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Mapping Open Science Scholarly Literature

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Abstract

Scholarly literature on open science over the past several decades has paralleled developments in research policy and practice, proliferated alongside mandates and directives, and increased in volume. Navigating the conceptually wide-ranging and versatile topic of open science makes analyzing its body of literature an ongoing challenge, often approached with a range of methods and perspectives. We use co-citations and direct citations to map the scholarly literature on open science and identify eleven clusters: open data, psychology-replication, tech and industry, participatory research, scholarly communication, neuroscience-reproducibility, social justice and diversity, public health-COVID-19, bio-data, publication bias/meta-research, and eating disorder-COVID-19, using Louvain community detection. This survey of the literature would prove useful for those looking to calibrate their research efforts with a dynamic and multifaceted area of inquiry, better navigate the field to understand its topical landscape, and perhaps influence or chart a course for the trajectory of scientific discourse related to open science.

1. Introduction

Open science aims to make research processes and outputs transparent and accessible to all (Fecher & Friesike, 2014; Tochtermann & Höfler, 2022; Vicente-Saez & Martinez-Fuentes, 2018). It has seen substantial adoption and progression by the scientific community since its emergence in the 1990s (Leonelli et al., 2015) and became a dominant element of the ethos and practices of certain fields by the 2010s (Molldrem et al., 2021). The COVID-19 pandemic and the 2021 UNESCO Recommendation on Open Science (UNESCO, 2021) further propelled developments, demonstrated the importance of establishing research openness for science and society at a global scale, and acknowledged the transformative potential of open science to reduce inequalities in science, technology, and innovation.

Substantial amounts of scholarly literature on open science have been generated in the past decades and an even broader corpus of literature peripherally references the conceptually versatile and wide-ranging topic. Mapping is a useful approach for understanding scientific domains or defined topics and for capturing these developments. Units of analysis, such as a literature corpus, are analyzed and interpreted to guide the exploration of intellectual structures or dynamic patterns (Chen, 2017). When domains are visualized, they can reveal realms of science communicated in the scholarly literature (Börner et al., 2003).

Several studies mapped the literature on open science in the past decade. Miguel et al. (2016) conducted a cluster analysis for publications published until 2014 on the topic of open access. Similarly, open access literature was examined using a co-word analysis based on publications from information science journals from 2013 to 2018 by Seo & Chung (2013). Detailed analyses on word co-occurrence networks on open data were conducted by Zhang et al. (2018) for publications published until 2016 and by Corrales-Garay et al. (2019) for publications until 2018. Lee and Chung (2022) created a keyword bibliographic coupling network for open science research, considering 1,000 publications published between 1982 and May 2021, based on the search term "open science." They identified nine clusters: open access, reproducibility, data sharing, preregistrations and registered reports, research data, open peer review, tools and platforms for reproducible research, open innovation and science policy, and preprints. A more recent effort by Ahmed et al. (2023) analyzed and identified key trends, influential authors, prominent journals, and leading countries and institutions from 5,875 publications about "open science" from 2013 to 2023. Shmagun et al. (2020) mapped open science and data through a systematic literature review with a keyword co-occurrence analysis of 33 research publications and produced five clusters: open science, open access, open research data, citizen science and science policy. Lasser et al. (2022) built a corpus of 695 publications focusing on empirical open science research annotated to five aspects: the action (e.g., open access), the method, the discipline, the study object (e.g., researcher, librarian) and the geographic scope on the country level, and identified open access as the dominant theme, followed by open data. In their scoping review, Cole et al. (2024) analyzed the evidence of the societal impact of open science from 196 publications and grey literature sources and found an emphasis on citizen science and open access but little evidence of the societal impact of open data. Marshall et al. (2024) qualitatively studied the international debate on open science during the COVID-19 pandemic based on 446 selected key articles, editorials, blogs, and thought pieces. They observed how the pandemic prompted an increased focus on open science.

These studies provide valuable approaches and knowledge foundations for understanding open science literature. However, at this juncture, some are no longer up to date, possess small sample sizes for a growing body of work (due to the limitations of search queries, databases used, or analysis criteria), are oriented qualitatively, or focus only on particular open science aspects (e.g., open data). Our ongoing study advances methodological approaches and aims in its first stage to generate new knowledge on open science developments and illuminate established and nascent topical areas in open science. It is guided by the research question: How are open science topics represented in scholarly literature?

2. Methods

Our study is based on an open science core publication set and an expanded set of literature consisting of citations and references of the core set. The chosen collection approach allows for capturing the broad open science research landscape without limiting the analysis to only publications mentioning open science as a keyword. Instead, hidden relevant publications are made discoverable under the premise that relevant open science research articles not containing any of the search string keywords at least cite open science literature or are themselves so relevant that they are cited.

2.1. Data collection of the core publication set

We first collected 1,787 publications retrieved from the German Kompetenznetzwerk Bibliometrie (KB) in-house Web of Science (WoS) version (Schmidt et al., 2024) licensing the Science Citation Index, Social Sciences Citation Index, Arts & Humanities Citation Index, the Science and Social Sciences Conference Proceedings Citation Indexes, 1980 to present from a snapshot dated to October 2023. PostgreSQL was used to query the publication title or keywords for the terms "%science 2.0%" OR "%open scien%" OR "%open scholar%" OR "%open research%" where % is a wildcard for zero or more characters. This query was constructed to retrieve literature specifically relating to open science in the context of research and scholarship to produce a relevant seed set from which an expanded set of papers more broadly relating to open science would be retrieved. The core publication set's titles and keywords were scanned for false positives, resulting in no obvious hits.

2.2. Identification of open science-related keywords for the core publication set

The core publication set contained 7,349 distinct keywords. 1,544 occurred at least 20 times and were manually coded for their relevance to open science. Three co-authors coded the 50 most assigned keywords together for coder training. The remaining keywords were coded by two of the co-authors independently, achieving an inter-coder reliability of 94.11% with 1,453 agreements (1,367 non-relevant keywords and 86 relevant keywords) and 91 disagreements. The disagreements were resolved by three co-authors, resulting in 27 additional relevant keywords. The 86 relevant keywords were revisited by three authors, and 20 were re-classified as non-relevant. This process resulted in a set of 93 open science-related keywords. The 93 keywords were distinctly categorized by two co-authors into ten categories obtained from the second level of the open science taxonomy by Da Silveira et al. (2023): 1. open access, 2. open data, 3. open reproducible research, 4. open and responsible evaluation of science, 5. policy, declarations and guidelines of open science, 6. open education, 7. open innovation, 8. open science infrastructure and tools, 9. citizen science, open and participative, and 10. open dialogue with other knowledge systems. An eleventh category, 11. open science drivers was added by the authors to capture issues (e.g., the reproducibility crisis) or events (e.g., the COVID-19 pandemic) perceived as catalysts to the open science movement. As taxonomy categories are interpretable, they were discussed between the three co-authors to reach a consensus on a single category per keyword. Only the category policy, declarations and guidelines of open science were not coded to any keywords.

2.3. Expanding the core publication set

We further collected 62,732 publications from the KB database that cited or were cited by at least one publication of the core list. We retained only 7,181 publications with at least one of the 93 open science-related keywords identified in the core publication set. This approach allowed us to keep only relevant literature and to sort out references or citations not directly related to open science.

2.4. Clustering

We created seven distinct networks using every combination of three citation-based approaches (direct citation (dc), co-citation (cc), and bibliographic coupling (bc)) and identified clusters using the Louvain community detection algorithm (Blondel et al., 2008).

We selected the network with the highest product of the three values: 1) the Gini coefficient of the distribution of themes across clusters, 2) the Gini coefficient of the distribution of clusters across themes, and 3) the number of publications in the network. Scores ranged from 3902.09 for the co-citation network to 5613.75 for the combined co-citation and direct citation network. We thus selected the latter (cc-dc) for the analysis, which contained 6,960 papers. We manually labelled the network by looking at the top journals, keywords, themes, and papers.

3. Results

3.1. Clusters description

Table 1 shows the number of included documents, the top journals, and the top keywords for each cluster. Figure 1 shows the publication network produced with Gephi using the force atlas 2 algorithm, with the nodes' colour representing their cluster. Our network consists of 11 clusters. The *open data* cluster is related to all open science data aspects and spans 1,254 publications, making it the largest cluster. The second largest is the *psychology-replication* cluster, which focuses on research replicability, the replication crisis, the preregistration of research plans, and publication bias. The third-largest cluster, *tech and industry*, focuses on the Internet of Things, blockchain, or Industry 4.0 and its security and digitalization. Concerning the non-scholarly body of stakeholders contributing to the academic system, the *participatory research* cluster refers to societal-related open science research. The *scholarly communication* cluster possesses a wide range of keywords: open access, scholarly communication, peer review, COVID-19, and altmetrics which are all (sub-)topics in the field of science of science prominent in recent years. A closer look at the journals supports this interpretation, as they are situated in scholarly communication and quantitative science studies. Linking reproducibility to a specific field, the *neuroscience-reproducibility* cluster addresses open science research in the medical context with 586 publications. Further looking at organizational structures of society in terms of diversity, misinformation, sexual assault, and social justice in open science, the *social justice and diversity* cluster refers to this in a decentralized manner within the network. The *public health-COVID-19* cluster is strongly influenced by the pandemic as a driver for open science. COVID-19 case monitoring, electronic health records, and social distancing dominate this cluster. Open science literature in the *bio-data* cluster with its sars-cov-2 keyword also relates to the pandemic. However, this cluster is not solely devoted to the pandemic but is also linked to open data. The *publication bias/meta-research* cluster is relatively small and focuses on publication bias, meta-analysis, and systematic reviews. With 142 publications, the *eating disorder-COVID-19 cluster* constitutes the smallest cluster in our network, entirely focusing on eating disorder(s).

The publication network and the concrete distribution of the 11 clusters displayed in Figure 1 reveal a dense, interconnected publication core with defined topical areas. The *open data* cluster is overlayed by many other research areas. The *psychology-replication* cluster is one of the most defined clusters, indicating how it receives concerted attention in the literature as a topic but also has a relationship to the *open data*, *publication bias/meta-research*, and *tech and industry* clusters. The *scholarly communication* cluster is connected to a range of clusters, mainly those focused on open data and society. Notably, publications from the *social justice and diversity* cluster are located throughout the network, showing how the topic possesses a wide bandwidth of connections to the topics of other clusters. Clusters *publication bias/meta-research*, *psychology-replication*, and *neuroscience-reproducibility* are closely connected. The *participatory research* cluster is also found among this grouping, indicating that it is frequently discussed in the context of replication. The *bio-data* and *tech and industry* clusters are interconnected, demonstrating the linkages between data and industry.

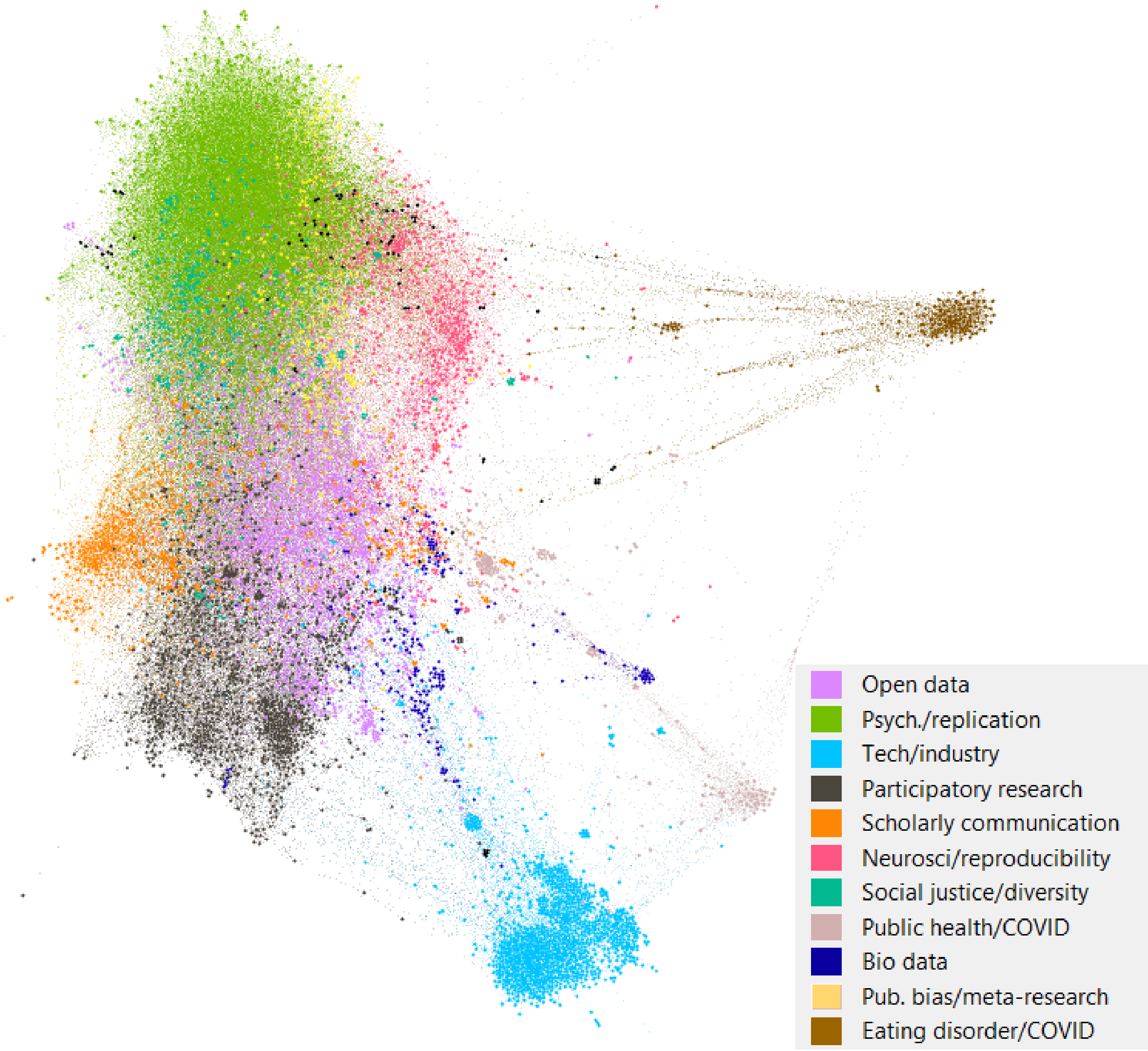
Furthermore, the *bio-data* cluster is connected with the *open data* cluster. It may be understood as a specialized extension of it, which also links the core open science literature with the *public health-COVID-19* cluster.

Interestingly, clusters *tech and industry*, *bio-data*, *public health-COVID-19*, and *eating disorder-COVID-19*, distinctly isolated from the larger cluster, are research areas not specifically focused on open science as an object of study. Overall, while the identified clusters tend to have clear disciplinary or topical foci, none have a monopoly on specific open science topics. They show a range of topic combinations emerging in the literature.

Table 1. Cluster overview with their number of publications and central journals and keywords.

Cluster (abbreviated)	**N pubs**	**Top journals**	**Top keywords**
Open data	1254	Ecosphere; Environmental modelling & software; Government information quarterly; Journal of empirical research on human research ethics	data sharing; open science; open data; reproducibility; data reuse
Psych./replication	1150	Advances in methods and practices in psychological science; Perspectives on psychological science; Psychological methods; Psychological science; Royal society open science	replication; publication bias; preregistration; replicability; replication crisis
Tech/industry	1134	Ieee access; Ieee communications surveys and tutorials; Ieee internet of things journal; Journal of industrial information integration; Sensors	industry 4.0; industry 4; internet of things; blockchain; security
Participatory research	1118	Biological conservation; Journal of technology transfer; Public understanding of science; Research policy; Sustainability	citizen science; open innovation; crowdsourcing; public engagement; intellectual property
Scholarly communication	613	Journal of academic librarianship; Journal of informetrics; Learned publishing; Profesional de la informacion; Scientometrics	open access; scholarly communication; peer review; covid-19; altmetrics
Neurosci/ reproducibility	586	Frontiers in neuroinformatics; Frontiers in neuroscience; Human brain mapping; Neuroimage; Neuroinformatics	fmri; neuroimaging; mri; reproducibility; reliability
Social justice/diversity	337	Digital journalism; Journal of communication; Proceedings of the national academy of sciences of the united states of america; Psychology of women quarterly; School psychology	diversity; misinformation; sexual assault; social justice; open science
Public health/COVID	241	Frontiers in medicine; Frontiers in public health; Journal of the american medical informatics association; Omics-a journal of integrative biology	covid-19; contact tracing; sars-cov-2; electronic health records; social distancing
Bio data	197	Agricultural systems; International journal of digital earth; Iucrj; Journal of proteome research; Metabolites; Proteomics	mass spectrometry; metabolomics; sars-cov-2; proteomics; data integration
Pub. bias/ meta-research	188	International review of sport and exercise psychology; Journal of clinical epidemiology; Musicae scientiae; Systematic reviews	publication bias; meta-analysis; funnel plot; adverse events; systematic reviews
Eating disorder/ COVID	142	Appetite; European eating disorders review; European journal of psychotraumatology; International journal of eating disorders; Journal of eating disorders	eating disorders; covid-19; anorexia nervosa; eating disorder; mental health

Figure 1. Publication network (n = 6,960).

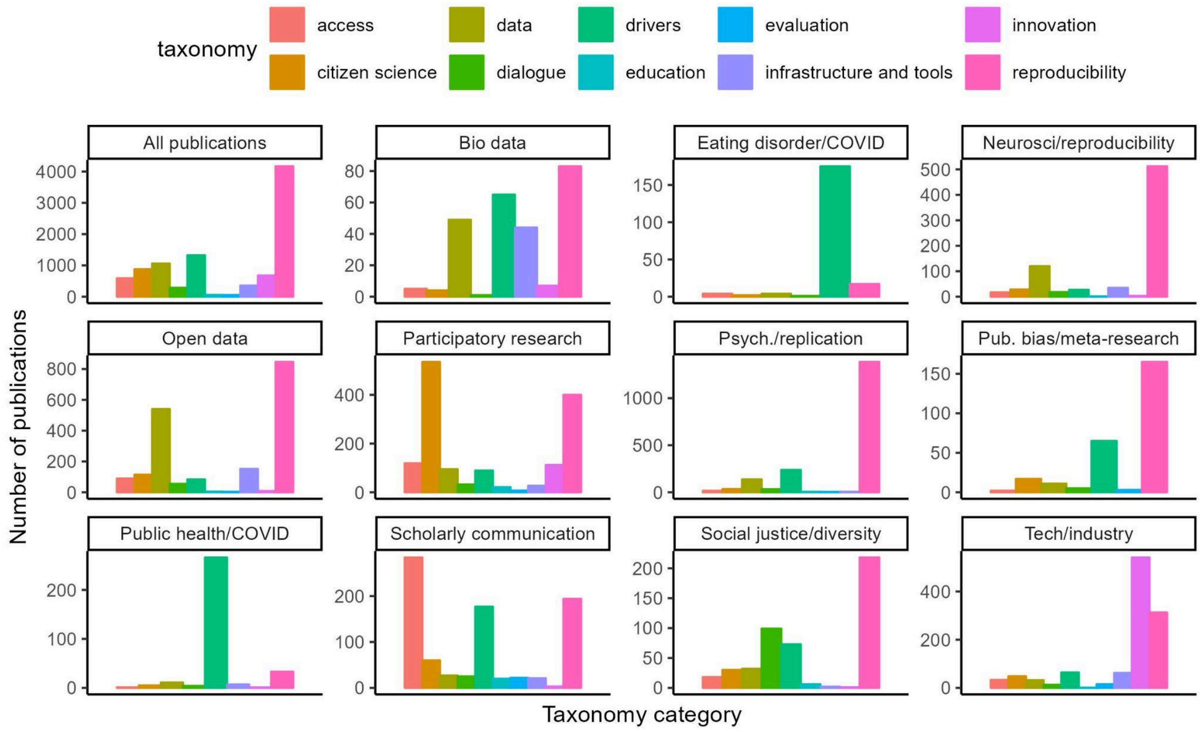


3.2. Open science themes distribution overall and across clusters

Using the second level of Da Silveira et al.'s (2023) open science taxonomy, the keyword distributions across abbreviated taxonomy categories for each cluster are shown in Figure 2.

Several taxonomy categories are represented through the coded keywords within the majority of clusters. Reproducibility occurs in the highest frequency across many clusters. Taxonomy categorization closely aligns with cluster labels and keywords. The *participatory research* cluster, for example, is defined by its keywords coded to the citizen science, open and participative taxonomy category. Similarly, the scholarly communication cluster overtly references the open access taxonomy category.

Figure 2. Keyword distribution across taxonomy categories for each cluster.



3.3. Open science theme frequency over time

Figure 3. Publication number by taxonomy category and year (2000 – 10-2023).

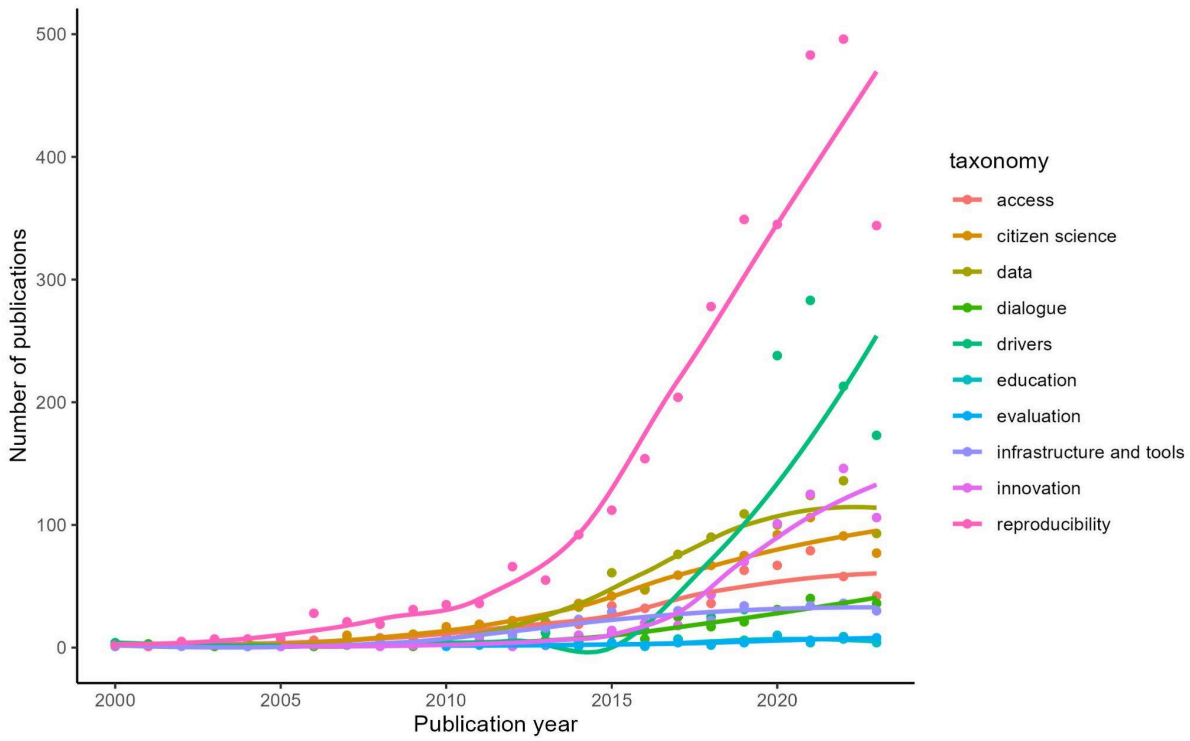
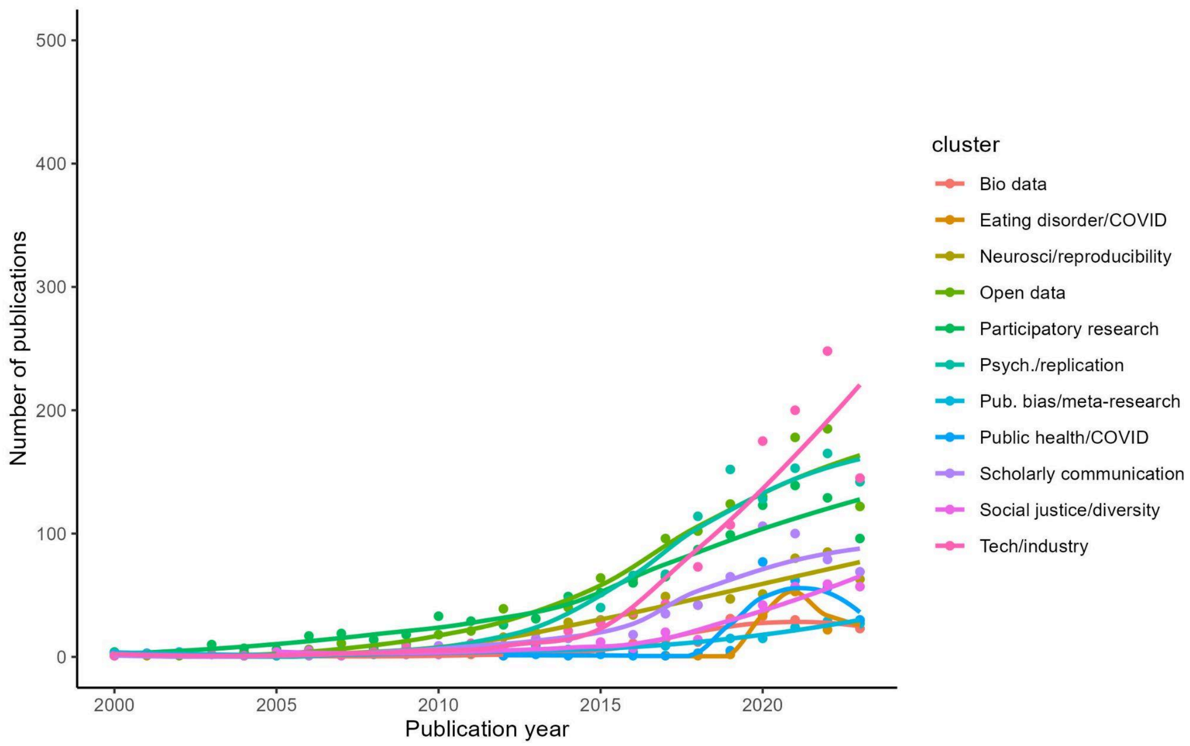


Figure 3 displays the number of publications for each abbreviated taxonomy category over the past two decades. It is apparent that reproducibility, a core tenet of science, has remained and grown consistently as a priority of open science. Open science drivers, as expected, rose substantially after 2019; COVID-19 related terms were associated with this category. Innovation similarly saw a significant boost starting in 2015 and became the second most frequent taxonomy category in the set.

3.4. Cluster size over time

Figure 4 shows the *tech and industry* cluster with the strongest increase in growth, which is a cluster that is rather isolated in the network (Figure 2). Likewise, the *open data, psychology-replication*, and *participatory research* clusters substantially rise after 2015. Similar to the taxonomy representation (Figure 3), the impact of COVID-19 after 2020 is apparent in the peaks of the *eating disorder-COVID-19* cluster and the *public health-COVID-19* cluster. Though it has fewer publications, there exists a stronger rise in the *social justice and diversity* cluster within the last years.

Figure 4. Publication number by cluster and year (2000 – 10-2023).



4. Discussion and conclusion

Our study maps scholarly literature on open science and derives 11 clusters based on 6,960 publications. The network shows a dense, interconnected publication core with defined topical clusters and four rather isolated clusters. *Open data*, *psychology-replication*, *tech and industry*, and *participatory research* possess the most publications. Interestingly, open access, mostly located in the *scholarly communication* cluster, is not a standalone cluster compared to previous studies (Lee & Chung, 2022; Shmagun et al., 2020) or dominates publications' scope (Lasser et al., 2022). Our map reveals both thematically broad and topically narrow clusters, indicating that some aspects of open science are both areas of concerted study and woven into the broader literature. Nearly all clusters exhibit an upward trend, demonstrating research growing concurrent to the open science movement.

4.1. Limitations

Our search query was focused on research and scholarship relating to open science; cited and citing articles were used to capture a broader literature set to offset this limitation. Further stages of this project will aim to use the OpenAlex database to make the process of information searching and retrieval more open. Our use of the Da Silviera et al. (2023) open science taxonomy also constrains our conceptualization of the topic. Co-authors engaged in extensive discussion to reach consensus during the coding process and supplemented existing categories with a new one (open science drivers). Furthermore, cluster algorithms have different strengths and weaknesses, depending on their purpose and the data used. The Louvain algorithm, as a general-purpose algorithm, might need further research in terms of its functionality for bibliometric topic reconstruction (Held, 2022).

4.2. Future research and outlook

We will use the topics that emerged during clustering to further develop our analyses. We will investigate the actors involved in conversations about specific topics, how literature on open science evolved before and after the onset of the COVID-19 pandemic, and how open the literature on open science is itself.

The results presented in this research-in-progress paper can help the scholarly community calibrate their research efforts in a dynamic and multifaceted area, better navigate the field to understand its topical landscape, and perhaps influence or chart a course for the trajectory of future scientific discourse related to open science. The dominance or absence of a topic could also be relevant for shaping policies and management decisions.

Open science practices

The R scripts produced for this analysis will be made available on Zenodo. The authors also intend to publish the final article in a fully open access venue so that it may reach as wide an audience as possible.

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Author contributions

I. D. Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing—original draft, Writing—review & editing.

M. H. Data curation, Formal analysis, Investigation, Methodology, Validation, Writing—original draft, Writing—review & editing.

P. M. Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing—original draft, Writing—review & editing.

I. P. Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing—review & editing.

Competing interests
The authors have no conflicts of interest to declare.

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