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R&D

Publications Output: U.S. Trends and International Comparisons

Technical Appendix

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This publication is part of the *Science and Engineering Indicators* suite of reports. *Indicators* is a congressionally mandated report on the state of the U.S. science and engineering enterprise. It is policy relevant and policy neutral. *Indicators* is prepared under the guidance of the National Science Board by the National Center for Science and Engineering Statistics, a federal statistical agency within the National Science Foundation. With the 2020 edition, *Indicators* is changing from a single report to a set of disaggregated and streamlined reports published on a rolling basis. Detailed data tables will continue to be available online.

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Technical Appendix: Publications Output Data and Methodology

The *Science and Engineering Indicators 2022* report “Publications Output: U.S. Trends and International Comparisons” (PBS) uses a large database of publication records as a source of bibliometric data. Bibliometric data include each article’s title; author(s); authors’ institution(s); references; journal title; unique article-identifying information (journal volume, issue, and page numbers or digital object identifier); and year or date of publication. The PBS report uses Scopus, a bibliometric database of scientific literature with English titles and abstracts from Elsevier, to examine national and global scientific publication–related activity.[1] This appendix discusses the Scopus data and data limitations as well as the coronavirus data used in the sidebar “Coronavirus Publication Output and International Collaboration.” More detailed documentation of the Scopus data and computation of bibliometric indicators is available in the report *Bibliometric Indicators for the Science and Engineering Indicators 2022. Technical Documentation* (Science-Metrix 2021).

Data

The counts, coauthorships, and citations presented in the publication output report are derived from information about research articles and conference papers (hereafter referred to collectively as *articles*) published in conference proceedings and peer-reviewed scientific and technical journals. The articles exclude editorials, commentaries, errata, letters, and other material that do not present new scientific data, theories, methods, apparatuses, or experiments. The articles also exclude working papers, which are not generally peer reviewed. The bibliometric data undergo review and processing to create the data presented in the PBS report (Science-Metrix 2021).

Beginning in the *Indicators 2016* report, the PBS report’s analysis shifted from using Web of Science by Clarivate (previously Thompson-Reuters) to the Scopus database by Elsevier. In 2016, an examination of the two databases found expanded data coverage in Scopus of internationally recognized peer-reviewed scientific journals (NSB ***Indicators 2016***: **New Data Source for Indicators Expands Global Coverage**). Since 2016, both databases have continued to expand coverage. A recent study comparing the databases found 27 million documents in Scopus and 23 million in Web of Science, with an overlap of 18 million (Visser, van Eck, and Waltman 2020). The *Indicators 2022* PBS report uses the Scopus database to ensure the broadest coverage of a curated database.[2]

This section of the appendix continues with a brief overview of the database composition, followed by an explanation of potential biases in the data, such as exclusion of non-peer-reviewed articles, English-language bias, and the reasoning behind removing conference papers from the highly cited articles (HCA) index.

Database Composition

Journal selection. Elsevier selects journals for the Scopus database based on evaluation by an international group of subject-matter experts who examine a candidate journal’s editorial policy, content quality, peer-review policies, peer-review process and capacity, citations by other publications, editor standing, regularity of publication, and content availability.

Conference selection. Elsevier selects conference materials for the Scopus database by subject field based on quality and relevancy, including the reputations of the sponsoring organization and the publisher of the proceedings.[3]

Database Filtering

The National Center for Science and Engineering Statistics (NCSES) undertakes additional filtering of the Scopus data to ensure that the statistics presented in *Indicators* measure original and high-quality research publications (Science-Metrix 2021). Around 2011, librarians and bibliometric experts began to note an increase in articles in the database from electronic journals and conference proceedings lacking substantive peer review.[4]

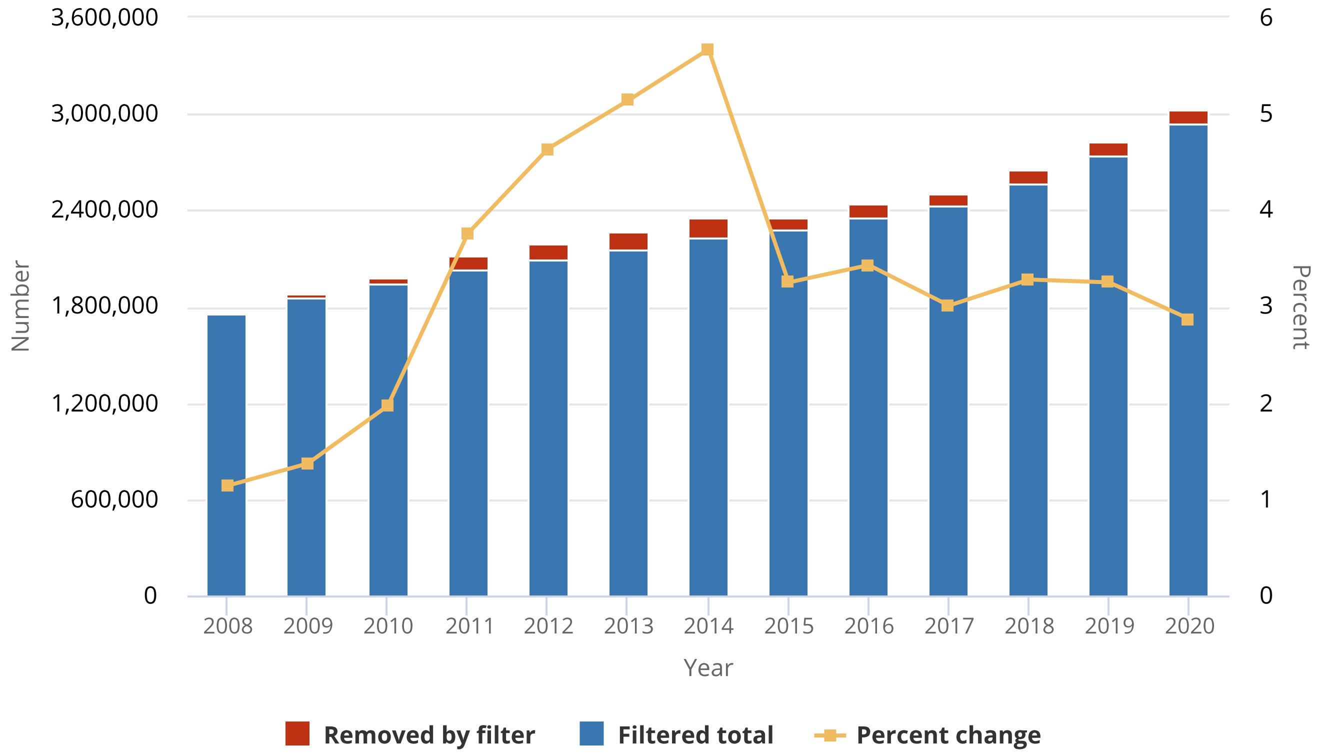
To exclude these publications from the bibliometric data used in this report, NCSES removed two sets of data from the Scopus database:

1. Journals and conference papers flagged by the Directory of Open Access Journals (DOAJ) for failing to adhere to its list of best practices or being suspected of editorial misconduct.[5]
2. Titles removed by Elsevier from the Scopus database beginning in 2014 were removed retroactively from the *Indicators* database for all publication years (Science-Metrix 2019).[6]

As a result, NCSES removed 2% or fewer articles from the Scopus database prior to 2011, then about 4% (more than 79,000 articles) in 2011, and then peaked with 5%–6% (102,0000–134,000 articles) each year from 2012 to 2014 (Figure SAPBS-1).[7] The removal rate then declined and has held steady from 2015 to 2020, averaging about 3% per year as Elsevier began instituting filters on the Scopus database.

Figure SAPBS-1

Filtered and unfiltered publications in Scopus, by year: 2008–20



Note(s):
Percent change is computed as the difference in number of publications between the filtered and the unfiltered approaches divided by the number of publications in the unfiltered approach.

Source(s):
National Center for Science and Engineering Statistics; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed May 2021.

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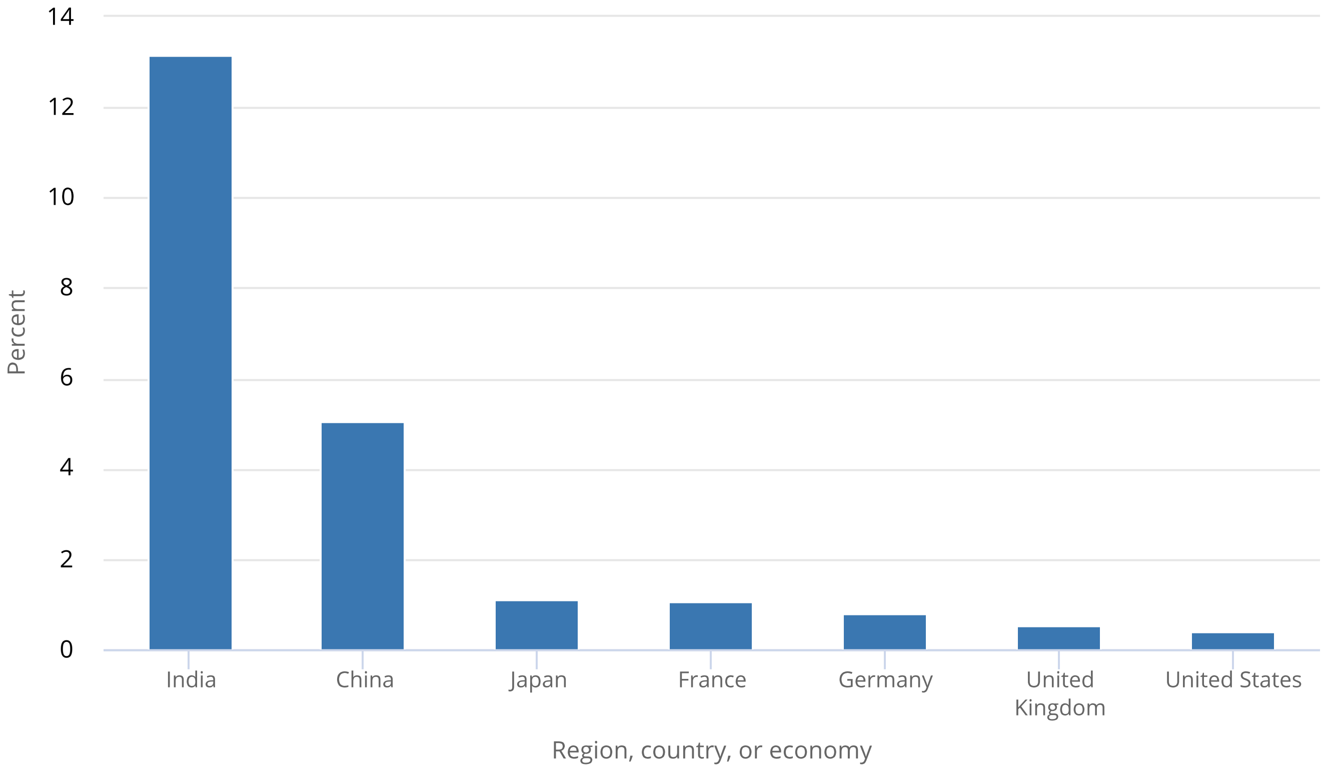
The filtering has different impacts by country and field of science. NCSES has examined the effect of this filtering to better understand any potential bias. Figure SAPBS-2 shows the numerical impact of the filters by country or economy. During 2008–20, India had the largest percentage of articles removed (approximately 13% of India's total unfiltered article count and 18% of all removed articles), followed by China (5% of China's total unfiltered article count and 28% of all removed articles). The 2008–20 data represent a change from the previous PBS report cycle (2008–18). During 2008–18, China was the country with the greatest percentage of articles removed (6%) (NSB 2019). The current period, 2008–20, shows China staying relatively unchanged, but there was a large increase in the percentage removed from India (from 8% in 2008–18 data to 13% in the 2008–20 data).

Figure SAPBS-2

Impact of removing low-quality publications from Scopus, by selected region, country, or economy: 2008–20



Note(s):
Percent change is computed as the difference in number of publications between the filtered and the unfiltered approaches divided by the number of publications in the unfiltered approach.

Source(s):
National Center for Science and Engineering Statistics; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed May 2021.

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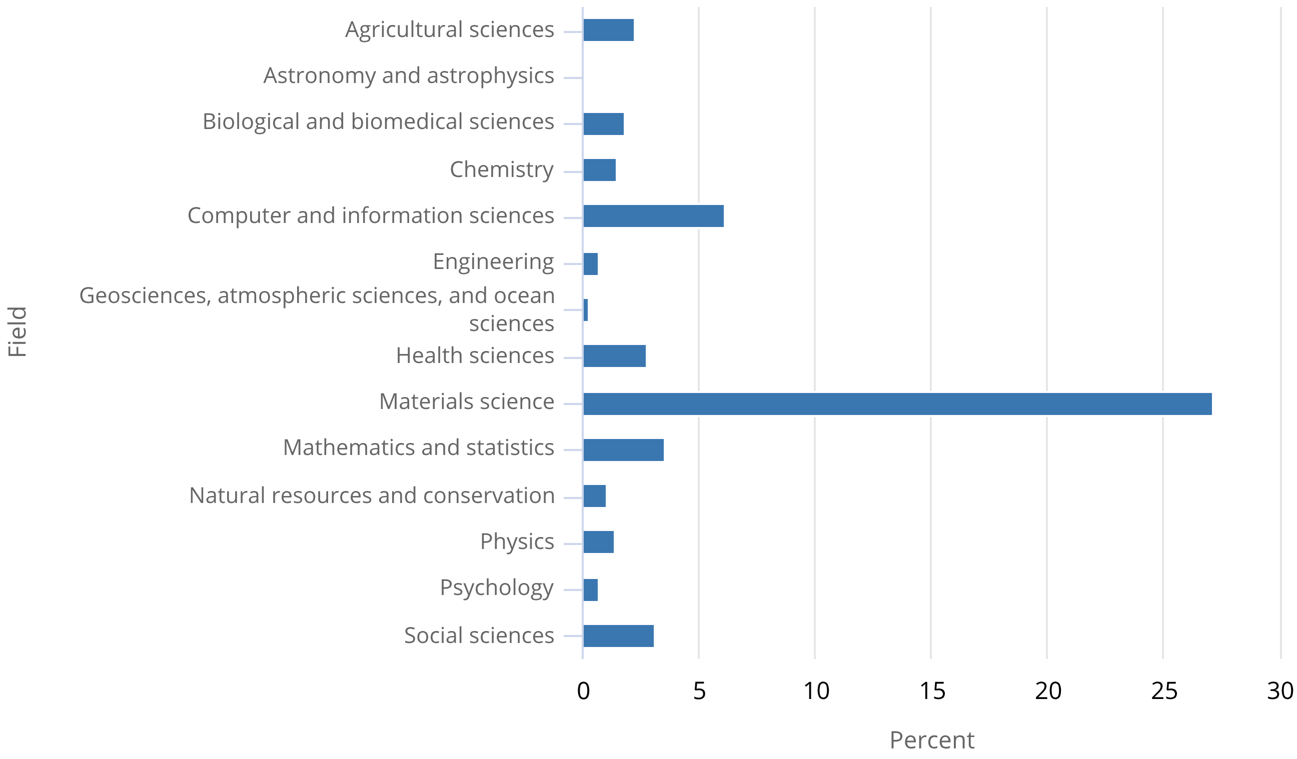
Conference papers accounted for 39% of articles removed by the NCSES filter. For example, conference papers were removed in cases in which publishers posted new conference proceedings every day, with each post containing many papers. This high-frequency publication presented concerns about robustness, originality, and peer review (Van Noorden 2014). Removing low-quality conference proceedings impacts fields of science differently; for example, conference proceedings are a large share of materials science articles (40%). Thus, filtering conference papers had the largest impact on the field of materials science by removing 27% of the unfiltered total articles in this field (Figure SAPBS-3).

Figure SAPBS-3

Impact of removing low-quality publications from Scopus, by field of science: 2008–20



Note(s):
Percent change is computed as the difference in number of publications between the filtered and the unfiltered approaches divided by the number of publications in the unfiltered approach.

Source(s):
National Center for Science and Engineering Statistics; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed May 2021.

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English-Language Bias

The Scopus database is constructed from articles and conference proceedings with an English-language title and abstract; therefore, the database contains an unmeasurable bias because not all science and engineering (S&E) articles and conference proceedings meet the English language requirement (Elsevier 2020). Scopus uses English because it is the assumed global language of science (Amano, González-Varo, and Sutherland 2016). The bias also undercounts citations associated with non-English publications because the non-English publications are not indexed in the database.

The language of articles is an issue for bibliometric measurement of scientific output. Publication output data for non-English-speaking countries underestimates the S&E research output for China, Japan, and other countries as well (Amano, González-Varo, and Sutherland 2016; Xie and Freeman 2019). Therefore, when comparing English-speaking and non-English-speaking countries (e.g., Figure PBS-7; Table PBS-1), there is a bias such that the non-English-speaking countries will be undercounted in the number of publications and of citations.

The bias varies by scientific field. Bibliometric researchers have found a native-language preference in citations (Liang, Rousseau, and Zhong 2012), and the social sciences exhibit more substantial linguistic bias than physical sciences, engineering, and mathematics (Mongeon and Paul-Hus 2015).

Conference Papers Removed from Highly Cited Articles (HCA) Index

Conference papers are included in the data analyzed in the report for output but not for HCA computation. Conference papers may bias HCA because of uneven inclusion in Scopus and widely different citation patterns compared with journal articles.

Generally, conference papers are cited less frequently than journal articles. Thus, a greater proportion of conference papers in the total article count for a country would tend to reduce impact based on HCA computation. Depending on the normalization approach, the score of countries could be heavily impacted compared with others because conference papers represent a larger proportion of their output. The issue is demonstrated in a simplified two-country example. Both countries publish 1,000 journal articles, but one publishes 10 conference papers, and the other publishes 200 conference papers. Assume that, based on the 1,000 journal articles, both countries have the same impact. If scores are lower for conference papers, adding conference papers into the computation will reduce the combined HCA score of the country with 200 conference papers. Therefore, in this case, two countries with similar impact in research published in journals may present much different impact because of the propensity of one to also send people to conferences.

In other cases, conference papers can increase the HCA for a country. Some fields of science publish and cite conference proceedings at different rates. A field with a low average number of citations for each article can have an increase in HCA by including conference papers, even those with relatively few citations. For example, if the country's average number of citations is one and a conference paper receives two citations, the normalized impact of the conference paper will be 2.0, which is quite high. Adding these *high-impact* conference papers could potentially boost the score of a country that specializes in a field with a below-average number of article citations and whose researchers participate in an above-average number of conferences.

The *Indicators 2022* PBS report removes conference proceedings from the HCA but keeps conference proceedings in the total output and collaboration analysis because conference proceedings for some fields and countries are an important component of their output. The exception to this rule is for computer and information sciences. The HCA for computer and information sciences for journal articles alone and for journal articles plus conference proceedings shows similar HCA trends for the United States and China (Table SPBS-63 and Table SPBS-73). For both countries, including conference proceedings boosts the HCA from 2014 through 2018. Computer and information sciences was selected for this comparison because conference proceedings are close to 20% of the references in that field (Lisée, Larivière, and Archambault 2008).

Coronavirus Publication Output

Global coronavirus publication output data for 2020 were extracted from two different sources. The COVID-19 Open Research Dataset (CORD-19) was created through a partnership between the Office of Science and Technology Policy, the Allen Institute for Artificial Intelligence, the Chan Zuckerberg Initiative, Microsoft Research, Kaggle, and the National Library of Medicine at the National Institutes of Health, coordinated by Georgetown University's Center for Security and Emerging Technology. CORD-19 is a highly inclusive, noncurated database.

The same keywords were used to build both CORD-19 and Scopus coronavirus data sets: "covid"; "coronavirus*"; "corona virus*"; "severe acute respiratory syndrome"; "middle east respiratory syndrome"; "SARS-CoV-2"; "spike protein*"; "mers-cov"; "nl63"; "229e"; "oc43"; "hcov"; "alphacoronavirus*"; "covid19"; "covid-19"; or "SARSCoV2" (Science-Metrix 2021; Wang et al. 2020).[8]

CORD-19 preprints were determined by having the source listed exclusively as a preprint server or a combination of preprint servers (ArXiv, BioRxiv, and MedRxiv). NCSES deduplicated the CORD-19 database. If an article exists both as a preprint and as a published article, the earliest date was used (usually the preprint). Only 2020 articles with a month and year in the database are included for this analysis. The majority of the papers are sourced from PubMed Central, PubMed, and the **WHO Coronavirus (COVID-19) Dashboard**.[9] From January 2020 (early in the pandemic) to December 2020 (during the pandemic), CORD-19 yielded over 103,000 published articles and 3,000 preprints as of 26 April 2021. With CORD-19 being a repository of coronavirus-related research, many of the articles were published prior to January 2020; those are not included in the present analysis.

The other coronavirus publication output data source was the Scopus database. After filtering for the same keywords, there were 58,627 Scopus coronavirus articles.[10] The Scopus data set permits more refined analysis because it includes more fields (e.g., instructional country of each author).

Network Analysis of Coronavirus Research Papers

The sidebar "Coronavirus Publication Output and International Collaboration" uses a network graph to show the interrelatedness of the international research effort. Visualization of the network uses a structure of nodes (representing countries) and edges (representing connections between the countries). The ForceAtlas2 force-directed layout algorithm (Jacomy et al. 2014) was used to define optimal bidimensional positions for the graph's nodes.

The ForceAtlas2 algorithm models the graph as a network of mutually repelling charged particles (the nodes) linked together by attractive forces (the edges), such that nodes that are linked together will naturally tend to cluster together. ForceAtlas2 is nondeterministic, such that even from identical starting positions and layout parameters, the final network layout may be slightly different. However, groups of nodes that are strongly linked together (clusters) will always tend to be visually close to each other. As such, the position of a single node carries no meaning on its own: it must be compared with that of the others to obtain insights into the collaboration ecosystem. The figure used Gephi's implementation of the ForceAtlas2 algorithm (Bastian, Heymann, and Jacomy 2009). Gephi is a widely used open-source network science software and is freely available.

The table below provides terminology and definitions for an in-depth understanding of the network analysis (Figure PBS-C; Table SPBS-57).

Indicator	**Description**
Degree	The degree of a node is the number of edges connected to the node. In the context of an international collaboration network, this corresponds to the number of other countries with which the country has collaborated. In this case, the maximum value of this indicator is the number of nodes in the network minus one because the node that has its degree computed cannot have collaborated with itself.
Node strength	The node strength is the sum of the weights of edges connected to the node. For international collaboration, a single paper can generate multiple collaboration links. For example, if one author from the United States cowrote an article with two authors from France and one author from Canada, this article generates three collaboration links: United States–France, United States–Canada, and Canada-France, each with a weight of one, regardless of the number of authors.
Betweenness centrality	Betweenness centrality measures how often a given node in a network lies along the shortest paths between two other nodes that are not directly connected to one another. For example, this indicator would highlight entities that play an important *brokering* role, acting as a connecting link between entities that do not co-publish with one another directly. Nodes with a high betweenness centrality score are the bridges that connect relatively isolated islands of research communities within the overall topography. These entities play an important role in the interconnection of subgroups within the network as a whole.

Closeness centrality	Closeness centrality assesses the degrees of separation between one node and other nodes within a network. That is, it assesses the length of the chains that connect a given node to the rest of its community. Whereas, for example, betweenness centrality highlights entities that play an interconnecting role for their community, closeness centrality measures the level of access that a given entity has to its surrounding community. It highlights those who can tap into a large section of a network without passing through many degrees of separation or through distant and mediated connections. When calculating closeness centrality, a node directly connected to every other node in the network would score 1, the highest possible closeness centrality score.
Weighted eigenvector centrality	Weighted eigenvector centrality is a measure of the level of integration of a node in a collaboration network. The level of integration of nodes within a collaboration network is reflected by the number of nodes to which they are connected and the quality of their collaborations (i.e., the strength of the ties measured by the number of coauthored publications and the importance of the nodes to which they are connected in the network). The mathematical definition of eigenvector centrality is such that the centrality score of a node in a network is proportional to the sum of the centrality scores of all nodes connected to it. Thus, this indicator offers a good appreciation of both the number and quality of an entity's collaborations because connections to high-scoring nodes contribute more to the score of that entity than equal connections to low-scoring nodes. A node scoring high for this indicator operates closer to the core of the network than a low-scoring node. High-scoring nodes are central and highly important to the network's structure. Eigenvector centrality provides a good appreciation of the integration of individual entities within a network; that is, the higher the score, the more integrated the entity. The weighted version of the indicator accounts for the size of the tie between nodes. Centrality scores are typically normalized between 1 (most central node) and 0 (least central node).
Weighted PageRank	PageRank, made famous by its use by the Google search engine, is a variant of eigenvector centrality. It can be thought of as the result of a *random walk*, meaning that the PageRank score of a given node corresponds to the probability that someone starting on a random node of the network and randomly following edges will end the walk on a particular node. The weighted version of the algorithm makes stronger links more likely to be followed than weaker links. PageRanks are shown as a percentage to clearly indicate the share of random walks in which the end point was the given node. All scores sum to 100%. In undirected networks, weighted PageRank yields results very similar to node strength.

Key to Acronyms and Abbreviations

CORD-19: COVID-19 Open Research Dataset

DOAJ: Directory of Open Access Journals

HCA: highly cited articles

NCSES: National Center for Science and Engineering Statistics

PBS: Publication Output: U.S. Trends and International Comparisons

S&E: science and engineering

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Notes

[1] Because the bibliometric database is constantly updated, the National Center for Science and Engineering Statistics (NCSES) does not recommend comparing bibliometric data across different editions of *Indicators*. For each edition of *Indicators*, NCSES uses a fixed snapshot of the database. This means that while trends are comparable, the exact number of articles, citations, and other data will vary across editions. For more information about comparing fixed versus dynamic journal data sets, see Schneider et al. (2019).

[2] Bibliometric databases such as Dimensions, Crossref, and Microsoft Academic are larger than Scopus and do not provide the same level of curation.

[3] More information about the selection of journals and conference papers is available at https://www.elsevier.com/online-tools/scopus/content-overview and https://www.elsevier.com/solutions/scopus/how-scopus-works/content/content-policy-and-selection.

[4] For articles on low quality publications, see Beall (2012), Bohannon (2013), Carey (2016), and Kolata (2013).

[5] For the DOAJ list of excluded journals, see https://docs.google.com/spreadsheets/d/183mRBRqs2jOyP0qZWXN8dUd02D4vL0Mov_kgYF8HORM/edit#gid=0. Note that DOAJ also flags serials that are no longer available in open access; although an important and evolving phenomenon in the research landscape, open access status is not associated here with any specific demarcation of quality, whether low or high. Thus, NCSES does not filter the titles flagged by DOAJ solely for open access–related reasons out of the *Indicators* database.

[6] For Elsevier's principles of quality, see https://docs.google.com/spreadsheets/d/183mRBRqs2jOyP0qZWXN8dUd02D4vL0Mov_kgYF8HORM/edit#gid=0.During its periodic reevaluation of items flagged for follow-up, the Scopus Content Selection and Advisory Board elected to remove 670 titles as of 2021. NCSES retroactively removed the 670 titles from the *Indicators* database to create a valid time series for bibliometric analysis, even though Elsevier does not claim that these titles were necessarily of low quality before 2021.

[7] Computation uses fractional counting of articles.

[8] Note that the * character is used to specify that the words should serve as prefixes, such that "coronavirus*" also captures articles that used "coronaviruses," for example.

[9] See WHO (2021).

[10] The initial query of the Scopus database found 108,000 publications, close to the 107,000 found in CORD-19. The Scopus database applied filters to remove preprints (15,500), letters (12,800), notes (6,300), editorials (5,200), errata or surveys (2,000), low-quality publications (2,300), and others for reasons such as not being attributable to a country or a nonstandard publication type (5,000). The Scopus coronavirus dataset was drawn from the full Scopus database using the same keywords as used to create CORD-19. Elsevier also created a Novel Coronavirus Information Center with a database of articles. The full Scopus database was used to ensure comparability between the CORD-19 and Scopus analytical data sets used in the report.