIF is an

276 inappropriate metric to assess individual researchers because it is an aggregate metric of a

277 journal's publication, and expresses nothing about any individual paper.(21, 49, 50, 74)

278 However, Bornmann et al. (2017) suggested one case in which it would be appropriate to use

279 JIF for assessing individual researchers: in relation to their recently published papers that had

280 not had the opportunity to accumulate citations.(75)

281 ***Researcher-Level Approaches***

282 *h-index*

283 The h-index was among the most commonly discussed metrics in the literature (254 [53.1%]

284 of the papers reviewed); in many of these papers, it was described by authors as more

285 sophisticated than citation and publication counts, but still straightforward, logical and

286 intuitive.(76-78) Authors noted its combination of productivity (h publications) and impact

287 indicators (h citations) as being more reliable(79, 80) and stable than average citations per

288 publications(41) because it is not skewed by the influence of one popular article.(81) One

289 study found that the h-index correlated with other metrics more difficult to obtain.(78) It also

290 showed convergent validity with peer-reviewed assessments(82) and was found to be a good

291 predictor of future achievement.(41)

292   However because of the lag-effect with citations and publications, the h-index

293 increases with a researcher's years of activity in the field, and cannot decrease, even if

294 productivity later declines.(83) Hence, numerous authors suggested it was inappropriate for

295 comparing researchers at different career stages,(84) or those early in their career.(70) The h-

296 index was also noted as being susceptible to many of the critiques leveled against citation

297 counts, including potential for gaming, and inability to reflect differential contributions by

298 co-authors.(85) Because disciplines differ in citation patterns(86) some studies noted

299 variations in author h-indices between different methodologies(87) and within medical

300 subspecialties.(88) Some therefore argued that the h-index should not be used as the sole

301 measure of a researcher's achievement.(88)

302 *h-index variants*

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303 A number of modified versions of the h-index were identified; these purported to draw on its

304 basic strengths of balancing productivity with impact while redressing perceived limitations.

305 For example, the g-index measures global citation performance,(89) and was defined

306 similarly to the h-index but with more weight given to highly cited articles by assuming the

307 top g articles have received at least g^2 citations.(90) Azer and Azer (2016) argued it was a

308 more useful measure of researcher productivity.(91) Another variant of the h-index identified,

309 the m-quotient, was suggested to minimize the potential to favor senior academics by

310 accounting for the time passed since a researcher has begun publishing papers.(92, 93) Other

311 h-index variations reported in the articles reviewed attempted to account for author

312 contributions, such as the h-maj index, which includes only articles in which the researcher

313 played a core role (based on author order); and the weighted h-index, which assigns credit

314 points according to author order.(89, 94)

315 *Recurring Issues with Citation-Based Metrics*

316 The literature review results suggested that no one citation-based metric was ideal for all

317 purposes. All of the common metrics examined focused on one aspect of an individual's

318 achievement, and thus failed to account for other aspects of achievement. The limitations

319 with some of the frequently used citation-based metrics are listed in **Box 1**.

320

321 **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

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323 **Non-Citation Based Approaches**

324 *altmetrics*

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325   In contradistinction with the metrics discussed above, fifty-four papers (11.3%) discussed

326   altmetrics (or "alternative metrics"), which included a wide range of techniques to measure

327   non-traditional, non-citation based usage of articles, that is, influence.(17) Altmetric

328   measures included the number of online article views,(95) bookmarks,(96) downloads,(41)

329   PageRank algorithms(97) and attention by mainstream news,(65) in books(98) and social

330   media, for example, in blogs, commentaries, online topic reviews or tweets.(99, 100) These

331   metrics typically measure the "web visibility" of an output.(101) A notable example is the

332   social networking site for researchers and scientists, ResearchGate, which uses an algorithm

333   to score researchers based on the use of their outputs, including citations, reads, and

334   recommendations.(102)

335   A strength of altmetrics lies in providing a measure of influence promptly after

336   publication.(70, 103, 104) 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),(105) 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,(106) 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   influence or even popularity,(107) instead of quality or productivity.(108) Hence, one study

347   suggested no correlation between attention on Twitter and expert analysis of an article's

348   originality, significance or rigour.(109) Another showed that Tweets predict citations.(110)

349   Overall, further work needs to assess the value of altmetric scores in terms of their

350   association with other traditional indicators of achievement.(111) Notwithstanding this, there

351   were increasing calls to consider altmetrics alongside more conventional metrics in assessing

352   researchers and their work.(112)

353

354   ***Past Funding***

355   A past record of being funded by national agencies was identified as a common measurement

356   of individual academic achievement (particularly productivity, quality and impact) in a

357   number of papers, and has been argued to be a reliable method that is consistent across

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358 medical research.(113-115) For example, the NIH's (National Institute of Health's) RePORT

359 (Research Portfolio Online Reporting Tools) system encourages public accountability for

360 funding by providing online access to reports, data and NIH-funded research projects.(113,

361 116)

362

363 **New Metrics and Models Identified**

364 The review also identified and assessed new metrics and models that were proposed during

365 the review period, many of which had not gained widespread acceptance or use. While there

366 was considerable heterogeneity and varying degrees of complexity among the 78 new

367 approaches identified, there were also many areas of overlap in their methods and purposes.

368 For example, some papers reported on metrics that used a PageRank algorithm,(117, 118) a

369 form of network analysis based on structural characteristics of publications (e.g., co-

370 authorship or citation patterns).(14) Metrics based on PageRank purported to measure both

371 the direct and indirect impact of a publication or researcher. Other approaches considered the

372 relative contributions of authors to a paper in calculating productivity.(119) Numerous

373 metrics and models that built upon existing approaches were also reported.(120) For example,

374 some developed composite metrics that included a publication's JIF alongside an author

375 contribution measure(121) or other existing metrics.(122) However, each of these approaches

376 reported limitations, in addition to their strengths or improvements upon other methods. For

377 example, in focusing on productivity, a metric necessarily often neglected impact.(123)

378 **Appendix 3** provides a summary of these new or re-fashioned metrics and models, with

379 details of their basis and purpose.

380

381

382 **DISCUSSION**

383 This systematic review identified a large number of diverse metrics and models for assessing

384 an individual's research achievement that have been developed in the last 10 years (2007-

385 2017), as evidenced in **Appendix 3.** At the same time, other approaches that pre-dated our

386 study time period of 2007-2017 were also discussed frequently in the literature reviewed,

387 including the h-index and JIF. All metrics and models proposed had their relative strengths,

388 based on the components of achievement they focused on, and their sophistication or

389 transparency.

13

390   The review also identified and assessed new metrics and over the past few decades.

391   Peer-review has been increasingly criticized for reliance on subjectivity and propensity for

392   bias,(7) and there have been arguments that the use of specific metrics may be a more

393   objective and fair approach for assessing individual research achievement. However, this

394   review has highlighted that even seemingly objective measures have a range of shortcomings.

395   For example, there are inadequacies in comparing researchers at different career stages, and

396   across disciplines with different citation patterns.(86) Furthermore, the use of citation-based

397   metrics can lead to gaming and potential ethical misconduct by contributing to a "publish or

398   perish" culture in which researchers are under pressure to maintain or improve their

399   publication records.(124, 125) New methods and adjustments to existing metrics have been

400   proposed to explicitly address some of these limitations; for example, normalizing metrics

401   with "exchange rates" to remove discipline-specific variation in citation patterns, thereby

402   making metric scores more comparable for researchers working in disparate fields.(126, 127)

403   Normalization techniques have also been used to assess researchers' metrics with greater

404   recognition of their relative opportunity and career longevity.(128)

405   Other criticisms of traditional approaches center less on how they calculated

406   achievement, and more on what they understood or assumed about its constituent elements.

407   In this review, the measurement of impact or knowledge gain was often exclusively tied to

408   citations.(129) Some articles proposed novel approaches to using citations as a measure of

409   impact, such as giving greater weight to citations from papers that were themselves highly

410   cited(130) or that come from outside the field in which the paper was published.(131)

411   However, even other potential means of considering scientific contributions and achievement,

412   such as mentoring, were still ultimately tied to citations because mentoring was measured by

413   the publication output of mentees.(132)

414   A focus only on citations was widely thought to disadvantage certain types of

415   researchers. For example, researchers who aim to publish with a focus on influencing practice

416   may target more specialized or regional journals that do not have high JIFs, where their

417   papers will be read by the appropriate audience and findings implemented, but they may not

418   be well-cited.(51) In this regard, categorizing the type of journal in which an article has been

419   published in terms of its focus (e.g., industry, clinical, regional/national) may go some way

420   toward recognizing those publications that have a clear knowledge translation intention, and

421   therefore prioritize real-world impact over academic impact.(124) There were only a few

422   other approaches identified that captured broader conceptualizations of knowledge gain, such

423   as practical impact or wealth generation for the economy, and these too were often simplistic,

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424 such as including patents and their citations(133) or altmetric data.(98) While altmetrics hold

425 potential in this regard, their use has not been standardized,(98) and they come with their own

426 limitations, with suggestions that they reflect popularity more so than real world impact.(107)

427 Other methodologies have been proposed for assessing knowledge translation and real-world

428 impact, but these can often be labor intensive.(134) For example, Sutherland et al.

429 (2011)(135) suggested that assessing individual research outputs in light of specific policy

430 objectives, through peer-review based scoring, may be a strategy, but this is typically not

431 feasible in situations such as grant funding allocation, where there are time-constraints and

432 large applicant pools to assess.

433   In terms of how one can make sense of the validity of many of these emerging

434 approaches for assessing an individual's research achievements, metrics should demonstrate

435 their legitimacy empirically, as well as having a theoretical basis for their use and clearly

436 differentiating what aspects of quality, achievement or impact they purport to examine.(55,

437 67) If the recent, well-publicized(136-138) San Francisco Declaration on Research

438 Assessment (DORA)(139) is anything to go by, internationally there is a move away from the

439 assessment of individual researchers using the JIF and the journal in which the research has

440 been published.

441

442 **Figure 3. The Comprehensive Researcher Achievement Model (CRAM)**

443 **<Insert Figure 3>**

444   There is momentum, instead, for assessment of researcher achievements on the basis

445 of a wider mix of measures, hence our proposed Comprehensive Researcher Achievement

446 Model (CRAM) (**Figure 3**). On the left-hand side of this model is the researcher to be

447 assessed, and key characteristics that influence the assessment. Among these factors, some

448 (i.e., field or discipline, co-authorship, career longevity) can be controlled for depending on

449 the metric, while other components, such as gaming or the research topic (i.e., whether it is

450 "trendy" or innovative) are less amenable to control or even prediction. Online databases,

451 which track citations and downloads and measure other forms of impact, hold much potential

452 and will likely be increasingly used in the future to assess both individual researchers and

453 their outputs. Hence, assessment components (past funding, articles, citations, patents,

454 downloads, and some media traction) included in our model are those primarily accessible

455 online.

456 **Strengths and Limitations**

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457   The findings of this review suggest assessment components should be used with care, and

458   with recognition of how they can be influenced by other factors, and what aspects of

459   achievement they reflect (i.e., productivity, quality, impact, influence). No metric or model

460   singularly captures all aspects of achievement, and hence use of a range, such as the

461   examples in our model, is advisable. CRAM recognizes that the configuration and weighting

462   of assessment methods will depend on the assessors and their purpose, the resources available

463   for the assessment process, and access to assessment components. Our results must be

464   interpreted in light of our focus on academic literature. The limits of our focus on peer-

465   reviewed literature were evident in the fact some new metrics were not mentioned in articles,

466   and therefore not captured in our results. While we defined impact broadly at the outset,

467   overwhelmingly the literature we reviewed focused on academic, citation-based impact.

468   Furthermore, although we assessed bias in the ways documented, the study design limited our

469   ability to apply a standardized quality assessment tool. A strength of our focus was that we

470   set no inclusion criteria with regard to scientific discipline, because novel and useful

471   approaches to assessing research achievement can come from diverse fields. Many of the

472   articles we reviewed were broadly in the area of health and medical research, and our

473   discussion is concerned with the implications for health and medical research, as this is where

474   our interests lie.

475

CONCLUSION

477   There is no ideal model or metric by which to assess individual researcher achievement. We

478   have proposed a generic model, designed to minimize risk of the use of any one or a smaller

479   number of metrics, but it is not proposed as an ultimate solution. The mix of assessment

480   components and metrics will depend on the purpose. Greater transparency in approaches used

481   to assess achievement including their evidence-base is required.(37) Any model used to

482   assess achievement for purposes such as promotion or funding allocation should include

483   some quantitative components, based on robust data, and be able to be rapidly updated,

484   presented with confidence intervals, and normalized.(37) The assessment process should be

485   difficult to manipulate, and explicit about the components of achievement being measured.

486   As such, no current metric suitably fulfills all these criteria. The best strategy to assess an

487   individual's research achievement is likely to involve the use of multiple approaches(140) in

488   order to dilute the influence and potential disadvantages of any one metric, while providing

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489 more rounded picture of a researcher's achievement;(85, 141) this is what the CRAM aims to

490 contribute.

491   All-in-all, achievement in terms of impact and knowledge gain is broader than the

492 number of articles published or their citation rates, and yet most metrics have no means of

493 factoring in these broader issues. Altmetrics hold promise in complementing citation-based

494 metrics and assessing more diverse notions of impact, but usage of this type of tool requires

495 further standardization.(98) Finally, despite the limitations of peer-review, the role of expert

496 judgement should not be discounted.(41) Metrics are perhaps best applied as a complement or

497 check on the peer-review process, rather than the sole means of assessment of an individual's

498 research achievements.(142)

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40
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55 525 agree to be accountable for all aspects of the work.
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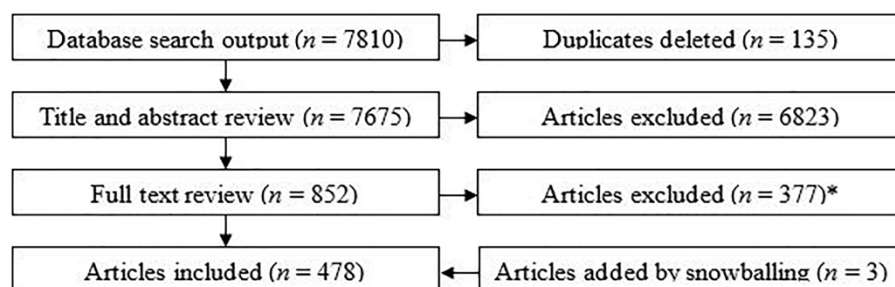673   *BioScience.* 2015;65(2):117. doi:10.1093/biosci/biu207

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Database search output ($n = 7810$)	→	Duplicates deleted ($n = 135$)
Title and abstract review ($n = 7675$)	→	Articles excluded ($n = 6823$)
Full text review ($n = 852$)	→	Articles excluded ($n = 377$)*
Articles included ($n = 478$)	←	Articles added by snowballing ($n = 3$)

*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)

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

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The Comprehensive Researcher Achievement Model (CRAM)

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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

Name	Year	Journal	Type							
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			

Author	Year	Journal	Type						
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	

Author	Year	Journal	Type								
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	

Author	Year	Journal	Type										
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

Author	Year	Journal	Type							
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							

Author	Year	Source	Type						
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	

Author	Year	Journal	Type							
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					

Author	Year	Journal	Type								
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				

Name	Year	Journal	Type							
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						

Name	Year	Journal	Type						
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

Author	Year	Journal	Type						
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	

Author	Year	Journal	Type							
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							

Author	Year	Journal	Type									
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			

Author	Year	Source	Type											
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				

Author	Year	Journal	Type						
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 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: $TotalImpact = P \times C \times FSL$.
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.

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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.

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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 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

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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](#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](#22)	Present results of any assessment of risk of bias across studies (see Item 15).	4-5
Additional analysis	[#23](#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](#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](#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](#26)	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	16-17
Funding	[#27](#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

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