The Journal of Academic Librarianship 49 (2023) 102714

Contents lists available at ScienceDirect

The Journal of Academic Librarianship

journal homepage: www.elsevier.com/locate/jacalib

Universal research index: An inclusive metric to quantify scientific research output

Mahsa Keshavarz-Fathi [a,b], Niloufar Yazdanpanah [a,b], Sajad Kolahchi [b], Heliya Ziaei [b], Gary L. Darmstadt [b,c], Tommaso Dorigo [b,d], Filip Dochy [b,e], Lisa Levin [b,f], Visith Thongboonkerd [b,g], Shuji Ogino [b,h,i,j], Wei-Hsin Chen [k,l,m], Matjaz Perc [b,n,o,p,q], Mark S. Tremblay [b,r], Bolajoko O. Olusanya [b,s], Idupulapati M. Rao [b,t,u], Nikos Hatziargyriou [b,v], Maziar Moradi-Lakeh [b,w], Federico Bella [b,x], Laszlo Rosivall [b,y], Amir H. Gandomi [b,z,bg], Armin Sorooshian [aa], Manoj Gupta [b,ab], Ciprian Gal [b,ac], Andres M. Lozano [b,ad,ae], Connie Weaver [b,af], Michael Tanzer [b,ag], Alessandro Poggi [b,ah], Sadaf G. Sepanlou [b,ai], Ralf Weiskirchen [b,aj], Anet Režek Jambrak [b,ak], Pedro J. Torres [b,al], Esra Capanoglu [b,am], Francisco J. Barba [b,an], Chua Kian Jon Ernest [b,ao], Mariano Sigman [b,ap,aq], Stefano Pluchino [b,ar], Gevork B. Gharehpetian [b,as], Seyed-Mohammad Fereshtehnejad [b,at,au], Muh-Hwa Yang [b,av], Sabu Thomas [b,aw], Wenju Cai [b,ax], Elisabetta Comini [b,ay], Neil J. Scolding [b,az,ba], Paul S. Myles [b,bb], Juan J. Nieto [b,bc], George Perry [bd], Constantine Sedikides [b,be], Nima Rezaei [a,b,bf,*], USERN Advisory Board Members

[a] School of Medicine, Tehran University of Medical Sciences, Tehran, Iran
[b] Universal Scientific Education and Research Network (USERN), Iran
[c] Department of Pediatrics, Stanford University School of Medicine, Stanford, CA, USA
[d] Istituto Nazionale di Fisica Nucleare (INFN), Via Francesco Marzolo, Sezione di Padova, Italy
[e] High Impact Learning Academy, Learning and Development Department, Brussels, Belgium
[f] Center for Marine Biodiversity and Conservation, Integrative Oceanography Division, Scripps Institution of Oceanography, University of California, San Diego, San Diego, CA, USA
[g] Medical Proteomics Unit, Office for Research and Development, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand
[h] Department of Epidemiology, Harvard T.H. Chan School of Public Health, Boston, MA, USA
[i] Program in MPE Molecular Pathological Epidemiology, Department of Pathology, Brigham and Women's Hospital, and Harvard Medical School, Boston, MA, USA
[j] Broad Institute of MIT and Harvard, Cambridge, MA, USA
[k] Department of Aeronautics and Astronautics, National Cheng Kung University, Tainan, Taiwan
[l] Research Center for Smart Sustainable Circular Economy, Tunghai University, Taichung 407, Taiwan
[m] Department of Mechanical Engineering, National Chin-Yi University of Technology, Taichung 411, Taiwan
[n] Faculty of Natural Sciences and Mathematics, University of Maribor, Maribor, Slovenia
[o] Department of Medical Research, China Medical University Hospital, China Medical University, Taichung, Taiwan
[p] Complexity Science Hub Vienna, Vienna, Austria
[q] Alma Mater Europaea, Maribor, Slovenia
[r] Children's Hospital of Eastern Ontario Research Institute, Department of Pediatrics, University of Ottawa, Ottawa, Ontario, Canada
[s] Centre for Healthy Start Initiative, Ikoyi, Lagos, Nigeria
[t] Alliance of Bioversity International, International Center for Tropical Agriculture, Cali, Colombia
[u] International Centre of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya
[v] School of Electrical and Computer Engineering, National Technical University of Athens (NTUA), Athens, Greece
[w] Preventive Medicine and Public Health Research Center, Psychosocial Health Research Institute, School of Medicine, Iran University of Medical Sciences, Tehran, Iran
[x] Department of Applied Science and Technology, Politecnico di Torino, Corso Duca degli Abruzzi, Turin, Italy
[y] Institute of Translational Medicine, International Nephrology Research and Training Center, Faculty of Medicine, Semmelweis University, Budapest, Hungary
[z] Faculty of Engineering and Information Technology, University of Technology Sydney, NSW 2007, Australia
[aa] Department of Chemical and Environmental Engineering, University of Arizona, Tucson, AZ, USA
[ab] Department of Mechanical Engineering, National University of Singapore, Singapore
[ac] Department of Mathematics, Florida International University, Miami, FL, USA
[ad] Division of Neurosurgery, Toronto Western Hospital, University Health Network, University of Toronto, Toronto, Ontario, Canada

* Corresponding author at: Research Center for Immunodeficiencies, Children's Medical Center, Dr Qarib St, Keshavarz Blvd, 14194 Tehran, Iran.
E-mail address: rezaei_nima@yahoo.com (N. Rezaei).

https://doi.org/10.1016/j.acalib.2023.102714
Received 8 September 2022; Received in revised form 6 April 2023; Accepted 10 April 2023
Available online 18 April 2023
0099-1333/

[ae] Krembil Research Institute, Toronto, Ontario, Canada
[af] Department of Exercise and Nutritional Sciences, San Diego State University, San Diego, CA, USA
[ag] Division of Orthopedic Surgery, McGill University, Montreal, Quebec, Canada
[ah] Molecular Oncology and Angiogenesis Unit, IRCCS Ospedale Policlinico San Martino, Genoa, Italy
[ai] Digestive Disease Research Institute, Tehran University of Medical Sciences, Tehran, Iran
[aj] Institute of Molecular Pathobiochemistry, Experimental Gene Therapy and Clinical Chemistry (IFMPEGKC), RWTH University Hospital Aachen, Aachen, Germany
[ak] Faculty of Food Technology and Biotechnology, University of Zagreb, Zagreb, Croatia
[al] Departamento de Matemática Aplicada, Facultad de Ciencias, Universidad de Granada, Granada, Spain
[am] Department of Food Engineering, Faculty of Chemical and Metallurgical Engineering, Istanbul Technical University, Istanbul, Turkey
[an] Nutrition and Food Science Area, Preventive Medicine and Public Health, Food Science, Toxicology and Forensic Medicine Department, Faculty of Pharmacy, Universitat de València, València, Spain
[ao] Department of Mechanical Engineering, National University of Singapore, Singapore
[ap] Laboratorio de Neurociencia, Universidad Torcuato Di Tella (UTDT), Buenos Aires, Argentina
[aq] Facultad de Lenguas y Educación, Universidad Nebrija, Madrid, Spain
[ar] Department of Clinical Neurosciences, University of Cambridge, Cambridge, UK
[as] Amirkabir University of Technology, Tehran, Iran
[at] Division of Neurology, Faculty of Medicine, University of Ottawa, Ottawa, Ontario, Canada
[au] Division of Clinical Geriatrics, NVS Department, Karolinska Institutet, Stockholm, Sweden
[av] Institute of Clinical Medicine, National Yang Ming Chiao Tung University, Taipei, Taiwan
[aw] School of Energy Materials, Mahatma Gandhi University, Kottayam, Kerala 686 560, India
[ax] Centre for Southern Hemisphere Oceans Research (CSHOR), CSIRO Oceans and Atmosphere, Hobart, Tasmania, Australia
[ay] SENSOR Laboratory, University of Brescia, Brescia, Italy
[az] Clinical Neurosciences, Translational Health Sciences, Bristol Medical School, University of Bristol, Bristol, UK
[ba] Department of Neurology, North Bristol NHS Trust, Southmead Hospital, Bristol, UK
[bb] Alfred hospital and Monash University, Melbourne, Australia
[bc] CITMAga, University of Santiago de Compostela, Galicia, Spain
[bd] Department of Neuroscience, Developmental and Regenerative Biology, University of Texas at San Antonio, San Antonio, TX, USA
[be] School of Psychology, University of Southampton, Southampton, UK
[bf] Research Center for Immunodeficiencies, Children's Medical Center, Tehran University of Medical Sciences, Tehran, Iran
[bg] University Research and Innovation Center (EKIK), Óbuda University, 1034 Budapest, Hungary

ARTICLE INFO

Keywords:
Scientometrics
Research impact
h-index
UR-Index
USERN
Citations
Impact factor
Leading author
CiteScore
Scholarly output
Scholarly impact

ABSTRACT

Scientometrics and bibliometrics, the subfields of library and information science, deal with the quantity and quality of research outputs. Currently, various scientometric indices are being used to quantify and compare research outputs. The most widely known is the h-index. However, this index and its derivatives suffer from dependence on the mere count of a scholar's highly cited publications. To remedy this deficiency, we developed a novel index, the Universal Research Index (UR-Index) (https://usern2021.github.io/UR-Index/) by which every single publication has its own impact on the total score. We developed this index by surveying international top 1 % cited scientists in various disciplines and included additional component variables such as publication type, leading role of a scholar, co-author count, and source metrics to this scientometric index. We acknowledge that unconscious biases built into the component variables included in the UR-Index might put research from specific groups at a disadvantage, thus continued efforts to improve equitable scholarly impact in science and academia are encouraged.

Introduction

Scientometrics and bibliometrics are among the subfields of library and information science that deal with the quantity and quality of research outputs (Chellappandi & Vijayakumar, 2018; Garfield, 2009). In this field of study, metrics are used as essential measures of quantitative, and to a lesser extent, qualitative research performance (Cuschieri, 2018). Metrics can be calculated at different levels including those of the article, author, institution, field, and journal (Aguinis et al., 2012; Cuschieri, 2018). The most frequently used author- and institution-level metrics are calculated based on counts of highly cited publications. Generally, the scholarly output is defined in terms of peer-reviewed publications, whereas scholarly impact is based on factors that demonstrate the influence of a publication on the research community of that discipline, such as citation count (Aguinis et al., 2012; Dev et al., 2015; Hobbs, 2017).

A variety of indices have been developed to assess the research output of a scholar or an institution. Most of these indices balance scholarly output with scholarly impact. The most prominent one is the Hirsch index (h-index), which is calculated by Scopus, Web of Science, and Google Scholar. The h-index reports the researcher's count (h) of publications that received ≥ h citations (Hirsch, 2005; Yang & Meho, 2006). If all publications of a researcher are sorted in descending order of citation count, the h-index is the rank of the publication with a citation count that is equal to or greater than the rank number (Table 1) (Hirsch, 2005). The h-index provides a simple estimation of research output, but it has limitations. In particular, it ignores publications with citations < h-index, the exact value of publications with citations > h-index, author's place in the byline, and the publication type. In addition, it provides an overestimate for scholars with too many publications that meet hyperauthorship criteria i.e., authors ≥100. The number of papers with hyperauthorship has been increased in recent years and this affects the citation patterns since the papers with ≥100 authors or ≥ 30 countries usually receive more citations than typical papers with ≤10 authors or ≤ 5 countries (Clarivate, 2019).

To overcome the limitations of the h-index, several modified versions of it have been proposed. For instance, the i10-index is based on the same notion as the h-index. It reports the count of publications with ≥10 citations. To enable differentiation of researchers with highly cited publications, the extended version of this index, that is, i100-index and i-1000 index (Teixeira da Silva, 2021), have been recommended. More importantly, the g-index is based on the count of publications with a specific citation count. It reports each researcher's count of publications that together received $\geq g^2$ citations. In other words, if all publications of a researcher are sorted in descending order of citation count, the g-index is the number of rank of the publication, which, together with its higher-ranked publications, has (square root of cumulative sums of citations) ≥ (the rank) (Table 1). Moreover, the average citation count is calculated from the top-cited publication to the g-th ranked one, and an average citation is equal to or greater than the number g (Egghe, 2006). The m-quotient (m-index) considers the period of academic productivity, and is calculated by the h-index divided by the count of years passed since the first publication (Harzing, 2012). The e-index evaluates the citations ignored by the h-index (Zhang, 2009). The segmented regression model uses h2-upper, h2-center, and h2-lower to differentiate "perfectionists" and "massive producers" (Bornmann et al., 2010). The individual h-index uses the co-author count to normalize the h-index (Batista et al., 2006). Although co-authors do not usually contribute equally, the author credit (including citation counts) is calculated by division of the credit by the count of co-authors. Harmonic coauthor credit is another fair method for the calculation of authorship credit which uses both author's place in the byline and the number of authors (Hagen, 2010; Walters & Wilder, 2016).

Despite the proliferation of scientometric indices, some issues remain. One of them is the failure to consider the complete scholarly record. For instance, a scholar with 90 publications and h-index of 10 has 80 unaccounted publications. The drawbacks of the h-index and its modified versions entail the simultaneous use of multiple metrics. Indeed, different measures including productivity, total citations, and h-index are concurrently used to compare research output (Chapman et al., 2019).

Other indices that consider additional component variables have been developed, although they are not as well-known as the h-index and its modified versions. Their development includes the addition of new variables, such as author-contribution (Boyer et al., 2017), usage citations (Callahan et al., 2018), standardized citation (Ioannidis et al., 2020), hub-authority or the score generated based on both citing and being cited (Kleinberg, 1998), and collaboration with leading scientists (Grossman, 1997). The credit of the citing journal has also been incorporated in a few scientometric indicators. Those indices emphasize the notion that being cited by a paper published in a high-quality journal is more valuable than being cited by a paper published in an ordinary journal (Pinski & Narin, 1976; Walters, 2017). However, these indices are not comprehensive, as they focus on a single additional component variable. We advocate that a set of component variables be used to develop a universal index. We further maintain that every single peer-reviewed publication matters to scholars and their institutions, and that all peer-reviewed publications are useful to the scientific community despite not having the same quality and impact. Therefore, implementation of a universal and comprehensive metric that incorporates all publications of a scholar, and assigns a fair and unequal (grading) score to each one, is required. To achieve this goal, it is necessary to identify component variables that determine the research impact of each publication.

As the Universal Scientific Education and Research Network (USERN), we aimed at proposing a universal index that includes important and practical component variables to measure the quantity and quality of research output. There are >70 active research interest groups within the USERN that are subject to annual evaluation since the USERN's establishment in 2016 (Rahmani et al., 2019). To assess the research output of these interest groups, we have implemented different indices and formulas including productivity, citation count, h-index, and other indicators commonly used for reviewing scientific reward nominees. However, we recognized the lack of a comprehensive and universal index for cross-evaluation. Therefore, we developed the Universal Research Index (UR-Index) with the cooperation of members of the USERN advisory board, which includes the top 1 % cited scientists from 22 scientific fields, are introduced by highlycited.com (Thomson

Table 1
Examples of common scientometric indices.

h-index		g-index				i10-index	
Rank of publication based on citations (R)	Citation count (C)	Rank of publication based on citations (R)	Citation count (C)	Cumulative sums of citations (CSC)	Square root of cumulative sums of citations (SQCSC)	Rank of publication based on citations	Citation count
1	53	1	53	53	7.28	1	53
2	45	2	45	98	9.90	2	45
3	35	3	35	133	11.53	3	35
4	29	4	29	162	12.73	4	29
5	27	5	27	189	13.75	5	27
6	17	6	17	206	14.35	6	17
7	12	7	12	218	14.76	7	12
8	5	8	5	223	14.93	8	5
9	2	9	2	225	15.00	9	2
10	1	10	1	226	15.03	10	1
The highest rank with C ≥ R is 7 so h-index[a] = 7		The highest rank with SQCSC ≥ R is 10 so g-index[b] = 10				i10-index[c] = 7	

a, h-index ignores publications with C < R.
b, g-index may saturate as it occurred in this example. The author could have g-index = 15 but it was limited by the count of publications.
c, i10-index only considers publications with C ≥ 10.

Reuters), and a number of Nobel/Abel Laureates (Rezaei, 2018). One of the long-term goals of USERN is to take a leading role in the scientific world by making universal science policies. To achieve this goal, the members of the Advisory Board of USERN were invited from the list of the top 1 % researchers who are experts in different fields of science. In this article, we introduce the UR-Index, an innovative, multidimensional metric to assess research output. First, we describe our method, formula, and validation; then we discuss the usage, advantages, and limitations of the UR-index.

General methods

We used Delphi method to conduct this study. First, we proposed component variables based on the literature review, expert comments from the corresponding author, and our background in the evaluation of research output in the USERN to address some of the significant limitations of common indices. We aimed at calculation of a unique score for each peer-reviewed publication by incorporation of eligible component variables and examined different functions and/or constant values assignable to each component variable in an Excel file to examine the validity and reliability of the range of results. We conducted prioritization of eligible component variables and assigned specific weights to each one based on their importance.

An eligible component variable needed to meet the following criteria:

(1) to be assignable to peer-reviewed publications
(2) to be extractable from online databases
(3) not to stimulate a new game playing like strategic self-citation or citation networks that were shaped due to the important role of citation metrics in the appraisal of scientists (Baccini et al., 2019; Seeber et al., 2019)
(4) to be agreed upon by the majority of USERN advisory board members who contribute to the survey.

Therefore, we solicited comments from the top 1 % cited scientist members of the USERN Advisory Board as the panel of experts in a survey (see appendix). In addition to the responses to our questionnaire, the participants sent us their complementary comments as Word Office files. Based on the results of the survey, the complementary comments of the experts, and comments of the corresponding author who was not included in the panel, we revised the component variables, their specific weights, and formula. For the second round, we sent the revision to all participants and solicited their comments. According to their comments, we finalized the component variables, their specific weights, and formula. Then, we developed an online application to calculate the UR-Index for each scholar and an offline application to extract data from Scopus and calculate the UR-Index. In the third round, we only received comments on the text of the manuscript which were amended.

Calculation of the UR-Index

Component variables and their contribution

We received 44 responses from USERN advisory board members (henceforth: participants), with the response rate being 88 %. In the first round, we received 24 comment files from the participants in Word Office format. In the second round, we received 25 comment files and in the third round, we received 3 comment files. The experts who participated in this study included 33 professors, 6 full professors, 2 associate professors, 1 emeritus scientist, 1 chief research scientist, and 1 researcher from 16 different disciplines and 24 countries (Fig. 1). Seven participants were female and the remaining were male. In this study, 9 component variables were proposed in the first round and five were included in the formula based on the consensus (Table 2). Specifically, all 44 (100 %) participants agreed with the inclusion of publication type; 43 (97.7 %) and 42 (95.5 %) agreed with the inclusion of citation count and journal metric, respectively; and 36 (81.8 %) and 34 (77.3 %) agreed with the inclusion of co-author count and the author's place in the byline for whom the score is being calculated, respectively. The remaining 4 proposed component variables that did not receive enough votes in the second round included journal rankings, availability of publications (i.e., open access), publication year, and years that the scholar has been active.

We assigned specific weights for each component variable based on their importance and participants' agreement. Accordingly, the maximum contribution of each component variable to the full score is as follows: 30 % for citation count, 20 % for publication type, 20 % for source metric, 20 % for author's place in the byline, and 10 % for co-author count. In this method, by summation of the sub-scores of these 5 component variables, each publication receives a score named "Universal Score for Publication (USP)" that ranges from 0.1 to 1. The sub-scores' ranges[1] based on the maximum contribution of each component variable are as follows:

- Citation count: [0, 0.3)
- Type of publication: {0.1, 0.2}
- Source metric: [0, 0.2)
- Author's place in the byline: (0, 0.2]
- Co-author count: (0, 0.1]

Table 3 displays the sub-scores' range for a set of examples.

UR-Index formula

To calculate the UR-Index for each scholar, we used the sum of USPs multiplied by the mean USP. The USP is calculated by the inclusion of the five component variables described above. We applied different formulas to achieve the desired sub-scores' range for each component variable.

- *Type of publication:* We assigned a constant sub-score to each publication based on its type. $T = 0.1$ for letter, editorial, note, case report, and conference paper; $T = 0.2$ for original article, review, short survey, data paper, book chapter, and book. We adopted these categories from the list of publication types available on Scopus (Fig. 2).
- *Co-author count:* We used the function $\frac{0.1}{1+log(N)}$ to achieve the desired range, where N is the number of authors of a publication. We considered $N = 1$ for the first, last, and corresponding author(s).
- *Author's place in the byline:* We used the function $\frac{0.2}{1+log(P)}$ to achieve the desired range, where P is the author's place in the byline. In publications with $N < 100$, we considered "P = 1" for the first, last, and corresponding authors, and considered "P = author's place in the byline" for other co-authors. In publications with hyperauthorship (i.e., $N \geq 100$), we similarly considered $P = 1$ for the first, last, and corresponding authors, and $P = 99$ for all other co-authors. We made this decision based on the fact that hyperauthorship has a direct effect on a publication's citation frequency. Some have even suggested that the publications with hyperauthorship should be omitted or otherwise treated differently (Clarivate, 2019).
- *Source metric:* We used the function $\frac{0.2S}{1.6+S}$ to achieve the desired range, where S is the journal's metric. The median of this range (i.e., 0.1) is achieved by assigning the median metric. The median metric differs based on the database used for data extraction. Median CiteScore (CS), which is routinely implemented by Scopus, was 1.6 based on the latest available distribution of CS among all journals in 2020

[1] "[" or "]" indicates that the stated value is included within the range while "(" or ")" indicates that the stated value is not included within the range. The symbols "{" and "}" include the exact values instead of a range.

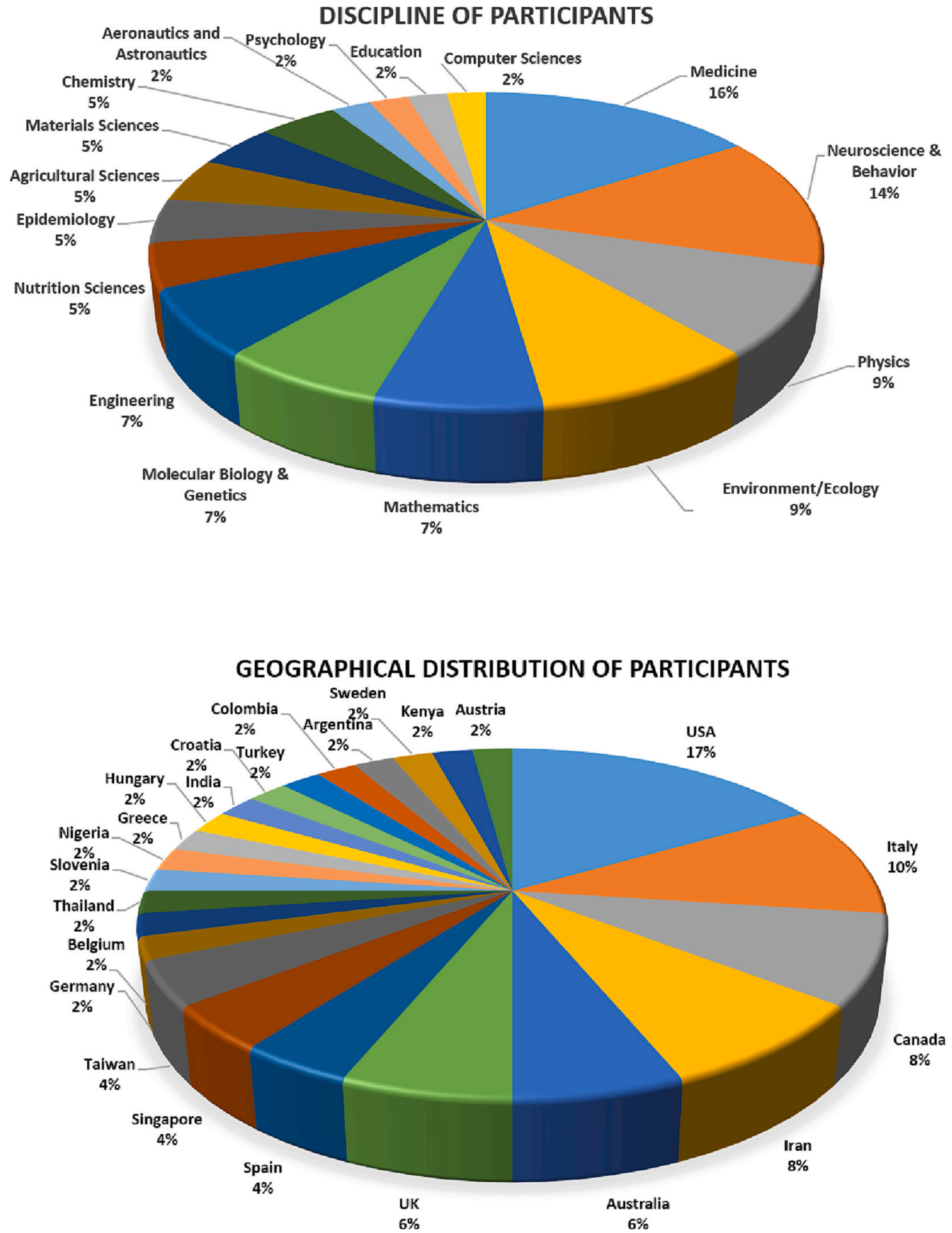

Fig. 1. Characteristics of Participants; 1a discipline of participants, 1b geographical distribution of participants.

Table 2
Reponses to the survey that were received from participants.

Component variables	Frequency (%)
Total responses	44
Agree with the inclusion of publication type	44 (100)
Agree with the inclusion of citations	43 (97.7)
Agree with the inclusion of journal metrics	42 (95.5)
Agree with the inclusion of co-author count	36 (81.8)
Agree with the inclusion of workload (author's place in the byline)	34 (77.3)

(Scopus Source List, 2020). Moreover, median Impact Factor (IF) was 2.4 based on the latest available distribution of IF among all journals in 2021 by Web of Science (Journal Citation Reports, 2021).

- *Citation count:* We used the function $\frac{0.3C}{50+C}$ to achieve the desired range, where C is the number of a publication's citations. The median of this range (i.e., 0.15) is achieved by the median number of citations which is selected based on the distribution of citations among median publications. An analysis of the distribution of paper citations over time revealed that the median publication receives 50 citations after 10 years in print (Ipeirotis, 2018).

The UR-Index is calculated via the following formula:

Table 3
Component variables contributing to the Universal Score for each peer-reviewed Publication (USP) and their range. In publications with ≥100 co-authors, all co-authors except leading authors receive 0.067 for the author's place sub-score.

Co-author count	Sub-score	Order of author	Sub-score	Journal metrics (CiteScore)	Sub-score	Citation count	Sub-score
1	0.100	1	0.200	0	0.000	0	0.000
2	0.077	2	0.154	1	0.077	1	0.006
3	0.068	3	0.135	2	0.111	3	0.017
5	0.059	5	0.118	3	0.130	5	0.027
10	0.050	10	0.100	4	0.143	10	0.050
15	0.046	15	0.092	5	0.152	15	0.069
20	0.043	20	0.087	6	0.158	20	0.086
25	0.042	25	0.083	10	0.172	30	0.113
30	0.040	30	0.081	15	0.181	40	0.133
40	0.038	35	0.079	20	0.185	50	0.150
50	0.037	40	0.077	30	0.190	60	0.164
75	0.035	50	0.074	35	0.191	75	0.180
100	0.033	99	0.067	40	0.192	100	0.200
250	0.029	100	0.067	50	0.194	250	0.250
500	0.027	500	0.067	75	0.196	500	0.273
1000	0.025	1000	0.067	100	0.197	1000	0.286
5000	0.021	10,000	0.067	500	0.199	10,000	0.299

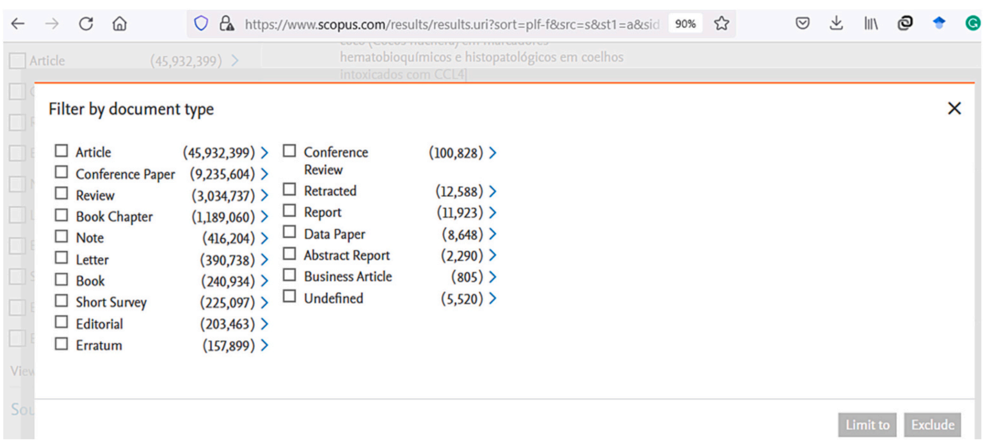

Fig. 2. Different document types enlisted by Scopus as of April 15th, 2022.

$$UR - Index = Sum\ of\ USPs \times Mean\ USP$$

$$USP = T + \frac{0.1}{1 + log(N)} + \frac{0.2}{1 + log(P)} + \frac{0.2 \times S}{1.6 + S} + \frac{0.3 \times C}{50 + C}$$

USP = Universal Score of Publication
T = publication type
N = co-author count
P = author's place in the byline
S = source metric; CS (Median = 1.6) or IF (Median = 2.4); here we used Median CS
C = citation count
We also highlight the following:

- Publications' "correction" or "erratum" versions are repetitive and need to be excluded from the list before the calculation of the UR-index.
- Retracted publications need to be excluded from the list before the calculation of the UR-index.

Moreover, by applying the statistical definition of "mean", the UR-Index can be re-written as follows:

$$Mean = \frac{Sum\ of\ the\ terms}{Number\ of\ the\ terms}$$

$$\rightarrow Sum\ of\ the\ terms = Number\ of\ the\ terms \times Mean$$

$$\rightarrow Sum\ of\ USPs = Number\ of\ the\ publication \times Mean\ USP$$

$$UR - Index = Sum\ of\ USPs \times Mean\ USP$$

$$\rightarrow UR - Index = Number\ of\ publications \times (Mean\ USP)^2$$

Table 4
Examples of calculated USPs. The USP for each publication can be calculated by using the online tool on the following link: https://usern2021.github.io/UR-Index/

Type	Author number	Author's place in the byline	CiteScore	Citation	USP
0.1	1	1	0	0	0.400
0.2	5	1	0	0	0.500
0.2	5	4	4.5	15	0.600
0.2	5	5	4.5	15	0.634
0.2	10	5	4.5	15	0.584
0.2	10	9	4.5	15	0.569
0.2	10	9	4.5	0	0.500
0.1	5	2	17.5	0	0.496
0.2	5	3	17.5	0	0.578
0.2	5	4	17.5	60	0.731
0.2	67	65	2.5	0	0.428
0.2	456	1	60.39	1	0.701
0.2	456	450	60.39	1	0.483
0.2	6	3	54	250	0.836
0.2	2	2	54	250	0.898
0.2	200	1	60.39	550	0.970

Table 4 displays some examples of the calculated USPs. We also developed an online application freely available at https://usern2021.github.io/UR-Index/ to calculate USP for each publication, and mean USP and the UR-Index for each scholar. The source metric we used for developing the application was CS.

Validation of the UR-Index

To validate the formula, we calculated the UR-Index for 67 scholars including junior researchers who were selected from the USERN organizing committee and well-known scientists opted from the USERN Advisory Board. We tried to have a diverse selection by the inclusion of scholars with publication count ranging from 6 to 1886 and citation count ranging from 9 to 106,376. We carried out this work by developing an application to extract data of publications of those scholars from Scopus as an indexing database. We selected Scopus since it has a broad coverage, a user-friendly data export feature, and indexes peer-reviewed publications. We retrieved data for the selected scholars (supplementary document) from Scopus as of 12 May 2022, and calculated the UR-Index and mean USP. The data of the supplementary document can be sorted based on the "UR-Index" and the "mean USP" which indicates that, compared to the publication count, citation count, and h-index, they present new rankings for scholarly output and act independently of each other. As is apparent from the supplementary document, the UR-Index is dependent on the publication and citation counts. Therefore, it is a useful single indicator summarizing and incorporating those metrics in only one measure. In other ways, the mean USP is calculated irrespectively of the publication count and is a beneficial metric for comparison of junior, senior, and expert scholars disregarding their productivity. We envision that the UR-index and particularly the mean USP may have predictive powers on scientific promotions (e.g., promotion to full professors), awarding grants and scientific prizes. The concept of mean USP in evaluation of research output and its usage in practice might be similar to the Google Reviews which uses star rating to find the best services around a region. Here, a higher mean USP indicates a higher quality considering the five component variables and the count of publications guarantees that quality similar to the role that the count of reviewers takes in the Google Reviews. The mean USP may be able to make a distinction between exceptional, good, and ordinary research output and a predictive power on awarding scientific prizes can be assumed for it given that the two top mean USP in the supplementary document belong to two Nobel Laureates, Kornberg R the Nobel Laureate in Chemistry with mean USP of 0.790 and 283 publications and Greengard P the Nobel Laureate in Medicine with mean USP of 0.748 and 987 publications. Totally, there are 6 Nobel Laureates in our list, including Kornberg R., Greengard P, Wüthrich K, Ratcliffe PJ, Gurdon JB, and Lehn J-M, all of which have a mean USP >0.700. This evidence indicates that the mean USP may be a novel metric for prediction of next Nobel Laureates/candidates. We believe that further studies can prove the predictive power of the mean USP and the practical usefulness of the UR-Index.

We used the software GraphPad Prism v8 to perform correlation analysis. We assessed the correlation matrix among the component variables incorporated into the UR-Index; however, there were no strong correlations. There were only negligible correlations between publication type and citation count ($r_\rho = 0.20$), as well as publication type and author count ($r_\rho = 0.11$). The remaining were neither strong nor significant. We did not perform the correlation analysis between the UR-index and its component variables such as citation count, and publication count given that they have mathematical coupling (Moreno et al., 1986) with the UR-Index i.e., they contribute to the UR-Index formula which results in spuriously high correlation coefficients that might not truly reflect the degree of association.

Discussion

Evaluation of research productivity and quality has received attention in the field of library and information. Many factors are determinant for assessment of research and it is essential to develop comprehensive metrics (Clyde, 2004; MacColl, 2010). To address the disadvantages of previously established research metrics, we developed the UR-Index which incorporates publication and citation counts and can serve as a single indicator replacing the concurrent use of those two metrics. It has some advantages over the already existing research metrics: it is not just a citation impact indicator but it is more inclusive and considers the parameters disregarded by many indices. The UR-Index provides the mean USP metric which enables the comparison of junior and senior scholars irrespective of their total publication count and provides an added value in research output assessment (Waltman, 2016). A predictive power on scientific promotions and awarding scientific prizes is assumed for the UR-Index and the mean USP which was described in the validation section and can be elucidated by further studies.

The UR-Index is calculated by the inclusion of five component variables: publication type, author's place in the byline, co-author count, citation count, and source metric of each publication. The inclusion of these parameters for quantification of research output is important, and we considered them based on surveying 44 top 1 % cited scientists.

Publication type is a component variable that all participants agreed to be included (Table 2). It associates with the level of evidence and the magnitude of the effect reported by a publication. Although quality of methodology, validity, and applicability would be superior component variables for the identification of the magnitude of an effect, they are not readily accessible through online databases. Therefore, we used publication type in the USP formula. We considered two constant values (i.e., 0.1 and 0.2) and two main categories for different publication types. Two participants suggested increasing these categories in order to assign a higher score to a specific publication type. A physicist and a biomedicine researcher suggested that review articles are more significant and deserve a higher score, whereas another biomedicine researcher emphasized the importance of original (empirical) articles. Given that the comparison of review versus original articles is not straightforward, both might have a substantial impact, and that meta-analyses which provide the highest quality in evidence-based research and practice in medical and social sciences are classified as review type of article on Scopus, we decided to consider the same sub-score for both types (i.e., 0.2). However, it should be mentioned that review papers might have inflated citation counts since they provide quick access to information and usually have broader coverage than original articles (Teixeira et al., 2013). Two participants suggested categorizing brief reports/ short communications in the 0.2 subgroup, given that such publication can represent concise and important original research. Indeed, from "short survey" on Scopus (Fig. 2), it is considered equal to brief report/ short communication; so, in agreement, we assigned 0.2 to that type of publication. In the preliminary version of this index, we were going to exclude conference papers due to their lesser importance in some fields; however, based on comments from 3 contributors about their importance in computer sciences this type was included.

Citation count is the most noticeable parameter implicated by almost all common indices. Although it is the main component variable of the h-index, its maximum contribution to USP is 30 % in the UR-Index. Four participants recommended increasing the contribution of this component variable and two participants mentioned that it is better to ignore citation count in order to develop an index completely different from h-index. However, due to the importance of citation count and based on agreement among 97.7 % of participants, we included this component variable with maximum value of 30 % contribution to USP. Four participants stated that publication year has a direct effect on citation count, and so it should be included in the formula. However, the formula is dynamic and is updated continuously by any increase in citation count. In fact, a publication can receive an increasing USP as it ages.

The UR-Index includes component variables that are ignored by previously established indices. For example, the h-index does not assign different values to leading authors versus co-authors, whereas the UR-Index considers the "author's place in the byline" which accounts for maximum 20 % of USP. Moreover, the "co-author count" component variable accounts for maximum 10 % of the USP, while its full score is assigned to leading authors somewhat paradoxically. Leading authors—including the first, last and corresponding author—receive the highest possible sub-score (i.e., 0.3) from these two component variables in their USP. To specify, the two component variables are author's place in the byline (0.2) and co-author count (0.1) attained by considering $P = 1$ and $N = 1$. This applies to leading authors who receive the full sub-score for the co-author count component variable irrespectively of the real co-author count. On the other hand, the rest of the authors of an article receive the sub-score calculated by N = real co-author count. We acknowledge ambiguity in clarifying the co-first author and co-corresponding author roles. We were unable to incorporate them as leading authors, because they were inaccessible from the Scopus data.

We included in the formula the "author's place" component variable based on authorship order by agreement of the majority of participants (77.3 %). However, 10 participants mentioned that, in their field or culture, co-author order does not strictly reflect the workload, as co-authors can be ordered by contribution, age, commitment, role in the project, seniority, expertise, and status in the field. For example, some disciplines, such as physics and mathematics, simply use alphabetical order for co-authors between the first and last. Nevertheless, the majority of participants agreed with differentiating between leading authors (e.g., first, last, and corresponding authors) and the rest of the co-authors. In addition, the placement of co-authors especially in articles with number of co-authors ranging from 3 to 10 usually reflects the workload. Therefore, we did not exclude this component variable. However, if mere alphabetical order is used to designate the authorship list no distinction is made between the leading authors and the rest of co-authors, thus an unfair sub-scores of the author's place and co-author count are assigned to the first and last authors just due to the alphabetical place of their surname. One participant mentioned a concern about articles with too many authors where one cannot readily conclude, for example, that the 40th and 50th co-authors contributed differently. We note that the function applied to calculate the "author's place" sub-score results in a slightly decreasing sub-score for different places. For example, the 40th place receives 0.077, whereas the 50th place receives 0.074. This indicates that the difference is negligible (Table 3). Also, due to the increase in publications with multiple authors, we applied a different treatment for articles with hyperauthorship (Castelvecchi, 2015; Chawla, 2019; Clarivate, 2019). To calculate the "author's place" sub-score in publications with $N \geq 100$, all co-authors except the leading authors receive the sub-score of the 99th co-author ($P = 99$) which is equal to 0.067. This means the 2nd co-author in a typical publication receives the sub-score of 0.154 while the same co-author in a publication with hyperauthorship receives the sub-score of 0.067 (Table 3).

Although publishing in a journal with high impact is not fully diagnostic of the quality of an individual article and the impact of the journal does not necessarily correspond to the citation count of its publications (Oswald, 2007; Seglen, 1997), high impact journals usually have stricter manuscript acceptance criteria. They set high standards for the quality of research. As such, journal's impact is often used to compare the quality of publications. In our survey, based on agreement among 95.5 % of participants, we included the source metric in the calculation of USP. Initially, we set the maximum contribution of 30 % for this component variable, but then decreased it to 20 % in line with nine participants' comments. This led to an increase in the author's place sub-score's maximum contribution from 10 % to 20 %. The UR-Index formula is compatible with both IF (reported by Web of Science) and CS (reported by Scopus). Here we used CS for the calculation of the UR-Index and it is worth mentioning that journals have a higher rank in Scopus compared to Web of Science because Scopus indexes far more journals which leads to a better relative position of a journal in the list.

Similar to the h-index, the UR-Index is not field-specific, does not omit self-citations or negative citations, and does not consider hidden citations (Seeber, 2008). Some of these shortcomings are due to the features of databases. Also, each article's influence on the field will be contingent on the magnitude of effect, scientific rigor, reproducibility, and originality, but none of this information is accessible through online databases. Therefore, the limitations of indexing databases affect the capabilities of not only the UR-index but also other indices. We should also pay attention to the point that disciplines and sub-disciplines are dramatically different in their publication counts, citation rates, and consequently average research output metrics such as the UR-Index; therefore, comparisons should be made only within particular disciplines or sub-disciplines. Lastly, all indices, including the UR-index, emphasize research output rather than application. However, scientometric indicators also need to consider the impact on the development of novel instruments and methods, as well as on clinical practice, livelihoods, education, and society.

Finally, there might be some inherent, unconscious biases built into the component variables that we included in the UR-Index that put research from specific social groups (e.g., age, gender, race, social class) at a disadvantage. Likelihood of being cited, opportunity to collaborate, authorship order, and opportunity to publish in high-impact journals might differ among men and women, younger and older scientists, or based on country of origin and ethnicity (Hopkins et al., 2013; Urlings et al., 2021). Often these differences stem from disparities in educational, academic hiring, research networking, and journal reviewing practices (Clauset et al., 2015; Edgerton et al., 2013; Kozlowski et al., 2022). For this reason, improved scholarly impact in science and academia will require efforts beyond metrics of research output.

Declaration of competing interest

The authors declare that they have no conflict of interest.

M.P. was supported by the Slovenian Research Agency (Grant Nos. P1-0403 and J1-2457).

Acknowledgement

We are thankful to Dr. Matin Qaim, Dr. Vivette Glover, Dr. Carlo Rovelli, Dr. Steven Sherwood, Dr. Carlos Camargo, Dr. Brian Cantor, and Dr. Michael Schreiber for providing their comments and concerns.

M.P. was supported by the Slovenian Research Agency (Grant Nos. P1-0403 and J1-2457).

Appendix A. Appendix

UR-Index questionnaire used to survey top 1 % cited scientists' comments

1. Name
2. Email address
3. Full affiliation address (department, University, City, Country)
4. Do you agree with inclusion of count of citations in calculation of the UR-Index?
   Yes No
5. Do you agree with inclusion of journal metrics in calculation of the UR-Index?
   Yes No
6. Do you agree with inclusion of count of collaborator(s) in calculation of the UR-Index?
   Yes No
7. Do you agree with inclusion of workload (place of the author) in calculation of the UR-Index?
   Yes No

8. Do you agree with inclusion of type of peer-reviewed publication in calculation of the UR-Index?
   Yes No
9. If you have any comments or suggestions regarding the parameters, please kindly provide them in this box.
10. We have considered the following maximum contributions of each parameter to the final score of each peer-reviewed publication: citation: 30 %, Journal metric: 30 %, count of author(s): 10 %, workload: 10 %, type of publication: 20 %. Please kindly let us know if you agree with the current contributions. If not, please make your comments.
11. We appreciate your helpful comments in developing the UR-Index. Please let us know any other comments regarding this index.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.acalib.2023.102714.

References

Aguinis, H., Suárez-González, I., Lannelongue, G., & Joo, H. (2012). Scholarly impact revisited. *Academy of Management Perspectives, 26*(2), 105–132. https://doi.org/10.5465/amp.2011.0088

Baccini, A., De Nicolao, G., & Petrovich, E. (2019). Citation gaming induced by bibliometric evaluation: A country-level comparative analysis. *PLoS ONE, 14*(9), Article e0221212. https://doi.org/10.1371/journal.pone.0221212

Batista, P., Campiteli, M., & Kinouchi, O. (2006). Is it possible to compare researchers with different scientific interests? *Scientometrics, 68*, 179–189. https://doi.org/10.1007/s11192-006-0090-4

Bornmann, L., Mutz, R., & Daniel, H.-D. (2010). The h index research output measurement: Two approaches to enhance its accuracy. *Journal of Informetrics, 4*(3), 407–414. https://doi.org/10.1016/j.joi.2010.03.005

Boyer, S., Ikeda, T., Lefort, M.-C., Malumbres-Olarte, J., & Schmidt, J. M. (2017). Percentage-based author contribution index: A universal measure of author contribution to scientific articles. *Research Integrity and Peer Review, 2*(1), 18. https://doi.org/10.1186/s41073-017-0042-y

Callahan, A., Winnenburg, R., & Shah, N. H. (2018). U-index, a dataset and an impact metric for informatics tools and databases. *Scientific Data, 5*(1), Article 180043. https://doi.org/10.1038/sdata.2018.43

Castelvecchi, D. (2015). Physics paper sets record with more than 5,000 authors. *Nature*. https://doi.org/10.1038/nature.2015.17567

Chapman, C. A., Bicca-Marques, J. C., Calvignac-Spencer, S., Fan, P., Fashing, P. J., Gogarten, J., & Chr. Stenseth, N. (2019). Games academics play and their consequences: How authorship, h-index and journal impact factors are shaping the future of academia. *Proceedings of the Royal Society B: Biological Sciences, 286*(1916), Article 20192047. https://doi.org/10.1098/rspb.2019.2047

Chawla, D. S. (2019). Hyperauthorship: global projects spark surge in thousand-author papers. https://www.nature.com/articles/d41586-019-03862-0. Access data: 03/01/2022.

Chellappandi, P., & Vijayakumar, C. (2018). Bibliometrics, scientometrics, webometrics/cybermetrics, informetrics and altmetrics–An emerging field in library and information science research. *Shanlax International Journal of Education, 7*(1), 5–8.

Clarivate. (2019). New Global Research Report from the Institute for Scientific Information examines impact of multi-authorship on citations. https://clarivate.com/blog/new-global-research-report-from-the-institute-for-scientific-information-examines-impact-of-multi-authorship-on-citations/. Access date: 02/15/2022.

Clauset, A., Arbesman, S., & Larremore, D. B. (2015). Systematic inequality and hierarchy in faculty hiring networks. *Science Advances, 1*(1), Article e1400005. https://doi.org/10.1126/sciadv.1400005

Clyde, L. A. (2004). Evaluating the quality of research publications: A pilot study of school librarianship. *Journal of the American Society for Information Science and Technology, 55*(13), 1119–1130. https://doi.org/10.1002/asi.20066

Cuschieri, S. (2018). WASP (write a scientific paper): Understanding research metrics. *Early Human Development, 118*, 67–71. https://doi.org/10.1016/j.earlhumdev.2018.01.015

Dev, C. S., Parsa, H. G., Parsa, R. A., & Bujisic, M. (2015). Assessing faculty productivity by research impact: Introducing Dp2 index. *Journal of Teaching in Travel & Tourism, 15*(2), 93–124. https://doi.org/10.1080/15313220.2015.1026471

Edgerton, J. D., Roberts, L. W., & Peter, T. (2013). Disparities in academic achievement: Assessing the role of habitus and practice. *Social Indicators Research, 114*(2), 303–322.

Egghe, L. (2006). Theory and practise of the g-index. *Scientometrics, 69*(1), 131–152. https://doi.org/10.1007/s11192-006-0144-7

Garfield, E. (2009). From the science of science to scientometrics visualizing the history of science with HistCite software. *Journal of Informetrics, 3*(3), 173–179. https://doi.org/10.1016/j.joi.2009.03.009

Grossman, W. (1997). Paul erdos: The master of collaboration. *Algorithms and Combinatorics, 14*, 467–475.

Hagen, N. T. (2010). Harmonic publication and citation counting: Sharing authorship credit equitably – Not equally, geometrically or arithmetically. *Scientometrics, 84*(3), 785–793. https://doi.org/10.1007/s11192-009-0129-4

Harzing, A.-W. (2012). Reflections on the H-index. *Business & Leadership, Scientific Society of Management from Romania, 1*(9), 101–106.

Hirsch, J. E. (2005). An index to quantify an individual's scientific research output. *Proceedings of the National Academy of Sciences of the United States of America, 102*(46), 16569–16572. https://doi.org/10.1073/pnas.0507655102

Hobbs, J. (2017). Library development of scholarly output measurement tool. *Journal of Hospital Librarianship, 17*(3), 179–186. https://doi.org/10.1080/15323269.2017.1328573

Hopkins, A. L., Jawitz, J. W., McCarty, C., Goldman, A., & Basu, N. B. (2013). Disparities in publication patterns by gender, race and ethnicity based on a survey of a random sample of authors. *Scientometrics, 96*(2), 515–534. https://doi.org/10.1007/s11192-012-0893-4

Ioannidis, J. P. A., Boyack, K. W., & Baas, J. (2020). Updated science-wide author databases of standardized citation indicators. *PLoS Biology, 18*(10), Article e3000918. https://doi.org/10.1371/journal.pbio.3000918

Ipeirotis, P. (2018). Distribution of paper citations over time. A Computer Scientist in a Business School. https://www.behind-the-enemy-lines.com/2018/11/distribution-of-paper-citations-over.html. Access date: 02/04/2022.

Journal Citation Reports. (2021). https://clarivate.com/blog/the-2021-journal-citation-reports-a-continuing-evolution-in-journal-intelligence/. Access date: 02/04/2022.

Kleinberg, J. M. (1998). Authoritative sources in a hyperlinked environment. In *Paper presented at the SODA conference*.

Kozlowski, D., Larivière, V., Sugimoto, C. R., & Monroe-White, T. (2022). Intersectional inequalities in science. *Proceedings of the National Academy of Sciences, 119*(2), Article e2113067119. https://doi.org/10.1073/pnas.2113067119

MacColl, J. (2010). Library roles in university research assessment. *LIBER Quarterly, 20*(2), 152–168.

Moreno, L. F., Stratton, H. H., Newell, J. C., & Feustel, P. J. (1986). Mathematical coupling of data: correction of a common error for linear calculations. *Journal of Applied Physiology (1985), 60*(1), 335-–343. https://doi.org/10.1152/jappl.1986.60.1.335

Oswald, A. J. (2007). An examination of the reliability of prestigious scholarly journals: Evidence and implications for decision-makers. *Economica, 74*(293), 21–31. https://doi.org/10.1111/j.1468-0335.2006.00575.x

Pinski, G., & Narin, F. (1976). Citation influence for journal aggregates of scientific publications: Theory, with application to the literature of physics. *Information Processing and Management, 12*, 297–312.

Rahmani, F., Keshavarz-Fathi, M., Hanaei, S., Aminorroaya, A., Delavari, F., Paryad-Zanjani, S., & Rezaei, N. (2019). Universal scientific education and research network (USERN): Step strong in scientific networking. *Acta Medica Iranica, 57*(1), 1–4. https://doi.org/10.18502/acta.v57i1.1747

Rezaei, N. (2018). Universal scientific education and research network (USERN): Twinkling stars unite to make the world glow. *Acta Medica Iranica, 56*(1), 1–3.

Scopus Source List. (2020). https://www.scopus.com/sources.uri?zone=TopNavBar&origin=searchbasic. Access date: 02/04/2022.

Seeber, F. (2008). Citations in supplementary information are invisible. *Nature, 451*(7181), 887. https://doi.org/10.1038/451887d

Seeber, M., Cattaneo, M., Meoli, M., & Malighetti, P. (2019). Self-citations as strategic response to the use of metrics for career decisions. *Research Policy, 48*(2), 478–491. https://doi.org/10.1016/j.respol.2017.12.004

Seglen, P. O. (1997). Why the impact factor of journals should not be used for evaluating research. *BMJ, 314*(7079), 498–502. https://doi.org/10.1136/bmj.314.7079.497

Teixeira da Silva, J. A. (2021). The i100-index, i1000-index and i10,000-index: Expansion and fortification of the Google scholar h-index for finer-scale citation descriptions and researcher classification. *Scientometrics, 126*(4), 3667–3672. https://doi.org/10.1007/s11192-020-03831-9

Teixeira, M. C., Thomaz, S. M., Michelan, T. S., Mormul, R. P., Meurer, T., Fasolli, J. V. B., & Silveira, M. J. (2013). Incorrect citations give unfair credit to review authors in ecology journals. *PLoS ONE, 8*(12), Article e81871. https://doi.org/10.1371/journal.pone.0081871

Urlings, M. J. E., Duyx, B., Swaen, G. M. H., Bouter, L. M., & Zeegers, M. P. (2021). Citation bias and other determinants of citation in biomedical research: Findings from six citation networks. *Journal of Clinical Epidemiology, 132*, 71–78. https://doi.org/10.1016/j.jclinepi.2020.11.019

Walters, W. (2017). Citation-based journal rankings: Key questions, metrics, and data sources. *IEEE Access, 5*, 22036–22053. https://doi.org/10.1109/ACCESS.2017.2761400

Walters, W. H., & Wilder, E. I. (2016). Disciplinary, national, and departmental contributions to the literature of library and information science, 2007–2012. *Journal of the Association for Information Science and Technology, 67*(6), 1487–1506. https://doi.org/10.1002/asi.23448

Waltman, L. (2016). A review of the literature on citation impact indicators. *Journal of Informetrics, 10*(2), 365–391. https://doi.org/10.1016/j.joi.2016.02.007

Yang, K., & Meho, L. I. (2006). Citation analysis: A comparison of Google Scholar, Scopus, and Web of Science. *Proceedings of the American Society for Information Science and Technology, 43*(1), 1–15. https://doi.org/10.1002/meet.14504301185

Zhang, C.-T. (2009). The e-index, complementing the h-index for excess citations. *PLoS ONE, 4*(5), Article e5429. https://doi.org/10.1371/journal.pone.0005429