Meta-research on COVID-19

An overview of the early trends

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Abstract

COVID-19 is having a dramatic impact on research and researchers. The pandemic has underlined the severity of known challenges in research and surfaced new ones, but also accelerated the adoption of innovations and manifested new opportunities. This review considers early trends emerging from meta-research on COVID-19. In particular, it focuses on the following topics: i) mapping COVID-19 research; ii) data and machine learning; iii) research practices including open access and open data, reviewing, publishing and funding; iv) communicating research to the public; v) the impact of COVID-19 on researchers, in particular with respect to gender and career trajectories. This overview finds that most early meta-research on COVID-19 has been reactive and focused on short-term questions, while more recently a shift to consider the long-term consequences of COVID-19 is taking place. Based on these findings, the author speculates that some aspects of doing research during COVID-19 are more likely to persist than others. These include: the shift to virtual for academic events such as conferences; the use of openly accessible pre-prints; the ‘datafication’ of scholarly literature and consequent broader adoption of machine learning in science communication; the public visibility of research and researchers on social and online media.

Keywords (up to 6): COVID-19, open science, machine learning, research practices, science communication, gender and career trajectories.

Introduction

The contribution of research to overcome COVID-19 has been significant. At the same time, the pandemic had and is still having a major impact on research and researchers, meta-research contributions on the matter abound. After more than one year since the start of the pandemic, this review focuses on early meta-research work on understanding how science reacted to COVID-19, as well as

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on the impact COVID-19 had on research and researchers. The following topics are considered:

1. Mapping COVID-19 research and research collaboration during the early stages of the pandemic.
2. COVID-19 research as data, its use for machine learning applications.
3. The impact of COVID-19 on research practices including open access and open data, reviewing and publishing, funding.
4. Science communication beyond peers and towards the general public, including altmetrics and Wikipedia.
5. The impact of COVID-19 on researchers, in particular with respect to disparate gender impact and career trajectories.

An earlier overview of the impact of COVID-19 on research offers a useful comparison, in particular from the perspective of clinical medicine [113].

The present overview cannot include all possible contributions related to meta-research on COVID-19. Instead, it provides for an overview of the early trends which have started to emerge from the literature. The reader will immediately appreciate how much work lays ahead and how several questions remain largely unanswered, in particular with respect to the long-term consequences of COVID-19 for scientific research. At the same time, this review finds clear patterns in the literature and showcases the meta-research rapid response to COVID-19.

**Methods and scope**

The literature considered for this review has been assembled in three steps.

The author selected a first set of impactful research contributions on the topics of the review, using keyword searches on Google Scholar and his expertise. A contribution, in this context, includes full articles, reviews and surveys, (working) research documents and reports, chapters, letters, either peer-reviewed or not (e.g., pre-prints), but not commentaries, viewpoints, position papers, editorials, news items, lectures and presentations or other forms of related outputs which do not contain novel results. Sometimes, such contributions might still be cited to provide context. What constitutes an “impactful” contribution depends on the discipline, publication venue, authors, citation counts and the time of publication. For example, citation counts have been taken into account more for older publications, while publication venue and authors have been taken into account more for recent publications, as a proxy for their present and future impact. The selection is particularly difficult for recent pre-prints, which have been included only when they make a clearly novel and complementary...
contribution with respect to other related and peer-reviewed work. Only contributions released in 2020 or 2021 are considered. These selection criteria have been applied consistently in all subsequent steps as well.

Next, the author systematically explored citation links, both in-citations and out-citations, to expand the initial set of contributions, following the same criteria. Contributions found via citation links were explored in their one-step citation networks accordingly as well. This process continued until no further contributions of interest were found. Google Scholar was again used for this purpose. Thirdly, the author sifted through all contributions mentioning the keyword “covid” in their title or abstract, for a selection of quantitative and qualitative science studies journals, as well as general multidisciplinary journals. This sifting was done using Dimensions. In the case of mega-journals, the author used Field of Research categories to only sift through contributions not included in the Biological Sciences (division 06), Agriculture and Veterinary Sciences (division 07) or Medical and Health Sciences (division 11).

At all stages, manifestly opinionated pieces which assume or strongly support personal, political or ideological views, even when published as research contributions, have not been included. Some exceptions have been made when substantially novel results are still brought forward. In such cases, their discussion here only focuses on results and not on the personal views of the authors. The resulting selection is necessarily influenced by the author’s expertise and critical choices, not to mention possible inadvertent omissions. Nevertheless, it is hoped that a reliable overview of early work on the impact of COVID-19 on research and researchers has been provided, and shall at least serve as a starting point for future work.

Mapping early COVID-19 research

Research maps are an important tool of meta-research. They allow to understand the volume, pace and typology of contributions, their thematic organization, as well as patterns of collaboration within and across teams, institutions and countries. Many contributions have mapped COVID-19 research, in particular during the early weeks and months of the pandemic, also in comparison.
with previous epidemic outbreaks. This section provides an overview of their approaches and findings.

**Tracking research**

One of the meta-research community’s most rapid reactions to the COVID-19 pandemic has been to map research efforts related to it. A wealth of studies focused on quantifying the sheer volume of new contributions, and their geographical provenance which follow the diffusion of the pandemic. These contributions are also characterized by a varied use of data sources, which makes them difficult to compare. The earliest publications on COVID-19 up until March 2020 included came primarily from China and other Asian countries [25] (using PubMed and the WHO database), followed rapidly by the US [37] (using Scopus) and EU countries [123] (using the Web of Science, Medline and Scopus), in particular the most severely hit ones (Italy, UK) [90]. Some studies could already spot variations in research focus according to the specific challenges facing different countries [123]. Eventually, several authors provided domain-specific early maps of research on COVID-19, on topics as varied as safety [62] or business and management [124].

The first early comparison of COVID-19 research coverage across bibliometric databases, up to mid April 2020, found that Dimensions and Google Scholar seemed to provide the best recall also outside of the biomedical domain [80]. This result broadly aligns with more general overviews of bibliometric databases [91, 128].

Another important trend which emerges in these early mappings relates to the publication typologies of early COVID-19 research. An overview of the typology of early studies in PubMed found significant increases in narrative reviews and expert opinions, followed by case series and reports [75]. The authors also found that meta-analyses, systematic reviews, and randomized controlled trials remained the least represented publication typology, signaling a lack of evidence-based contributions. These results are echoed by other studies, also reporting an abundance of opinion pieces and a relative lack of novel, evidence-based contributions during the early weeks of the pandemic [39, 56, 148]. Arguably, since evidence-based studies take more time to conduct and publish than opinion pieces, it is possible that future work will find that this early trend is at least partially a self-correcting one.

**Research topics**

The study of the volume, typology and provenance of publications has been complemented by work focused on uncovering the topics of early COVID-19 research, primarily using text mining and citation network analysis.

The use of text mining techniques, ranging from keyword analysis to topic
modelling, rapidly allowed to establish that health and medical contributions dominate early COVID-19 work. Three clear broad themes emerge in this literature: virology, emergency care and public health, as well as contributions on the global and local responses to the pandemic [123]. While the biomedical disciplines were understandably leading on early COVID-19 research contributions, the expansive trend of COVID-19 research could already be noticed before mid-2020 with other disciplines such as those in the social sciences and humanities joining the effort [9]. Further examples of the use of machine learning and natural language processing to map early COVID-19-research abound. [32] uses topic modelling on the July 1, 2020 version of CORD-19 [130] (see below) to find a clear focus on few research topics including coronaviruses (primarily SARS-CoV, MERS-CoV and SARS-CoV-2), public health and viral epidemics, the molecular biology of viruses, influenza and other families of viruses, immunology and antivirals, clinical medicine. Useful comparisons to this study, yielding similar results, can be found for the very same version of CORD-19 [4] and for other data sources as well [43].

Citation network analyses of the early COVID-19 literature offer a similar picture, showcasing a clear rise of research on public health, including COVID-19 treatment and epidemiology, as well as its psychological impact [80], and including analyses of temporal trends [55]. Comparisons with previous epidemics, including SARS and MERS, found that all three outbreaks generated similarly distinct cohorts of studies: public health responses and epidemic control; virology; treatment, vaccines and clinical care [61]. Furthermore, COVID-19 research appeared since early on to not only be much larger in volume, but also broader and more driven by international collaboration and geographical patterns related to when and how the pandemic unfolded [98], although such results are contested [108]. Importantly, research on COVID-19 shows less cohesion and more new directions emerging when compared with previous, more localized outbreaks. Epidemiology research appears to be the most stable topic before and during COVID-19 [140].

Patterns of collaboration

A substantial number of publications has focused on the geography of COVID-19 research, including from the point of view of collaborations. Other studies have considered different scales of collaboration, down to the laboratory or research group.

A useful starting point is a comparison of early COVID-19 research with five other disease outbreaks since 2000 [145]. The authors show that “academia always responded quickly to public health emergencies with a sharp increase in the number of publications immediately following the declaration of an outbreak by the WHO.” While most countries are primarily concerned with epidemics impacting their own region, European and North American countries tend to have a global focus and conduct collaborative research with the countries co-
cerned with an outbreak, such was for example the case of Ebola in Africa. A substantial international degree of collaboration, the dominance of big research players (US, China, EU, UK, India), and consistent open access availability have been amply confirmed for COVID-19 research since [85, 12]. Given the global scope of COVID-19, these patterns do not surprise [88]. Indeed, a study of mainstream medical journals found that the geographical origins of COVID-19 authors break down as follows: European (47.7%), North-American (37.3%), China (8.8%) and the rest. While these results align with general research publication patterns, including in times of epidemic outbreak, they also showcase the persisting imbalances in research capacity across countries and regions [15].

Patterns of collaboration at the team scale have also been considered. A narrowing of team membership has been spotted in early COVID-19 research, as well as an even greater visibility of elite institutions [65]. Both the size and the location of teams in elite institutions might be related to access to resources. This is further evidenced by fewer than expected acknowledgements of funders in publications from the early months of the pandemic, when compared to pre-pandemic research. The teams more readily able to respond to the outbreak have been those with funding already in place, or no need for funding at all, and they acted in smaller, agile groups at first [54]. The same authors have found all these trends to persist or even increase in a closely-related followup after a few months [23].

Outlook

The impact of these abundant efforts into mapping early COVID-19-related research remains unclear. After an initial enthusiasm, maps of research seem to have been less popular after the initial months of the pandemic, as it became clear that the magnitude of the event was gaining attention from most fields of science. At the same time, early maps of research might have helped to track the immediate research reactions to the pandemic, while specialized tools and search engines were not yet available for this purpose. Global retrospective maps of COVID-19-related research have still to be produced and fully analysed, while more topically localised maps could still be useful to serve the specific needs of a given community.

The early research response to the COVID-19 pandemic also shows clear signs of the enduring strengths and weaknesses in global research capacity. The US, EU, UK, China and India led the early and subsequent research efforts, acting as hubs for international collaboration, while other countries seemed more focused on local issues. At a small, team scale too, being able to leverage existing resources has been key in allowing elite groups and institutions, in particular, to move quicker and earlier. This evidence underlines, yet again, the importance of an existing, long-term research capacity in rapidly and effectively reacting to a crisis.

Substantive questions in terms of global research trends on COVID-19 re-
main open and are only starting to be approached by the community. For example, [73] considers the rapidity and scale at which authors from any field of research shifted their focus on COVID-19 topics during the first full year of pandemic – using Scopus, up to March 1, 2021. They find that all fields of research contributed to COVID-19 research, with half a million researchers having published something on COVID-19 and 98 over 174 sub-fields having at least one influential author publishing on COVID-19. Such massive shift of focus is unprecedented, the authors in fact refer to a “covidization” of research including cases of “hyper-productivity”, whose implications will have to be monitored and are largely to be understood.

Data and machine learning

Health crises are also information crises [137]. COVID-19 has accelerated the existing trend in making scientific literature available as data, to be mined and analysed using techniques from data science and machine learning. Furthermore, it has fostered the development of tools to navigate and make rapid sense of it, such as search engines or question answering systems.

COVID-19 research as data

Several initiatives have focused on providing rapid access to COVID-19 literature as data, sometimes also via graphical user interfaces. Collections of scholarly articles on COVID-19 are one of the main related open source contributions which have been made [111]. Notable initiatives include LitCOVID, CORD-19, and Dimensions [66]. LitCOVID [28] is innovative in that it extensively applies machine learning to select COVID-19 literature from PubMed, extracting topics, geolocations and other keywords. The dataset is updated daily and free to download. The COVID-19 Open Research Dataset (CORD-19) [130], developed by The Allen Institute for Artificial Intelligence and steadily improved over time [106, 76, 32], has become the de facto standard for text-mining tools on COVID-19 literature. This dataset gathers publications from a variety of sources, including PubMed and pre-print servers, and equips them with metadata and the full-text, when available. This dataset is also updated daily and free to download. Another related and high-potential innovation are knowledge graphs, which offer a machine-readable and expressive way to represent scholarly literature and its contents and constitute an emerging area of active research which promises to be rapidly integrated into science communication tools in the near future [74]. Several contributions extracted knowledge graphs from scientific literature on COVID-19 [42, 133, 24, 103, 131]. While these experiments might need more time to find their way into systematic usage, they are promising and have been substantially accelerated by COVID-19. See [20] for a recent overview.
Machine learning applications

The importance of machine learning and data science in fighting COVID-19 has been recognized and surveyed early on [20, 120, 110]. This also applies to science communication and the need to make sense of a very rapidly growing body of literature. In particular, several search engines have been developed since the very early stages of the pandemic [81]. Overviews of these tools and their use to follow topics of COVID-19 research are also available [100, 92]. Given the recent rapid growth of machine learning and data science, and their current importance for many research and industry tools, it perhaps does not come as a surprise that COVID-19 ushered an abundance of attempts to use them in order to make sense and contribute to the research effort.

Many machine learning contributions have relied on CORD-19, and derived datasets have been created. Examples include entity recognition and concept extraction [133, 82, 24, 103, 131], question answering [119], textual evidence mining [132], text similarity [50, 135], search engines [133, 59, 144, 47], graphical interfaces to explore scientific evidence on COVID-19 [127, 68], keyword extraction and clustering [41], summarization [79]. Text mining approaches to COVID-19 literature have been critically assessed in a recent review [129].

Following an established approach in machine learning research, special conference tracks and shared tasks have been set-up to mine and enrich COVID-19 literature. A special TREC COVID track was set-up to test search engines for COVID-19 literature using CORD-19, and to develop a test collection of searches for assessing future systems in this respect [104]. The track has been extremely popular and achieved its stated goals [105], as shown by the continued use of their data for evaluation (e.g., [47]). It is important to note that significant limitations might exist in such academic prototypes when compared to industry search engines [115]. Other shared tasks include the Kaggle CORD-19 research challenge[6] and the epidemic question answering challenge[7]. Further initiatives included a workshop on Natural Language Processing for COVID-19 at the 2020 Annual Meeting of the Association for Computational Linguistics (ACL) [126] and its followup at the Empirical Methods in NLP conference (EMNLP) [127].

Outlook

Data science and machine learning contributions to COVID-19 require, first of all, the availability of scientific literature as data to be mined. In this respect, COVID-19 has shown that well-maintained, well-resourced and regularly updated initiatives fare better, making a longer-lasting impact. Furthermore, widespread institutional backing and an openness to talk to and be informed by domain users also play a crucial role in fostering the adoption and improvement of a dataset. A clear exemplar in this respect is CORD-19.

[6]https://www.kaggle.com/allen-institute-for-ai/CORD-19-research-challenge
[7]https://biolnp.nlm.nih.gov/epic_qa

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During the first year of the pandemic, a variety of machine learning and other data-driven methods have been used. It is likely that most of them will not make a direct lasting impact, yet they signal and accelerate trends that were already in place before COVID-19. Search engines such as the Semantic Scholar, also from the Allen Institute, since quite some time integrate machine learning services to support the search, retrieval and understanding of scientific literature [6, 22, 13, 30]. Advances in making the scientific literature machine readable were ongoing too [74]. A systematic and extensive use of machine learning and other data-driven methods, such as knowledge graphs, clearly constitutes a next frontier in science communication. COVID-19 has made their necessity clear, and also likely accelerated the pace of their experimentation, if not adoption.

Research practices

COVID-19 has not only impacted what scientists focus on, but also how they operate. This section reviews meta-research on open access and open data, reviewing, publishing and funding early COVID-19 research.

Open access and open data

The pandemic has prompted researchers and many publishers to rapidly adopt radical open access initiatives, which made most related research openly available. In this way, most (more than 90%) early COVID-19 literature was already made available in open access during the early stages of the pandemic [12]. At the same time, the sheer volume of publications likely overloaded the traditional publication system and led to issues with data and code availability for those same early publications [65]. A relatively low degree of data sharing in early COVID-19 research has indeed been confirmed looking at PubMed Central publications. Research found that only about 28.5% articles provided at least one link to a dataset [147], despite efforts in this direction [147]. It appears that, while many publishers opened up their publications, the adoption of open science principles and practices would have avoided many issues in early COVID-19 research, including “research waste” (repeated studies), dubious quality and even retractions [10].

Reviewing and publishing

The use of pre-prints to share COVID-19 research has been widespread, similarly to their unprecedented and sometimes non-transparent relay by news media [51]. COVID-19 pre-prints are on average shorter, reviewed faster, and receive more

[https://wellcome.org/coronavirus-covid-19/open-data]
engagement, including from news media and the public, than non-COVID-19 pre-prints. Importantly, a study found that only a small fraction of early pre-prints were eventually published as journal articles (5.7%), despite accelerated review times. Those eventually published also showcased higher citation rates on average. These results should be taken with caution given that the quality of the linkage between pre-prints and journal articles remains poorly understood.

The rapid adoption of pre-prints clearly signals a need for speed which was not met by the scientific publishing system. The abundance of COVID-19 literature, as well as the pressure to publish rapidly, might also have led to more lenient peer-review practices. A qualitative assessment of COVID-19 peer-review for medical journals found that “no clear differences between the review processes of articles not related to Covid-19 published during or before the pandemic. However, it does find notable diversity between Covid-19 and non-Covid-19-related articles, including fewer requests for additional experiments, more cooperative comments, and different suggestions to address too strong claims”.

Several concrete suggestions on how to improve peer review practices have been advanced. A variety of initiatives have since started to speed reviews up while attempting not to compromise on quality. An example is the journal eLife, which adopted pre-prints by default, no more experiments asked nor deadlines in revisions, mobilized junior academics and attempted to smooth competition for priority. Another example is the rapid review initiative. Innovative forms of reviewing have also been used, for example via crowdsourcing on pre-prints. Examples include the Outbreak Science PREview and the MIT Press Rapid Reviews COVID-19.

Despite clear successes in accelerating the speed of peer reviews, the deluge of COVID-19 articles was soon coupled with warnings of how rapid acceptance speeds might also come at the detriment of integrity. The relatively high rate of retractions in early COVID-19 research was also found to be a possible consequence of the speed and sometimes carelessness in publishing. The lack of research data integrity has been suggested as another aggravating factor in this respect and, eventually, predatory publishing practices were also spotted. Nevertheless, other authors have cautioned to rush to conclusions until more systematic studies become available.

**Research funding**

Funding agencies rapidly reacted to COVID-19 with measures to mitigate its impact, including extensions of deadlines and dedicated support. At the same time, many countries have by now released dedicated funding instruments for COVID-19 which are still to be mapped out and assessed. It is worth noting that several communities, in particular during the early months of the

[9] https://outbreaksci.prereview.org
[10] https://rapidreviews.covid19.mitpress.mit.edu
pandemic, stressed the importance of long-term, stable funding over that of reactive, short-term funding\[101\]. The importance of shifting focus to the long-term consequences of COVID-19, in particular from an interdisciplinary perspective, have also been clearly stressed \[138\], notwithstanding the need to meet immediate priorities \[142\]. Indeed, public and long-term funding is key in delivery preparedness such as in the case of the development of the Oxford-AstraZeneca COVID-19 vaccine \[34\]. The authors of this study found that nearly all funding related to the development of this vaccine came from public sources, since at least 2002. Furthermore, the authors “encountered a severe lack of transparency in research funding reporting mechanisms.” It is doubtful whether COVID-19 rapidly deployed instruments will fare much better in this respect.

**Outlook**

The early research response to COVID-19 has come as a flurry of results, often released and re-used as open pre-prints. The importance to find solutions, and share them openly, has been met in this way by many. The shortcomings of the traditional publishing system, with its slow procedures, have become clearly visible during the pandemic. Nevertheless, the rapid release of research likely had negative consequences as well, including poor open science practices, possibly lower quality standards and a higher rate of retractions, a proliferation of superficial or duplicated results. In terms of research funding, while understanding what has been done and its impact remains an open question, there seems to be agreement on the need to shift focus from short-term projects to understanding the long-term impact of COVID-19. It also appears clear that scientific excellence and preparedness cannot be summoned overnight but require structural planning and resourcing.

**Communicating research**

COVID-19 has put science and scientists on the spotlight. The search for a vaccine, the evidence for public policy measures, and more recently discussions on their impact are among the topics which attract wide public interest. Furthermore, conveying science-backed information to the public has been key, in particular to mitigate misinformation, as is the case of Wikipedia. Lastly, social media such as Twitter play an increasingly important role in sharing and discussing results among peers and more broadly.

**Altmetrics and Wikipedia**

While the diffusion of trusty and untrustworthy information on social media has been a clear theme of COVID-19 \[29\], the same social media can also pro-
vide a venue to rapidly share scientific results and identify noteworthy ones via altmetrics [118]. Indeed, there have been proposals to use altmetrics to identify impactful COVID-19 research since early in the pandemic [17]. Similarly, another application of altmetrics might be to detect early signs of criticism leading to a retraction [63]. In fact, initial analyses have shown that COVID-19 research gathers higher than average mentions on Twitter, also thanks to the dissemination efforts of scientists [49]. Other work has also found evidence for a correlation between altmetrics, such as Twitter mentions, and later citation counts [80]. While it seems premature to draw general conclusions, the heavy use of social media in science communication is definitely a significant aspect of the COVID-19 pandemic, which warrants more attention.

Wikipedia is another source of reliable and trustworthy information on the Web [112, 89]. Wikipedia showed a remarkable surge in editorial activity and onboarding of new editors during the early stages of the pandemic, with a 20% increase in contributions for English Wikipedia, when compared to a pre-pandemic baseline [107]. These contributions have been particularly significant in creating new or updating existing COVID-19-related articles [78]. In this respect, new COVID-19 contents added to Wikipedia during the early months of the pandemic have usually relied on recent, highly-visible, open access and peer-reviewed scientific sources [31], or trustworthy news media sources [14]. Notably, similar high-bar inclusion criteria have been found to hold for policy documents, particularly those released by inter-governmental organizations (IGOs), such as the World Health Organization (WHO) [141].

Scientists and the public

An early and visible contribution discussed an array of insights and open challenges related to COVID-19 from the perspective of social and behavioural sciences [11]. The main challenges associated with science communication as identified by the authors were: conspiracy theories, fake news and misinformation, persuasion. These themes are now new [134], yet they came to the fore with COVID-19. Indeed, some studies have considered the public role of scientists during COVID-19. For example, a US-focused survey found no evidence of the alleged negative impact that President Trump’s negative remarks might have had on scientists’ perceived trustworthiness [48]. Instead, the authors found a broad public agreement on scientists’ claims about COVID-19, but more resistance and disagreement when descriptions turn into prescriptions and value-laden policy recommendations. Social media, and in particular Twitter, have also offered an important venue for scientists to reach the public. Crucially, evidence seems to show that while false information on COVID-19 in generally tweeted more, science-based evidence and fact-checking tweets receive capture more engagement [102]. The seemingly positive role of scientists in conveying trust, or the spokesperson effect, has found evidence in the case of COVID-19 information. A large-scale survey found that “across countries and demographic
strata, immunology expert Dr. Anthony Fauci achieved the highest level of respondents’ willingness to reshare a call to social distancing, followed by a government spokesperson. Celebrity spokespersons were least effective” [4]. Similar results have also found independent confirmation [50].

Outlook

The research on COVID-19 has rapidly become highly visible on online and social media. Similarly, scientists appear to have been more active in sharing their work and thoughts. On average, there are early positive signs of the impact of such activities. Social media showed promise to help identify impactful COVID-19 research, while Wikipedia appears to have stood up to the challenge of updating its contents with reliable evidence, as it became available. Lastly, scientists have been found able to play a significant role as spokespersons for trustworthy information. Taken together, these signs underline the increasing importance and potential of social and online media in science communication, in particular during times of crises when science is asked to provide answers and solutions. At the same time, they underline how little we know on the mechanics of science communication beyond peers. Finally, it must be noted that other important aspects of science communication, namely to medical professionals and to policy makers, have not been considered in this section.

The impact of COVID-19 on researchers

The impact that COVID-19 had on researchers and research is hard to underestimate. Questions abound, including understanding the possibly disparate impact of COVID-19 on different groups and individuals, on career trajectories, on the mental health of researchers and students, on teaching and virtual events, and much more. Nevertheless, caution should be applied as short-term trends might not necessarily be indicative of substantial long-term consequences.

Gender and caring responsibilities

Several early and descriptive studies rapidly and alarmingly called for a possible under-representation of women in COVID-19 research. A lower contribution of women as first authors in medical journals during the very first months of the pandemic has indeed been individuated, which apparently was not present for women senior authors [7]. Another study took this approach one step further by using differences-in-differences to estimate the impact of lock-downs on general research productivity [35]. Controlling for discipline, career stage and institutions, as well as gender, the authors found that the only significant effects of COVID-19 lock-downs on research productivity, during the first 10 weeks of the
pandemic, concentrated on assistant professors, in particular at top-rated institutions. This suggest that higher-pressure and a possible gender imbalance in caring responsibilities (e.g., child-caring), in aggregate, could have led to a disparate impact on research productivity for some women. These points are supported by other studies, focused on the early impact of the pandemic on (academically) younger women [116], and with a particular severe drop of women’s contribution to COVID-19 biomedical research [95]. Caution should still be applied, as country-level results in this respect appear to differ markedly [2], while some domain-specific studies even found an overall higher women productivity in 2020 than 2019, when considering non-COVID-19-related research, as shown for cardiovascular journals [36]. Furthermore, there are since indications that the reduced productivity of young women on COVID-19 research is a resolving trend [87].

The connection among research productivity, parenting and other caring responsibilities has been further explored with survey-based methods. Despite their misleading title, [38] show that being a parent and, in particular, a woman parent, often entails substantial reductions in research productivity, as compared with non-parents of either sex. Similar results have been amply supported [140, 83, 96], and have been confirmed outside of the academic context as well [57, 64]. The disparate impact of parenthood in academia is known more generally, and it appears to explain a significant share of the gender productivity gap [93], including by higher drop-out rates and different career lengths for young academics with caring responsibilities [71]. This trend, in particular when considering mothers, also appears to be shrinking over time.

Gendered funding policies have already been put in place [136]. Such measures do not seem to be justified given the available evidence, which would if anything support interventions targeted at supporting young academics (of any gender) with caring responsibilities. Nevertheless, more systematic studies on the longer-term impact of COVID-19 on researchers from different demographic groups, backgrounds and career trajectories are necessary, as is the constant monitoring of the situation, in order to potentially inform policy interventions.

Other challenges

While this section cannot do justice to all the multifaceted ways in which COVID-19 is impacting researchers, a few emerging trends can already be mentioned. While rapidly shifting to working from home has been a complex and at times traumatic experience, recent work suggests that many academics might prefer to keep more flexibility in this respect in the future [4]. Indeed, some recent changes in work arrangements, such as remote meetings, might stay in the post-COVID academic life. Another example in this respect are conferences and other academic events. COVID-19 has, if anything, called for a reflection on the costs (e.g., for the environment) of the academic lifestyle, as well as made it clear that virtual options are viable in this respect. Conferences thus
face both challenges and opportunities in a post-COVID academic world [94]. Less optimistically, it is likely that COVID-19 has exerted a heavy toll on researchers mental health, physical and psychological well-being. Early evidence finds higher burnout and stress levels, in particular for the medical disciplines involved with COVID-19 patients [97, 77, 52]. The impact of COVID-19 on students will also be a significant area of future work. Early research suggested a possible impact on their psychological well-being [19, 45] and on learning [8, 59], not necessarily all negative. This finds echo in primary and secondary schools as well [46].

Outlook

The impact of COVID-19 on researchers and students remains largely to be understood. Early research seems to suggest that, at least during the early stages of the pandemic, the shift to virtual and the lock-downs have negatively impacted the productivity of younger academics with caring responsibilities, primarily parents. Such finding seems largely, albeit not completely, to explain a possible disparate impact on women as well. Several other important topics have at least started to emerge in early meta-research on COVID-19, including discussions on the future of academic work and events in a post-COVID world, the psychological and physical consequences of the pandemic, the impact of restrictions due to COVID-19 on teaching and education more broadly. All these topics, and more, constitute important areas for future research.

Conclusions

This review has provided an overview of early COVID-19-related meta-research, after little more than one year from the beginning of the pandemic (including contributions released until May 6, 2021). Some trends emerge, which can be summarized as follows:

- COVID-19 determined a rapid and massive shift of attention by researchers in most disciplines. This is understandable as COVID-19 has impacted so many aspects of life, yet it remains to be seen how stable the shift will actually be. In particular, as research on COVID-19 will move from a focus on the short to the long-term impact of COVID-19, a partial attention re-balancing might occur.

- The availability of scholarly literature as data generated a surge in experiments with machine learning techniques to facilitate research communication and understanding. While most of these results will likely not find immediate use, they constitute an acceleration of a trend pre-dating COVID-19. Success stories such as CORD-19, further exemplify how a combination of resource availability, institutional support, and continued
maintenance are important ingredients in not only creating but also establishing a successful data resource or machine learning application.

- Science communication has been significantly impacted by COVID-19. The need for rapidly sharing results fostered the adoption of open access, the use of pre-prints and of accelerated and sometimes innovative reviewing procedures. Nevertheless, traditional practices such as peer-review and grant-based funding have been visibly challenged by COVID-19, in particular because they often could not cope with the rapid action which was required. At the same time, and partially as a consequence, a deluge of low quality contributions was produced. While peer-review and funding systems seem likely to withstand COVID-19, the growing use of openly accessible pre-prints might become increasingly more common after it.

- Science communication went increasingly social with COVID-19. The pandemic gave some scientists a prominent public role on both traditional and social media. COVID-19 made it clear that science and scientists do not exist in a vacuum, but instead they increasingly have public visibility. Social media-based altmetrics, such as Twitter mentions, have also been found to correlate with later citation impact for COVID-19 literature: a novel trend which will require further monitoring. Lastly, the pandemic also put to the test the resilience and responsiveness of open commons such as Wikipedia, which responded admirably.

- COVID-19 has had a significant and still largely to be understood impact on researchers. Worrying signals of gender-based disparate impact appear to be primarily related to caring responsibilities – such as parenting – and the high pressures on young academics due to hyper competition and lack of job safety, in particular at elite institutions. The future of academic work also remains open for change, as some virtual options might be here to stay.

The most important questions related to the impact of COVID-19 on research and researchers remain open. This review highlighted how early meta-research on COVID-19 reacted to short-term questions and challenges, and has only recently started to more systematically explore the longer-term consequences of COVID-19. Indeed, over the coming years it will be crucial to shift attention from spotting short-term trends to understanding the long-term consequences of COVID-19 for science, broadly construed. While it is impossible to overstate the grim impact that COVID-19 had and is having on society, it can also be an opportunity to cast new light on many outstanding questions in the social sciences and beyond [33]. Perhaps this crisis shall serve as a catalyst to reflect and improve on how we do science too.
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References

[1] Alaa Abd-Alrazaq, Jens Schneider, Borbala Mifsud, Tanvir Alam, Mowafa Househ, Mounir Hamdi, and Zubair Shah. A Comprehensive Overview of the COVID-19 Literature: Machine Learning–Based Bibliometric Analysis. Journal of Medical Internet Research, 23(3):e23703, March 2021.

[2] Giovanni Abramo, Cirriaco Andrea D’Angelo, and Ida Mele. Gendered impact of COVID-19 pandemic on research production: a cross-country analysis. arXiv:2102.05360 [cs, econ, q-fin], February 2021. arXiv: 2102.05360.

[3] Alison Abritis, Adam Marcus, and Ivan Oransky. An “alarming” and “exceptionally high” rate of COVID-19 retractions? Accountability in Research, 28(1):58–59, January 2021.

[4] Ahmad Abu-Akel, Andreas Spitz, and Robert West. The effect of spokesperson attribution on public health message sharing during the COVID-19 pandemic. PLOS ONE, 16(2):e0245100, February 2021.

[5] Balazs Aczel, Marton Kovacs, Tanja van der Lippe, and Barnabas Szaszi. Researchers working from home: Benefits and challenges. PLOS ONE, 16(3):e0249127, March 2021.

[6] Waleed Ammar, Dirk Groeneveld, Chandra Bhagavatula, Iz Beltagy, Miles Crawford, Doug Downey, Jason Dunkelberger, Ahmed Elgohary, Sergey Feldman, Vu Ha, Rodney Kinney, Sebastian Kohlmeier, Kyle Lo, Tyler Murray, Hsu-Han Ooi, Matthew Peters, Joanna Power, Sam Skjonsberg, Lucy Wang, Chris Willhelm, Zheng Yuan, Madeleine van Zuylen, and Oren Etzioni. Construction of the Literature Graph in Semantic Scholar. In Proceedings of the 2018 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, Volume 3 (Industry Papers), pages 84–91, New Orleans - Louisiana, June 2018. Association for Computational Linguistics.

[7] Jens Peter Andersen, Mathias Wullum Nielsen, Nicole L Simone, Resa E Lewiss, and Reshma Jagsi. COVID-19 medical papers have fewer women first authors than expected. eLife, 9:e58807, June 2020.

[8] Aleksander Aristovnik, Damijana Keržič, Dejan Ravšelj, Nina Tomaževič, and Lan Umek. Impacts of the COVID-19 Pandemic on Life of Higher Education Students: A Global Perspective. Sustainability, 12(20):8438, October 2020.
[9] Aleksander Aristovnik, Dejan Ravšelj, and Lan Umek. A Bibliometric Analysis of COVID-19 across Science and Social Science Research Landscape. *Sustainability*, 12(21):9132, November 2020.

[10] Diego Añazco, Bryan Nicolalde, Isabel Espinosa, Jose Camacho, Mariam Mushtaq, Jimena Gimenez, and Enrique Teran. Publication rate and citation counts for preprints released during the COVID-19 pandemic: the good, the bad and the ugly. *PeerJ*, 9:e10927, March 2021.

[11] Jay J. Van Bavel, Katherine Baicker, Paulo S. Boggio, Valerio Capraro, Aleksandra Cichocka, Mina Cikara, Molly J. Crockett, Alia J. Crum, Karen M. Douglas, James N. Druckman, John Drury, Ocindrila Dube, Naomi Ellemers, Eli J. Finkel, James H. Fowler, Michele Gelfand, Shihui Han, S. Alexander Haslam, Jolanda Jetten, Shinobu Kitayama, Dean Mobbs, Lucy E. Napper, Dominic J. Packer, Gordon Pennycook, Ellen Peters, Richard E. Petty, David G. Rand, Stephen D. Reicher, Simone Schnall, Azim Shariff, Linda J. Skitka, Sandra Susan Smith, Cass R. Sunstein, Nassim Tabri, Joshua A. Tucker, Sander van der Linden, Paul van Lange, Kim A. Weeden, Michael J. A. Wohl, Jamil Zaki, Sean R. Zion, and Robb Willer. Using social and behavioural science to support COVID-19 pandemic response. *Nature Human Behaviour*, 4(5):460–471, May 2020.

[12] Simone Belli, Rogério Mugnaini, Joan Baltà, and Ernest Abadal. Coronavirus mapping in scientific publications: When science advances rapidly and collectively, is access to this knowledge open to society? *Scientometrics*, 124(3):2661–2685, September 2020.

[13] Iz Beltagy, Kyle Lo, and Arman Cohan. SciBERT: A Pretrained Language Model for Scientific Text. In *Proceedings of the 2019 Conference on Empirical Methods in Natural Language Processing and the 9th International Joint Conference on Natural Language Processing (EMNLP-IJCNLP)*, pages 3613–3618, Hong Kong, China, November 2019. Association for Computational Linguistics.

[14] Omer Benjakob, Rona Aviram, and Jonathan Sobel. Meta-Research: Citation needed? Wikipedia and the COVID-19 pandemic. *bioRxiv*, March 2021.

[15] Stan Benjamens, Vincent E. de Meijer, Robert A. Pol, and Martijn P. D. Haring. Are all voices heard in the COVID-19 debate? *Scientometrics*, 126(1):859–862, January 2021.

[16] Lonni Besançon, Nathan Peiffer-Smadja, Corentin Segalas, Haiting Jiang, Paola Masuzzo, Cooper Snout, Eric Billy, Maxime Deforet, and Clémence Leyrat. Open Science Saves Lives: Lessons from the COVID-19 Pandemic. *bioRxiv*, August 2020.

[17] Erik Boetto, Maria Pia Fantini, Aldo Gangemi, Davide Golinelli, Manfredi Greco, Andrea Giovanni Nuzzolese, Valentina Presutti, and Flavia
Rallo. Using altmetrics for detecting impactful research in quasi-zero-day time-windows: the case of COVID-19. *Scientometrics*, 126(2):1189–1215, February 2021. arXiv: 2004.06179.

[18] Katrina A Bramstedt. The carnage of substandard research during the COVID-19 pandemic: a call for quality. *Journal of Medical Ethics*, 46(12):803–807, December 2020.

[19] Matthew H. E. M. Browning, Lincoln R. Larson, Iryna Sharaievska, Alessandro Rigolon, Olivia McAnirlin, Lauren Mullenbach, Scott Cloutier, Tue M. Vu, Jennifer Thomsen, Nathan Reignier, Elizabeth Covelli Metcalf, Ashley D’Antonio, Marco Helbich, Gregory N. Bratman, and Hector Olvera Alvarez. Psychological impacts from COVID-19 among university students: Risk factors across seven states in the United States. *PLOS ONE*, 16(1):e0245327, January 2021.

[20] Joseph Bullock, Alexandra Luccioni, Katherine Hoffman Pham, Cynthia Sin Nga Lam, and Miguel Luengo-Oroz. Mapping the landscape of Artificial Intelligence applications against COVID-19. *Journal of Artificial Intelligence Research*, 69:807–845, November 2020.

[21] Guillaume Cabanac, Theodora Oikonomidi, and Isabelle Boutron. Day-to-day discovery of preprint–publication links. *Scientometrics*, 126(6):5285–5304, June 2021.

[22] Isabel Cachola, Kyle Lo, Arman Cohan, and Daniel Weld. TLDR: Extreme Summarization of Scientific Documents. In *Findings of the Association for Computational Linguistics: EMNLP 2020*, pages 4766–4777, Online, November 2020. Association for Computational Linguistics.

[23] X. Cai, C. V. Fry, and C. S. Wagner. International collaboration during the COVID-19 crisis: Autumn 2020 developments. *Scientometrics*, 126(4):3683–3692, April 2021.

[24] George Cernile, Trevor Heritage, Neil J Sebire, Ben Gordon, Taralyn Schwering, Shana Kazemlou, and Yulia Borecki. Network graph representation of COVID-19 scientific publications to aid knowledge discovery. *BMJ Health & Care Informatics*, 28(1):e100254, January 2021.

[25] Mohamad Chahrouf, Sahar Assi, Michael Bejjani, Ali A Nasrallah, Hamza Salhab, Mohamad Y Fares, and Hussein H Khachfe. A Bibliometric Analysis of COVID-19 Research Activity: A Call for Increased Output. *Cureus*, March 2020.

[26] Avishek Chatterjee, Cosimo Nardi, Cary Oberije, and Philippe Lambin. Knowledge Graphs for COVID-19: An Exploratory Review of the Current Landscape. *Journal of Personalized Medicine*, 11(4):300, April 2021.

[27] Chaomei Chen. Science Mapping: A Systematic Review of the Literature. *Journal of Data and Information Science*, 2(2):1–40, March 2017.
[28] Qingyu Chen, Alexis Allot, and Zhiyong Lu. LitCovid: an open database of COVID-19 literature. *Nucleic Acids Research*, 49(D1):D1534–D1540, January 2021.

[29] Matteo Cinelli, Walter Quattrococchi, Alessandro Galeazzi, Carlo Michele Valensise, Emanuele Brugnoli, Ana Lucia Schmidt, Paola Zola, Fabiana Zollo, and Antonio Scala. The COVID-19 social media infodemic. *Scientific Reports*, 10(1), December 2020.

[30] Arman Cohan, Sergey Feldman, Iz Beltagy, Doug Downey, and Daniel Weld. SPECTER: Document-level Representation Learning using Citation-informed Transformers. In *Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics*, pages 2270–2282, Online, November 2020. Association for Computational Linguistics.

[31] Giovanni Colavizza. COVID-19 research in Wikipedia. *Quantitative Science Studies*, 1(4):1349–1380, December 2020.

[32] Giovanni Colavizza, Rodrigo Costas, Vincent A. Traag, Nees Jan van Eck, Thed van Leeuwen, and Ludo Waltman. A scientometric overview of CORD-19. *PLOS ONE*, 16(1):e0244839, January 2021.

[33] Dalton Conley and Tim Johnson. Opinion: Past is future for the era of COVID-19 research in the social sciences. *Proceedings of the National Academy of Sciences*, 118(13): e2104155118, March 2021.

[34] Samuel Cross, Yeannuk Rho, Henna Reddy, Toby Pepperrell, Florence Rodgers, Rhiannon Osborne, Ayolola Eni-Olotu, Rishi Banerjee, Sabrina Wimmer, and Sarai Keestra. Who funded the research behind the Oxford-AstraZeneca COVID-19 vaccine? Approximating the funding to the University of Oxford for the research and development of the ChAdOx vaccine technology. *Health Policy*, April 2021.

[35] Ruomeng Cui, Hao Ding, and Feng Zhu. Gender Inequality in Research Productivity During the COVID-19 Pandemic. *SSRN Electronic Journal*, September 2020.

[36] Ersilia M. DeFilippis, Lauren Sinnenberg, Nadim Mahmud, Malissa J. Wood, Sharone N. Hayes, Erin D. Michos, and Nosheen Reza. Gender Differences in Publication Authorship During COVID-19: A Bibliometric Analysis of High-Impact Cardiology Journals. *Journal of the American Heart Association*, 10(5), March 2021.

[37] Hojat Dehghanbanadaki, Farhad Seif, Yasmin Vahidi, Farideh Razi, Ehsan Hashemi, Majid Khoshmirsafa, and Hossein Aazami. Bibliometric analysis of global scientific research on Coronavirus (COVID-19). *Medical Journal of the Islamic Republic of Iran*, 34:51, May 2020.
[38] Tatyana Deryugina, Olga Shurchkov, and Jenna Stearns. COVID-19 Disruptions Disproportionately Affect Female Academics. Technical Report w28360, National Bureau of Economic Research, Cambridge, MA, January 2021.

[39] Nicola Di Girolamo and Reint Meursinge Reynders. Characteristics of scientific articles on COVID-19 published during the initial 3 months of the pandemic. *Scientometrics*, 125(1):795–812, October 2020.

[40] Ricardo Jorge Dinis-Oliveira. COVID-19 research: pandemic versus “paperdemic”, integrity, values and risks of the “speed science”. *Forensic Sciences Research*, 5(2):174–187, April 2020.

[41] Anhvinh Doanvo, Xiaolu Qian, Divya Ramjee, Helen Piontkivska, Angel Desai, and Maimuna Majumder. Machine Learning Maps Research Needs in COVID-19 Literature. *Patterns*, 1(9):100123, December 2020.

[42] Daniel Domingo-Fernández, Shounak Baksi, Bruce Schultz, Yojana Gadiya, Reagon Karki, Tamara Raschka, Christian Ebeling, Martin Hofmann-Apitius, and Alpha Tom Kodamullil. COVID-19 Knowledge Graph: a computable, multi-modal, cause-and-effect knowledge model of COVID-19 pathophysiology. *Bioinformatics*, page btaa834, September 2020.

[43] Ashkan Ebadi, Pengcheng Xi, Stéphane Tremblay, Bruce Spencer, Raman Pall, and Alexander Wong. Understanding the temporal evolution of COVID-19 research through machine learning and natural language processing. *Scientometrics*, 126(1):725–739, January 2021.

[44] Michael B Eisen, Anna Akhmanova, Timothy E Behrens, and Detlef Weigel. Publishing in the time of COVID-19. *eLife*, 9:e57162, March 2020.

[45] Timon Elmer, Kieran Mepham, and Christoph Stadtfeld. Students under lockdown: Comparisons of students’ social networks and mental health before and during the COVID-19 crisis in Switzerland. *PLOS ONE*, 15(7):e0236337, July 2020.

[46] Per Engzell, Arun Frey, and Mark D. Verhagen. Learning loss due to school closures during the COVID-19 pandemic. *Proceedings of the National Academy of Sciences*, 118(17):e2022376118, April 2021.

[47] Andre Esteva, Anuprit Kale, Romain Paulus, Kazuma Hashimoto, Wenpeng Yin, Dragomir Radev, and Richard Socher. COVID-19 information retrieval with deep-learning based semantic search, question answering, and abstractive summarization. *NPJ Digital Medicine*, 4(1):68, December 2021.
[48] John H. Evans and Eszter Hargittai. Who Doesn’t Trust Fauci? The Public’s Belief in the Expertise and Shared Values of Scientists in the COVID-19 Pandemic. *Socius: Sociological Research for a Dynamic World*, 6:237802312094733, 2020.

[49] Zhichao Fang and Rodrigo Costas. Tracking the Twitter attention around the research efforts on the COVID-19 pandemic. *arXiv:2006.05783 [cs]*, June 2020. *arXiv: 2006.05783*.

[50] Mike Farjam, Federico Bianchi, Flaminio Squazzoni, and Giangiacomo Bravo. Dangerous liaisons: an online experiment on the role of scientific experts and politicians in ensuring public support for anti-COVID measures. *Royal Society Open Science*, 8(3):rsos.201310, 201310, March 2021.

[51] Alice Fleerackers, Michelle Riedlinger, Laura Moorhead, Rukhsana Ahmed, and Juan Pablo Alperin. Communicating Scientific Uncertainty in an Age of COVID-19: An Investigation into the Use of Preprints by Digital Media Outlets. *Health Communication*, pages 1–13, January 2021.

[52] Marco Fornili, Davide Petri, Carmen Berrocal, Giuseppe Fiorentino, Fulvio Ricceri, Alessandra Macciotta, Andreina Bruno, Domenica Farinella, Michela Baccini, Gianluca Severi, and Laura Baglietto. Psychological distress in the academic population and its association with sociodemographic and lifestyle characteristics during COVID-19 pandemic lockdown: Results from a large multicenter Italian study. *PLOS ONE*, 16(3):e0248370, March 2021.

[53] Nicholas Fraser, Liam Brierley, Gautam Dey, Jessica K. Polka, Máté Pálfy, Federico Nanni, and Jonathon Alexis Coates. The evolving role of preprints in the dissemination of COVID-19 research and their impact on the science communication landscape. *PLOS Biology*, 19(4):e3000959, April 2021.

[54] Caroline V. Fry, Xiaojing Cai, Yi Zhang, and Caroline S. Wagner. Consolidation in a crisis: Patterns of international collaboration in early COVID-19 research. *PLOS ONE*, 15(7):e0236307, July 2020.

[55] Leonardo B. Furstenaau, Bruna Rabaioli, Michele Kremer Sott, Danielli Cossul, Mariluza Sott Bender, Eduardo Moreno Júdice De Mattos Farina, Fabiano Novaes Barcellos Filho, Priscilla Paola Severo, Michael S. Dohan, and Nicola Luigi Bragazzi. A Bibliometric Network Analysis of Coronavirus during the First Eight Months of COVID-19 in 2020. *International Journal of Environmental Research and Public Health*, 18(3):952, January 2021.

[56] Silvia Gianola, Tiago S. Jesus, Silvia Bargeri, and Greta Castellini. Characteristics of academic publications, preprints, and registered clinical trials on the COVID-19 pandemic. *PLOS ONE*, 15(10):e0240123, October 2020.
[57] Laura M. Giurge, Ashley V. Whillans, and Ayse Yemisciogil. A multi-country perspective on gender differences in time use during COVID-19. *Proceedings of the National Academy of Sciences*, 118(12):e2018494118, March 2021.

[58] Paul P. Glasziou, Sharon Sanders, and Tammy Hoffmann. Waste in COVID-19 research. *BMJ*, 369:m1847, May 2020.

[59] T. Gonzalez, M. A. de la Rubia, K. P. Hincz, M. Comas-Lopez, Laia Subirats, Santi Fort, and G. M. Sacha. Influence of COVID-19 confinement on students’ performance in higher education. *PLOS ONE*, 15(10):e0239490, October 2020.

[60] Xiao Guo, Hengameh Mirzaalian, Ekraam Sabir, Ayush Jaiswal, and Wael Abd-Almageed. CORD19STS: COVID-19 Semantic Textual Similarity Dataset. *arXiv:2007.02461 [cs]*, November 2020. arXiv: 2007.02461.

[61] Milad Haghani and Michiel C. J. Bliemer. Covid-19 pandemic and the unprecedented mobilisation of scholarly efforts prompted by a health crisis: Scientometric comparisons across SARS, MERS and 2019-nCoV literature. *Scientometrics*, 125(3):2695–2726, December 2020.

[62] Milad Haghani, Michiel C.J. Bliemer, Floris Goerlandt, and Jie Li. The scientific literature on Coronaviruses, COVID-19 and its associated safety-related research dimensions: A scientometric analysis and scoping review. *Safety Science*, 129:104806, September 2020.

[63] Robin Haunschild and Lutz Bornmann. Can tweets be used to detect problems early with scientific papers? A case study of three retracted COVID-19/SARS-CoV-2 papers. *Scientometrics*, April 2021.

[64] Lena Hipp and Mareike Bünning. Parenthood as a driver of increased gender inequality during COVID-19? Exploratory evidence from Germany. *European Societies*, 23(sup1):S658–S673, February 2021.

[65] J. Homolak, I. Kodvanj, and D. Virag. Preliminary analysis of COVID-19 academic information patterns: a call for open science in the times of closed borders. *Scientometrics*, 124(3):2687–2701, September 2020.

[66] Daniel W. Hook, Simon J. Porter, Hélène Draux, and Christian T. Herzog. Real-Time Bibliometrics: Dimensions as a Resource for Analyzing Aspects of COVID-19. *Frontiers in Research Metrics and Analytics*, 5:595299, January 2021.

[67] Daniel W. Hook, Simon J. Porter, and Christian Herzog. Dimensions: Building Context for Search and Evaluation. *Frontiers in Research Metrics and Analytics*, 3, August 2018.
[68] Tom Hope, Jason Portenoy, Kishore Vasan, Jonathan Borchardt, Eric Horvitz, Daniel Weld, Marti Hearst, and Jevin West. SciSight: Combining faceted navigation and research group detection for COVID-19 exploratory scientific search. In Proceedings of the 2020 Conference on Empirical Methods in Natural Language Processing: System Demonstrations, pages 135–143, Online, November 2020. Association for Computational Linguistics.

[69] Serge P. J. M. Horbach. Pandemic publishing: Medical journals strongly speed up their publication process for COVID-19. Quantitative Science Studies, 1(3):1056–1067, August 2020.

[70] Serge P J M Horbach. No time for that now! Qualitative changes in manuscript peer review during the Covid-19 pandemic. Research Evaluation, page rva037, January 2021.

[71] Junming Huang, Alexander J. Gates, Roberta Sinatra, and Albert-László Barabási. Historical comparison of gender inequality in scientific careers across countries and disciplines. Proceedings of the National Academy of Sciences, 117(9):4609–4616, March 2020.

[72] Phil Hurst and Sarah Greaves. COVID-19 Rapid Review cross-publisher initiative: What we have learned and what we are going to do next. Learned Publishing, page leap.1375, March 2021.

[73] John P.A. Ioannidis, Maia Salholz-Hillel, Kevin W. Boyack, and Jeroen Baas. The rapid, massive growth of COVID-19 authors in the scientific literature. bioRxiv, December 2020.

[74] Mohamad Yaser Jaradeh, Allard Oelen, Kheir Eddine Farfar, Manuel Prinz, Jennifer D’Souza, Gábor Kismihók, Markus Stocker, and Sören Auer. Open Research Knowledge Graph: Next Generation Infrastructure for Semantic Scholarly Knowledge. In Proceedings of the 10th International Conference on Knowledge Capture, pages 243–246, Marina Del Rey CA USA, September 2019. ACM.

[75] Rebecca C Jones, Jasper C Ho, Hannah Kearney, Meghan Glibbery, Daniel L Levin, John Kim, Sara Markovic, Jillian Howden, Maya Amar, and Mark A Crowther. Evaluating Trends in COVID-19 Research Activity in Early 2020: The Creation and Utilization of a Novel Open-Access Database. Cureus, August 2020.

[76] Anshul Kanakia, Kuansan Wang, Yuxiao Dong, Boya Xie, Kyle Lo, Zhihong Shen, Lucy Lu Wang, Chiyuan Huang, Darrin Eide, Sebastian Kohlmeier, and Chieh-Han Wu. Mitigating Biases in CORD-19 for Analyzing COVID-19 Literature. Frontiers in Research Metrics and Analytics, 5:596624, November 2020.
[77] Thomas G. Kannampallil, Charles W. Goss, Bradley A. Evanoff, Jaime R. Strickland, Rebecca P. McAlister, and Jennifer Duncan. Exposure to COVID-19 patients increases physician trainee stress and burnout. *PLOS ONE*, 15(8):e0237301, August 2020.

[78] Brian C. Keegan and Chenhao Tan. A Quantitative Portrait of Wikipedia’s High-Tempo Collaborations during the 2020 Coronavirus Pandemic. *arXiv:2006.08899 [physics]*, June 2020. arXiv: 2006.08899.

[79] Virapat Kieuvongngam, Bowen Tan, and Yiming Niu. Automatic Text Summarization of COVID-19 Medical Research Articles using BERT and GPT-2. *arXiv:2006.01997 [cs]*, June 2020. arXiv: 2006.01997.

[80] Kayvan Kousha and Mike Thelwall. COVID-19 publications: Database coverage, citations, readers, tweets, news, Facebook walls, Reddit posts. *Quantitative Science Studies*, 1(3):1068–1091, August 2020.

[81] Larry J. Kricka, Sergei Polevikov, Jason Y. Park, Paolo Fortina, Sergio Bernardini, Daniel Satchkov, Valentin Kolesov, and Maxim Grishkov. Artificial Intelligence-Powered Search Tools and Resources in the Fight Against COVID-19. *EJIFCC*, 31(2):106–116, June 2020.

[82] Hermann Kroll, Jan Pirklbauer, Johannes Ruthmann, and Wolf-Tilo Balke. A Semantically Enriched Dataset based on Biomedical NER for the COVID19 Open Research Dataset Challenge. *arXiv:2005.08823 [cs]*, May 2020. arXiv: 2005.08823.

[83] Rebecca A. Krukowski, Reshma Jagsi, and Michelle I. Cardel. Academic Productivity Differences by Gender and Child Age in Science, Technology, Engineering, Mathematics, and Medicine Faculty During the COVID-19 Pandemic. *Journal of Women’s Health*, 30(3):341–347, March 2021.

[84] Francois Lachapelle. COVID-19 Preprints and Their Publishing Rate: An Improved Method. *Infectious Diseases (except HIV/AIDS)*, September 2020.

[85] Jenny J. Lee and John P. Haupt. Scientific globalism during a global crisis: research collaboration and open access publications on COVID-19. *Higher Education*, 81(5):949–966, May 2021.

[86] Florian Lemmerich, Diego Sáez-Trumper, Robert West, and Leila Zia. Why the World Reads Wikipedia: Beyond English Speakers. In *Proceedings of the Twelfth ACM International Conference on Web Search and Data Mining*. ACM Press, 2019. arXiv: 1812.00474.

[87] Carolin Lerchenmüller, Leo Schmollenbach, Anupam B Jena, and Marc J Lerchenmueller. Longitudinal analyses of gender differences in first authorship publications related to COVID-19. *BMJ Open*, 11(4):e045176, April 2021.
[88] Weirong Li, Kai Sun, Yunqiang Zhu, Jia Song, Jie Yang, Lang Qian, and Shu Wang. Analyzing the Research Evolution in Response to COVID-19. *ISPRS International Journal of Geo-Information*, 10(4):237, April 2021.

[89] Sean MacAvaney, Arman Cohan, and Nazli Goharian. SLEDGE-Z: A Zero-Shot Baseline for COVID-19 Literature Search. In *Proceedings of the 2020 Conference on Empirical Methods in Natural Language Processing (EMNLP)*, pages 4171–4179, Online, November 2020. Association for Computational Linguistics.

[90] Clara Martinez-Perez, Cristina Alvarez-Peregrina, Cesar Villa-Collar, and Miguel Angel Sanchez-Tena. Citation Network Analysis of the Novel Coronavirus Disease 2019 (COVID-19). *International Journal of Environmental Research and Public Health*, 17(20):7690, October 2020.

[91] Alberto Martin-Martín, Mike Thelwall, Enrique Orduna-Malea, and Emilio Delgado Lopez-Cozar. Google Scholar, Microsoft Academic, Scopus, Dimensions, Web of Science, and OpenCitations’ COCI: a multidisciplinary comparison of coverage via citations. *Scientometrics*, 126(1):871–906, January 2021.

[92] Daniele Mercatelli, Andrew N Holding, and Federico M Giorgi. Web tools to fight pandemics: the COVID-19 experience. *Briefings in Bioinformatics*, 22(2):690–700, March 2021.

[93] Allison C. Morgan, Samuel F. Way, Michael J. D. Hoefer, Daniel B. Larremore, Mirta Galesic, and Aaron Clauset. The unequal impact of parenthood in academia. *Science Advances*, 7(9):eabd1996, February 2021.

[94] Omar Mubin, Fady Alnajjar, Abdullah Shamail, Suleman Shahid, and Simeon Simoff. The new norm: Computer Science conferences respond to COVID-19. *Scientometrics*, 126(2):1813–1827, February 2021.

[95] Goran Muric, Kristina Lerman, and Emilio Ferrara. Gender Disparity in the Authorship of Biomedical Research Publications During the COVID-19 Pandemic: Retrospective Observational Study. *Journal of Medical Internet Research*, 23(4):e25379, April 2021.

[96] Kyle R. Myers, Wei Yang Tham, Yian Yin, Nina Cohodes, Jerry G. Thursby, Marie C. Thursby, Peter Schiffer, Joseph T. Walsh, Karim R. Lakhani, and Dashun Wang. Unequal effects of the COVID-19 pandemic on scientists. *Nature Human Behaviour*, 4(9):880–883, September 2020.

[97] Paula Odriozola-González, Álvaro Planchuelo-Gómez, María Jesús Irurtia, and Rodrigo de Luis-García. Psychological effects of the COVID-19 outbreak and lockdown among students and workers of a Spanish university. *Psychiatry Research*, 290:113108, August 2020.

[98] Jiban K. Pal. Visualizing the knowledge outburst in global research on COVID-19. *Scientometrics*, 126(5):4173–4193, May 2021.
[99] Adam Palayew, Ole Norgaard, Kelly Safreed-Harmon, Tue Helms Andersen, Lauge Neimann Rasmussen, and Jeffrey V. Lazarus. Pandemic publishing poses a new COVID-19 challenge. *Nature Human Behaviour*, 4(7):666–669, July 2020.

[100] Alan L. Porter, Yi Zhang, Ying Huang, and Mengjia Wu. Tracking and Mining the COVID-19 Research Literature. *Frontiers in Research Metrics and Analytics*, 5:594060, November 2020.

[101] Miguel Prudêncio and Joana C. Costa. Research funding after COVID-19. *Nature Microbiology*, 5(8):986–986, August 2020.

[102] Cristina M Pulido, Beatriz Villarejo-Carballido, Gisela Redondo-Sama, and Aitor Gómez. COVID-19 infodemic: More retweets for science-based information on coronavirus than for false information. *International Sociology*, 35(4):377–392, July 2020.

[103] Justin T. Reese, Deepak Unni, Tiffany J. Callahan, Luca Cappelletti, Vida Ravanmehr, Seth Carbon, Kent A. Shefchek, Benjamin M. Good, James P. Balhoff, Tommaso Fontana, Hannah Blau, Nicolas Matentzoglu, Nomi L. Harris, Monica C. Munoz-Torres, Melissa A. Haendel, Peter N. Robinson, Marcin P. Joachimiak, and Christopher J. Mungall. KG-COVID-19: A Framework to Produce Customized Knowledge Graphs for COVID-19 Response. *Patterns*, 2(1):100155, January 2021.

[104] Kirk Roberts, Tasmeer Alam, Steven Bedrick, Dina Demner-Fushman, Kyle Lo, Ian Soboroff, Ellen Voorhees, Lucy Lu Wang, and William R Hersh. TREC-COVID: rationale and structure of an information retrieval shared task for COVID-19. *Journal of the American Medical Informatics Association*, 27(9):1431–1436, September 2020.

[105] Kirk Roberts, Tasmeer Alam, Steven Bedrick, Dina Demner-Fushman, Kyle Lo, Ian Soboroff, Ellen Voorhees, Lucy Lu Wang, and William R. Hersh. Searching for Scientific Evidence in a Pandemic: An Overview of TREC-COVID. *arXiv:2104.09632 [cs]*, April 2021. arXiv: 2104.09632.

[106] Shaurya Rohatgi, Zeba Karishma, Jason Chhay, Sai Raghav Reddy Keesara, Jian Wu, Cornelia Caragea, and C. Lee Giles. COVIDSeer: Extending the CORD-19 Dataset. In *Proceedings of the ACM Symposium on Document Engineering 2020*, pages 1–4, Virtual Event CA USA, September 2020. ACM.

[107] Thorsten Rüprecht, Manoel Horta Ribeiro, Tiago Santos, Florian Lemmerich, Markus Strohmaier, Robert West, and Denis Helic. Volunteer contributions to Wikipedia increased during COVID-19 mobility restrictions. *arXiv:2102.10090 [cs]*, February 2021. arXiv: 2102.10090.

[108] Digital Science, Daniel Hook, and Simon Porter. How COVID-19 is Changing Research Culture. Technical report, Digital Science, 2020. Artwork Size: 16210082 Bytes.
[109] Adil E. Shamoo. Validate the integrity of research data on COVID 19. *Accountability in Research*, 27(6):325–326, August 2020.

[110] Connor Shorten, Taghi M. Khoshgoftaar, and Borko Furht. Deep Learning applications for COVID-19. *Journal of Big Data*, 8(1):18, December 2021.

[111] Junaid Shuja, Eisa Alanazi, Waleed Alasmary, and Abdulaziz Alashaikh. COVID-19 open source data sets: a comprehensive survey. *Applied Intelligence*, 51(3):1296–1325, March 2021.

[112] Philipp Singer, Florian Lemmerich, Robert West, Leila Zia, Ellery Wulczyn, Markus Strohmaier, and Jure Leskovec. Why We Read Wikipedia. In *Proceedings of the 26th International Conference on World Wide Web*, pages 1591–1600, Perth Australia, April 2017. International World Wide Web Conferences Steering Committee.

[113] Catrin Sohrabi, Ginimol Mathew, Thomas Franchi, Ahmed Kerwan, Michelle Griffin, Jennick Soleil C Del Mundo, Syed Ahsan Ali, Maliba Agha, and Riaz Agha. Impact of the coronavirus (COVID-19) pandemic on scientific research and implications for clinical academic training – A review. *International Journal of Surgery*, 86:57–63, February 2021.

[114] Parisa Soltani and Romeo Patini. Retracted COVID-19 articles: a side-effect of the hot race to publication. *Scientometrics*, 125(1):819–822, October 2020.

[115] Sarvesh Soni and Kirk Roberts. An evaluation of two commercial deep learning-based information retrieval systems for COVID-19 literature. *Journal of the American Medical Informatics Association*, 28(1):132–137, January 2021.

[116] Flaminio Squazzoni, Giangiacomo Bravo, Francisco Grimaldo, Daniel García-Costa, Mike Farjam, and Bahar Mehmami. No Tickets for Women in the COVID-19 Race? A Study on Manuscript Submissions and Reviews in 2347 Elsevier Journals during the Pandemic. *SSRN Electronic Journal*, October 2020.

[117] Emma Stoye. How research funders are tackling coronavirus disruption. *Nature*, pages d41586–020–01120–2, April 2020.

[118] Cassidy R. Sugimoto, Sam Work, Vincent Larivière, and Stefanie Haustein. Scholarly use of social media and altmetrics: A review of the literature. *Journal of the Association for Information Science and Technology*, 68(9):2037–2062, September 2017.

[119] Raphael Tang, Rodrigo Nogueira, Edwin Zhang, Nikhil Gupta, Phuong Cam, Kyunghyun Cho, and Jimmy Lin. Rapidly Bootstrapping a Question Answering Dataset for COVID-19. *arXiv:2004.11339 [cs]*, April 2020. arXiv: 2004.11339.
[120] Mohammad-H. Tayarani N. Applications of artificial intelligence in battling against covid-19: A literature review. *Chaos, Solitons & Fractals*, 142:110338, January 2021.

[121] Jaime A. Teixeira da Silva. An Alert to COVID-19 Literature in Predatory Publishing Venues. *The Journal of Academic Librarianship*, 46(5):102187, September 2020.

[122] Jaime A. Teixeira da Silva, Helmar Bornemann-Cimenti, and Panagiotis Tsigaris. Optimizing peer review to minimize the risk of retracting COVID-19-related literature. *Medicine, Health Care and Philosophy*, 24(1):21–26, March 2021.

[123] Bach Xuan Tran, Giang Hai Ha, Long Hoang Nguyen, Giang Thu Vu, Men Thi Hoang, Huong Thi Le, Carl A. Latkin, Cyrus S.H. Ho, and Roger C.M. Ho. Studies of Novel Coronavirus Disease 19 (COVID-19) Pandemic: A Global Analysis of Literature. *International Journal of Environmental Research and Public Health*, 17(11):4095, June 2020.

[124] Surabhi Verma and Anders Gustafsson. Investigating the emerging COVID-19 research trends in the field of business and management: A bibliometric analysis approach. *Journal of Business Research*, 118:253–261, September 2020.

[125] Karin Verspoor, Kevin Bretonnel Cohen, Michael Conway, Berry de Bruijn, Mark Dredze, Rada Mihalcea, and Byron Wallace, editors. *Proceedings of the 1st Workshop on NLP for COVID-19 (Part 2) at EMNLP 2020*. Association for Computational Linguistics, Online, December 2020.

[126] Karin Verspoor, Kevin Bretonnel Cohen, Mark Dredze, Emilio Ferrara, Jonathan May, Robert Munro, Cecile Paris, and Byron Wallace, editors. *Proceedings of the 1st Workshop on NLP for COVID-19 at ACL 2020*. Association for Computational Linguistics, Online, July 2020.

[127] Karin Verspoor, Simon Šuster, Yulia Otmakhova, Shevon Mendis, Zenan Zhai, Biaoyan Fang, Jey Han Lau, Timothy Baldwin, Antonio Jimeno Yepes, and David Martínez. COVID-SEE: Scientific Evidence Explorer for COVID-19 Related Research. *arXiv:2008.07880 [cs]*, August 2020. arXiv: 2008.07880.

[128] Martijn Visser, Nees Jan van Eck, and Ludo Waltman. Large-scale comparison of bibliographic data sources: Scopus, Web of Science, Dimensions, Crossref, and Microsoft Academic. *Quantitative Science Studies*, 2(1):20–41, April 2021.

[129] Lucy Lu Wang and Kyle Lo. Text mining approaches for dealing with the rapidly expanding literature on COVID-19. *Briefings in Bioinformatics*, 22(2):781–799, March 2021.
[130] Lucy Lu Wang, Kyle Lo, Yoganand Chandrasekhar, Russell Reas, Jiangjiang Yang, Douglas Burdick, Darrin Eide, Kathryn Funk, Yannis Katsis, Rodney Kinney, Yunyao Li, Ziyang Liu, William Merrill, Paul Mooney, Dewey Murdick, Devvret Rishi, Jerry Sheehan, Zhihong Shen, Brandon Stilson, Alex D Wade, Kuansan Wang, Nancy Xin Ru Wang, Chris Wilhelm, Boya Xie, Douglas Raymond, Daniel S Weld, Oren Etzioni, and Sebastian Kohlmeier. CORD-19: The COVID-19 Open Research Dataset. In Proceedings of the 1st Workshop on NLP for COVID-19 at ACL 2020. Association for Computational Linguistics, July 2020.

[131] Qingyun Wang, Manling Li, Xuan Wang, Nikolaus Parulian, Guangxing Han, Jiawei Ma, Jingxuan Tu, Ying Lin, Haoran Zhang, Weili Liu, Aabhas Chauhan, Yingjun Guan, Bangzheng Li, Ruisong Li, Xiangchen Song, Heng Ji, Jiawei Han, Shih-Fu Chang, James Pustejovsky, Jasmine Rah, David Liem, Ahmed Elsayed, Martha Palmer, Clare Voss, Cynthia Schneider, and Boyan Ouyshkevych. COVID-19 Literature Knowledge Graph Construction and Drug Repurposing Report Generation. arXiv:2007.00576 [cs], April 2021. arXiv: 2007.00576.

[132] Xuan Wang, Weili Liu, Aabhas Chauhan, Yingjun Guan, and Jiawei Han. Automatic Textual Evidence Mining in COVID-19 Literature. arXiv:2004.12563 [cs], April 2020. arXiv: 2004.12563.

[133] Xuan Wang, Xiangchen Song, Bangzheng Li, Yingjun Guan, and Jiawei Han. Comprehensive Named Entity Recognition on CORD-19 with Distant or Weak Supervision. arXiv:2003.12218 [cs], April 2020. arXiv: 2003.12218.

[134] Jevin D. West and Carl T. Bergstrom. Misinformation in and about science. Proceedings of the National Academy of Sciences, 118(15):e1912444117, April 2021.

[135] Colby Wise, Vassilis N. Ioannidis, Miguel Romero Calvo, Xiang Song, George Price, Ninad Kulkarni, Ryan Brand, Parminder Bhatia, and George Karypis. COVID-19 Knowledge Graph: Accelerating Information Retrieval and Discovery for Scientific Literature. In Proceedings of the First Knowableable Natural Language Processing Workshop. Association for Computational Linguistics, December 2020.

[136] Holly O. Witteman, Jenna Haverfield, and Cara Tannenbaum. COVID-19 gender policy changes support female scientists and improve research quality. Proceedings of the National Academy of Sciences, 118(6):e2023476118, February 2021.

[137] Bo Xie, Daqing He, Tim Mercer, Youfa Wang, Dan Wu, Kenneth R. Fleischmann, Yan Zhang, Linda H. Yoder, Keri K. Stephens, Michael Mackert, and Min Kyung Lee. Global health crises are also information crises: A call to action. Journal of the Association for Information Science and Technology, 71(12):1419–1423, December 2020.
[138] Dana Yelin, Eytan Wirtheim, Pauline Vetter, Andre C Kalil, Judith Bruchfeld, Michael Runold, Giovanni Guaraldi, Cristina Mussini, Carlota Gudiol, Miquel Pujol, Alessandra Bandera, Luigia Scudeller, Mical Paul, Laurent Kaiser, and Leonard Leibovici. Long-term consequences of COVID-19: research needs. *The Lancet Infectious Diseases*, 20(10):1115–1117, October 2020.

[139] Nicole Shu Ling Yeo-Teh and Bor Luen Tang. An alarming retraction rate for scientific publications on Coronavirus Disease 2019 (COVID-19). *Accountability in Research*, 28(1):47–53, January 2021.

[140] Murat T. Yildirim and Hande Eslen-Ziya. The differential impact of COVID-19 on the work conditions of women and men academics during the lockdown. *Gender, Work & Organization*, 28(S1):243–249, January 2021.

[141] Yian Yin, Jian Gao, Benjamin F. Jones, and Dashun Wang. Coevolution of policy and science during the pandemic. *Science*, 371(6525):128–130, January 2021.

[142] Eleftheria Zeggini, Michael Baumann, Magdalena Götz, Stephan Herzig, Martin Hrabe de Angelis, and Matthias H. Tschöp. Biomedical Research Goes Viral: Dangers and Opportunities. *Cell*, 181(6):1189–1193, June 2020.

[143] Edwin Zhang, Nikhil Gupta, Rodrigo Nogueira, Kyunghyun Cho, and Jimmy Lin. Rapidly Deploying a Neural Search Engine for the COVID-19 Open Research Dataset: Preliminary Thoughts and Lessons Learned. In *Proceedings of the 1st Workshop on NLP for COVID-19 at ACL 2020*. Association for Computational Linguistics, July 2020.

[144] Edwin Zhang, Nikhil Gupta, Raphael Tang, Xiao Han, Ronak Pradeep, Kuang Lu, Yue Zhang, Rodrigo Nogueira, Kyunghyun Cho, Hui Fang, and Jimmy Lin. Covidex: Neural Ranking Models and Keyword Search Infrastructure for the COVID-19 Open Research Dataset. In *Proceedings of the First Workshop on Scholarly Document Processing*. Association for Computational Linguistics, November 2020.

[145] Lin Zhang, Wenjing Zhao, Beibei Sun, Ying Huang, and Wolfgang Glänzel. How scientific research reacts to international public health emergencies: a global analysis of response patterns. *Scientometrics*, 124(1):747–773, July 2020.

[146] Yi Zhang, Xiaojing Cai, Caroline V. Fry, Mengjia Wu, and Caroline S. Wagner. Topic evolution, disruption and resilience in early COVID-19 research. *Scientometrics*, 126(5):4225–4253, May 2021.

[147] Xu Zuo, Yong Chen, Lucila Ohno-Machado, and Hua Xu. How do we share data in COVID-19 research? A systematic review of COVID-19 datasets
in PubMed Central Articles. Briefings in Bioinformatics, 22(2):800–811, March 2021.

[148] Sa'ed H. Zyoud and Samah W. Al-Jabi. Mapping the situation of research on coronavirus disease-19 (COVID-19): a preliminary bibliometric analysis during the early stage of the outbreak. BMC Infectious Diseases, 20(1):561, December 2020.