

Exploring the Current State and Research Trends of the Reproducibility Crisis: A Bibliometric Analysis

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Abstract: This paper explores the current state and research trends of the reproducibility crisis through a bibliometric analysis using data from Web of Science. The reproducibility crisis has been a major challenge in contemporary science since 2010, and it poses a threat to the credibility of experiments and the academic authority of papers. The paper provides a historical context of the crisis, identifies the research hotspots and trends of the articles about this crisis at various stages, hoping to offer a foundation for further research on the reproducibility crisis. The study found that the number of articles published on the reproducibility crisis has been increasing year by year, indicating an increase in research intensity and attention from the academic community. The paper suggests that bibliometric analysis can be a useful tool for comprehending the progression of the reproducibility crisis and identifying research hotspots and trends. Finally, the paper recommends that institutional constructs and a register of responsible research practices should be established to improve reproducibility in scientific research.

1. Introduction

Scientific research plays a vital role in exploring the unknown and sharing academic knowledge. It is crucial to ensure that the research methods recorded are reliable, and the research results are reproducible, as they are essential in recording and validating scientific findings. Reproducibility is a crucial criterion that distinguishes science from non-science[1]. However, in the 21st century, the research community has witnessed a concerning trend: the findings of some research papers are not reproducible. This lack of reproducibility has led to a crisis in the academic community. The issue first arose in the field of psychology when Daryl J. Bem claimed the existence of extrasensory perception in 2011, suggesting that people could peer into the future a short time ago[2]. However, many scholars were unable to replicate his experiments, and this sparked a wave of concern regarding the reproducibility of research. To address this issue, the Open Science Collaboration conducted a 'Reproducibility Project' in 2015, involving over a hundred scientists, which showed that only 36% of the results could be significantly replicated[3]. This project validated the existence of the reproducibility crisis in the field of psychology and sparked further concerns about the reproducibility of research across all scientific disciplines.

The reproducibility crisis constitutes a major challenge for contemporary science since 2010, shaking the credibility of experiments and seriously threatening the academic authority of papers. In

addition to obtaining erroneous scientific conclusions, the reproducibility crisis is a significant challenge in contemporary science since 2010, posing a threat to the credibility of experiments and seriously jeopardizing the academic authority of papers. In addition to producing erroneous scientific conclusions, the referencing of irreproducible conclusions generated through falsification by future generations can cause a series of serious academic harms such as the dissemination of false information and the waste of academic resources. This is particularly critical in the post-epidemic era, where irreproducible conclusions may cause irreparable harm if applied to the treatment of an epidemic or patient care. To improve reproducibility, in January 2017, Marcus R. Munafò et al. co-authored a 'Declaration on Reproducibility' in *Nature Human Behaviour*[4]. The Declaration identified a series of institutional constructs that could be used to improve reproducibility. In the same year, The World Conferences on Research Integrity Foundation's implementation agenda suggested that a 'register of responsible research practices' should be established[5]. As a result, over 300 journals have implemented the Register publication format, either as a regular submission option or as part of a single special issue, thereby addressing the reproducibility crisis[6].

This paper provides a bibliometric and visual analysis of the literature on the reproducibility crisis in Web of Science. Using VOSviewer software, we examine the evolution of the reproducibility crisis by analyzing the temporal changes in the number of publications, authors, institutions, disciplines, and journals. Our goal is to assist scholars in comprehending the progression of the reproducibility crisis, identifying the research hotspots and trends of the crisis at various stages, and providing a foundation for further research on the reproducibility crisis.

2. Review of Reproducibility Crisis Research

We can identify three levels of research: firstly, investigations into the existence of the crisis; secondly, analyses and explorations of the causes that lead to the crisis; and thirdly, explorations and findings on the measures to address the crisis.

Initially, the existence of a reproducibility crisis was a topic of debate in academic circles. The crisis began when Daryl J. Bem proposed the phenomenon of extrasensory perception in his article 'Feeling the future: experimental evidence for anomalous retroactive influences on cognition and affect.' [2] However, after the article was published, many scientists were unable to identify the phenomenon. In 2014, a multi-laboratory project replicated 13 classic experiments in psychology, 10 of which were consistent with the effects of the original experiments, providing strong evidence in defense of the reproducibility of psychological experiments [7]. However, a year later, a larger study produced results that were diametrically opposed to these experiments. The Open Science Collaboration replicated 100 experiments from top three experimental psychology journals in 2008, involving over a hundred scientists and various statistical methods. Their findings show that only 36% of the results could be significantly replicated [3]. In 2016, Gilbert challenged the project's conclusions, pointing out methodological problems [8]. In response, Anderson et al. rebutted Gilbert's challenge and acknowledged OSC's shortcomings [9]. These debates led to the term "Reproducibility Crisis" [10] and sparked interest in studying the issue in academia.

Currently, the identification of the causes of the reproducibility crisis is also underway. The reproducibility crisis is attributed to the conflict between researchers' need to publish and the publication bias of journals. Researchers' selective reporting due to pressure to publish is a major factor contributing to irreproducibility [11]. Journals favor statistically significant and novel results over negative results or replication studies, leading to a large number of studies being left unpublished [12].

Researchers are actively searching for ways to address the reproducibility crisis. One influential proposal is Christopher D. Chambers' idea of pre-registration, published in *Cortex* in 2013 [13]. The

TOP Committee published guidelines on implementing pre-registration in 2014[14], which were followed by the publication of the world's first pre-registration paper in Cortex in 2015[15]. Munafò and other prominent scientists and editors endorsed pre-registration as an important tool for ensuring reproducible science in 2017, and the concept of a "register of responsible research practices" was proposed in 2017[4]. Nosek et al. used the term "pre-registration revolution" in 2018, and since then, pre-registration has become a major institutional construct for addressing the reproducibility crisis[16]. As of May 15, 2019, 191 journals worldwide had published papers using pre-registration[6].

In addition, scholars are actively exploring other approaches to implementation from different perspectives. Open Science is an influential way forward for addressing the reproducibility crisis. The Transparency and Openness Promotion (TOP) guidelines provide a framework consisting of four criteria, ranging from superficial to deep [14]. The Peer Reviewed Open Initiative has further divided these criteria into ones that need to be reviewed by journals [17]. Additionally, open science hubs and open science framework platforms created by Nosek and others facilitate global collaborations among researchers, enabling large-scale replications to take place. The preprint system, starting from the traditional peer review mechanism, realizes the sharing of research results before formal publication [18]. The TOP factors, starting from the journal evaluation indicators, enrich the journal evaluation system and promote the quality improvement of journals in transparency and openness [19]. Concrete solutions from the discipline of psychology have improved psychological research methods to some extent, partially addressing the reproducibility crisis [20-23].

3. Study Design

3.1. Data Sources and Processing

This article uses data from the Web of Science Core Collection. The search query was "(ALL=(reproducibility crisis)) OR ALL=(replicability crisis)", with a collection time frame of "1991-01-01 to present", and the search was conducted on November 16, 2022. Each article's title and abstract were manually reviewed to remove irrelevant literature that was not related to the "reproducibility crisis". A total of 720 results were obtained, and their bibliographic information was imported into VOSviewer software for analysis.

3.2. Research Methodology

This study utilized EXCEL, Web of Science platform visualization functions, and VOSviewer software as analysis tools, and employed bibliometrics as a research method. Bibliometrics is a research method that integrates mathematics, statistics, and library science, and conducts critical evaluation through quantitative and qualitative analysis. It can be used to assess the quality of research, analyze key research areas, and predict future research directions [24]. VOSviewer is a bibliometric analysis software used for creating knowledge maps. It was jointly developed by Professor Nees Jan van Eck and Professor Ludo Waltman from Leiden University in the Netherlands. Using mathematical and statistical methods, VOSviewer analyzes bibliographic information such as titles, subject terms, keywords, and authors to create knowledge maps for various fields [25].

This article used Excel and the visualization function of the Web of Science platform to conduct statistical analysis of the year of publication and its statistical relationships. Additionally, the distribution of authors, institutions, disciplines, and journals was analyzed. VOSviewer software was also used to create visualizations of co-citations, author collaboration networks, and research hotspots.

4. Data Analysis

4.1. Characteristics of Temporal Changes in the Volume of Articles Issued

When analyzing the development process of a research field using bibliometric methods, statistical analysis of the annual publication volume of relevant papers based on the growth and aging rules of scientific literature can reveal the current development status and predict the research prospects and trends. This paper used the Web of Science Core Collection as the data source and retrieved 720 papers between January 1, 1991 and November 16, 2022, which were statistically analyzed and plotted in Figure 1. In Figure 1, the blue bars represent the number of papers published each year, the orange solid line represents the cumulative number of papers published, and the orange dashed line represents the fitting of the cumulative number of papers published.

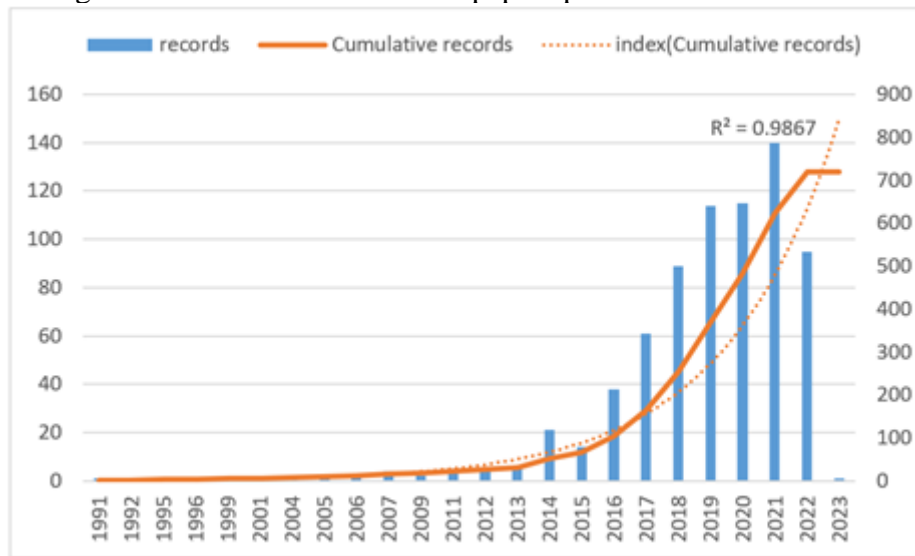


Figure 1: Diagram of the chronological distribution of the Reproducibility Crisis research papers.

The horizontal axis represents the chronological changes in units of years, while the numerical values on the left vertical axis represent the number of articles published each year, corresponding to the blue bar graph. The numerical values on the right vertical axis represent the cumulative number of published articles, corresponding to the orange curve.

It can be seen from the chart that the overall number of papers on the reproducibility crisis is on the rise and can be roughly divided into two stages. The first stage (1991-2010): during this stage, the number of papers was sporadically distributed and did not form a scale. The number of papers was very limited and there was no obvious upward trend. As mentioned earlier, the reproducibility crisis was triggered by Daryl J. Bem's work on extrasensory perception in 2011. This indicates that prior to this, some scholars had already perceived the existence of the reproducibility crisis and conducted some research, laying a foundation for its development.

The second stage (2011-): during this stage, the number of papers showed a linear upward trend and grew rapidly, reaching 369 papers from 2019 to 2021, accounting for 51.25% of the total, with 140 papers published in 2021 alone, accounting for 19.44% of the total. This indicates that the reproducibility crisis has been increasingly valued since 2011, and the growth rate of paper publications has been fast, making it a research hotspot at the time and widely discussed and studied, with many research achievements obtained. To determine the distribution characteristics of the growth of paper publications, the year cumulative distribution of papers between 1991 and 2023 was fitted with a curve, and the orange dashed line result was obtained. The results showed that the fitting

degree of the exponential curve was high, with an r^2 value of 0.9867, indicating that the number of papers in the reproducibility crisis field showed exponential growth, further demonstrating the trend of exponential growth in the total number of papers. Since the search cutoff date has not fully counted the papers published in 2022, the data for 2022 in the chart is significantly less than the number of papers published in 2021, but this is not the basis for our trend judgment.

4.2. Distribution of Posting Authors

Table 1 illustrates the number of articles published by each author, revealing a relatively consistent publication output among different scholars. Eric-Jan Wagenmakers from the University of Amsterdam published the highest number of articles (6).

The study of the reproducibility crisis has received attention from researchers in the United States and various European countries. The widespread attention given to the reproducibility crisis by scholars around the world underscores the importance of this issue.

Table 1: Distribution of high-yield authors of reproducible crisis studies

Rank	Author	Records	Nationality	Institution
1	Wagenmakers EJ	6	Netherlands	University of Amsterdam
2	Krueger RF	5	America	State University of New York (SUNY) Stony Brook
2	Richter SH	5	Germany	University of Munster
2	Saltelli A	5	Norway	University of Bergen
5	Aguinis H	4	America	George Washington University
5	Bickel DR	4	America	University of North Carolina
5	Forbes MK	4	Australia	Macquarie University
5	Ioannidis JPA	4	America	Stanford University
5	Makel MC	4	America	Johns Hopkins University
5	Markon KE	4	America	University of Iowa
5	Romero F	4	Spain	University of Groningen
5	Ropovik I	4	Czech Republic	Charles University Prague
5	Ulrich R	4	Germany	Eberhard Karls University of Tubingen
5	Van Ravenzwaaij D	4	Netherlands	University of Groningen
5	Vazire S	4	Australia	University of Melbourne
5	Wright AGC	4	America	Pennsylvania Commonwealth System of Higher Education (PCSHE)
5	Wurzel H	4	Switzerland	University of Bern

The co-citation graph of the literature (Figure 2) depicts three authors with a significant impact. The first is Ioannidis, John P. A., whose primary research focus lies in the reproducible crisis research in the clinical and life sciences, as well as in assessing the recruitment, promotion, and tenure of scientists. The second is Nosek, Brian A., who has evaluated the reproducibility of research across various disciplines and has played a key role in proposing the widely-recognized pre-registration and preprint system, which offers an effective solution to the reproducibility crisis. The third is Wagenmakers, Eric-Jan, who has provided various methods to address the reproducibility crisis, particularly in the fields of experimental psychology and psychological sciences.

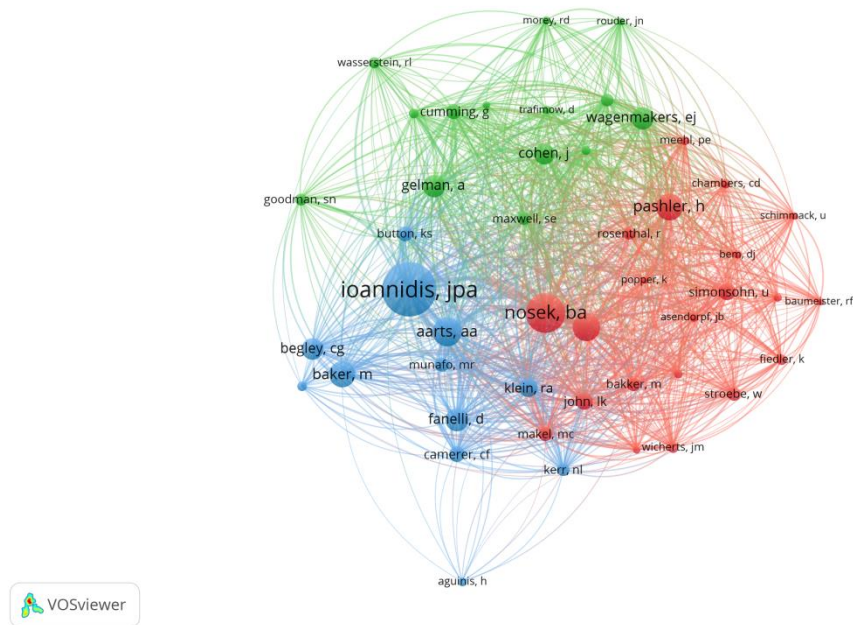


Figure 2: Reproducibility crisis study authors co-cited

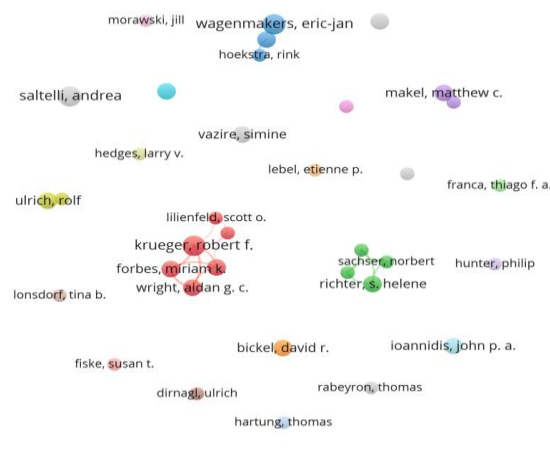


Figure 3: Reproducibility crisis study author collaboration network

In collaborative network analysis, Figure 3 illustrates that the reproducibility crisis study had both independent authors and author collaborations. Krueger, RF, who specializes in reproducibility crisis research in personality psychology and personality disorder, has the largest number of collaborative circles. On the other hand, the research circle centred on van Ravenzwaaij, Don, focuses more on methods to address the reproducibility crisis. Notably, research circles in this area tend to be concentrated in the same country/region, indicating that reproducibility research has a stable core group of authors. Highly prolific authors mostly have their own collaborative circles. Overall, reproducibility crisis research shows a stable and positive research trend.

4.3. Distribution of Issuing Institutions

In terms of institutional publications, the top 15 institutions (Table 2) include 14 higher education institutions and one research institute. Regarding institutional distribution by region, the United States

holds seven of the top 15 positions, with three in the top five. The United Kingdom, the Netherlands, and France each have two positions, while Canada and Germany have one each.

Regarding the number of articles published by institutions, the UNIVERSITY OF CALIFORNIA SYSTEM ranks first with 49 articles, about 1.5 times the number of articles published by the second-ranked UNIVERSITY OF LONDON, indicating the former's leading position in this area. The second largest non-US institution, with 30 articles, also contributes significantly to research on the reproducibility crisis. US higher education institutions are overwhelmingly involved and influential, contributing 317 papers, accounting for 44% of the total. Meanwhile, Germany, the UK, and the Netherlands contribute 116, 94, and 67 papers, respectively, also significantly higher than other countries, indicating a dominant "one over many" research situation.

Table 2: Ranking of high yielding institutions for reproducible crisis research

Rank	Institution	Nationality	Records	Percentage
1	university of california system	America	49	6.806
2	university of london	England	30	4.167
3	harvard university	America	23	3.194
4	stanford university	America	20	2.778
5	university of amsterdam	Netherlands	20	2.778
6	university of toronto	Canada	19	2.639
7	udice french research universities	France	17	2.361
8	university of groningen	Netherlands	15	2.083
9	university of oxford	England	15	2.083
10	state university system of florida	America	14	1.944
11	university of minnesota system	America	14	1.944
12	university of minnesota twin cities	America	14	1.944
13	centre national de la recherche scientifique cnrs	France	13	1.806
14	northwestern university	America	13	1.806
15	humboldt university of berlin	Germany	12	1.667

4.4. Distribution of Issuing Disciplines

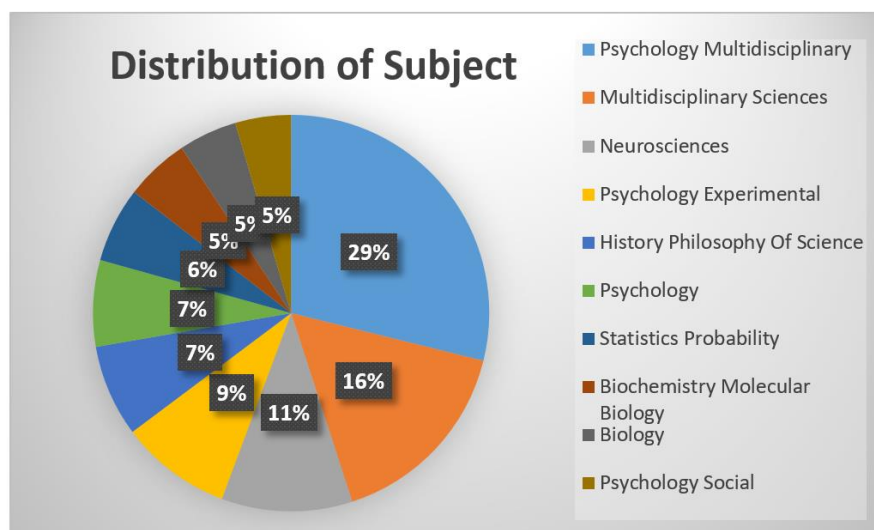


Figure 4: Distribution of major disciplines in reproducibility crisis research

Reproducibility crises, as a pervasive phenomenon in scientific research, have been observed to spread from psychology to other disciplines. As shown in Figure 4, the field of Psychology Multidisciplinary has the most discussions on reproducibility crises, accounting for approximately 29% of the total number of articles published, thus dominating the field of reproducibility crisis research. This may be attributed to the experimental nature of psychology, where dubious research practices and over-reliance on null hypothesis testing in psychological experimental research practice can be a major cause of reproducibility crises. Following Psychology Multidisciplinary, Multidisciplinary Sciences accounts for about 16% of the total. In addition, Biochemistry Molecular Biology, which is the main discipline of Biology, is also a discipline where the reproducibility crisis is widespread, particularly in Neurosciences, which accounts for 11% of the total Science articles. This suggests that the reproducibility crisis has spread to numerous disciplines.

4.5. Distribution of Published Journals

Table 3: Distribution of major journals for reproducibility crisis studies

Publication Title	Category	Records	Percentage	IF (2021)
Frontiers In Psychology	Psychology, Multidisciplinary - SSCI	23	3.194	4.232
Perspectives On Psychological Science	Psychology, Multidisciplinary - SSCI	21	2.917	11.621
Plos One	Multidisciplinary Sciences - SCIE	19	2.639	3.752
Royal Society Open Science	Multidisciplinary Sciences - SCIE	13	1.806	3.653
Review Of General Psychology	Psychology, Multidisciplinary - SSCI	10	1.389	4.615
Scientific Reports	Multidisciplinary Sciences - SCIE	9	1.25	4.997
European Journal For Philosophy Of Science	History & Philosophy Of Science - AHCI	8	1.111	1.602
Behavior Research Methods	Psychology, Experimental - Ssci & Psychology, Mathematical - SSCI	7	0.972	5.953
Advances In Methods And Practices In Psychological Science	Psychology, Multidisciplinary - SSCI	6	0.833	15.817
Psychological Methods	Psychology, Multidisciplinary - SSCI	6	0.833	10.929

The distribution of publications on the Reproducibility Crisis (Table 3) is generally consistent with the disciplinary distribution, focusing on the three main disciplines of Psychology, Multidisciplinary Sciences, and History & Philosophy of Science.

Within the discipline of Psychology, the top two publications are Frontiers in Psychology and Perspectives on Psychological Science, both classified under Psychology, Multidisciplinary, with 23 and 21 articles, respectively, and impact factors of 4.232 and 11.621, both in the Q1 division. The highest impact factor for journals with articles on reproducibility crises in this discipline is Advances in methods and practices in psychological science, with an impact factor of 15.817, but the number of related articles is low, with only six. The impact factors of related journals under the Psychological theme, namely 4.232, 11.621, 4.615, 5.953, 15.817, and 10.929, are all high, indicating that the reproducibility crisis has received considerable attention within the Psychological discipline.

Within the Multidisciplinary Sciences branch, three journals, namely Plos One, Royal Society Open Science, and Scientific Reports, are among the top ten in terms of the number of publications, with impact factors of 3.752, 3.653, and 4.997, respectively, in the same Q2 sub-region, indicating

that the reproducibility crisis has an impact across several disciplines.

Within the discipline of History & Philosophy Of Science, The European Journal For Philosophy Of Science is the only journal in the top ten in terms of the number of articles published, with eight articles and an impact factor of 1.62, ranking it 12/62 in the field, in the Q1 division. This journal focuses on the communication dimensions of reproducibility crises and the limits of reproducibility, providing philosophical reflections on the study of reproducibility crises.

4.6. Analysis of Research Hotspots

Eight clusters were generated through cluster analysis of 172 high-frequency keywords with word frequencies ≥ 5 in the literature search results, representing the themes of reproducibility crisis research (see Figure 5 and Table 4).

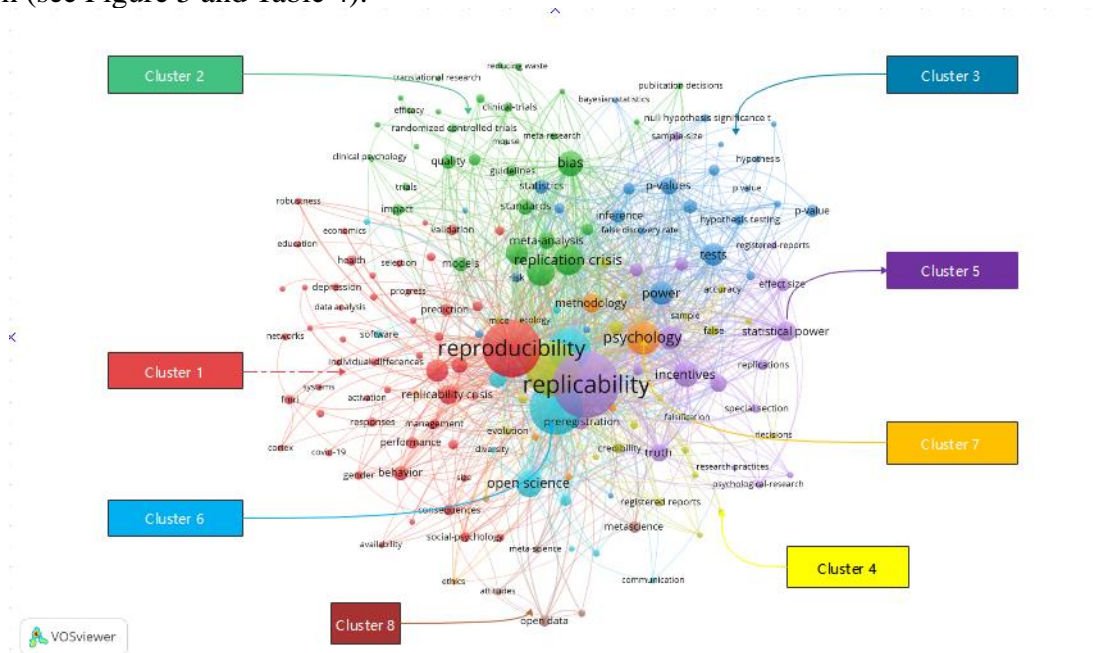


Figure 5: Reproducibility crisis research keyword topic clustering

Under the eight clusters, specific research themes can be identified based on the high-centrality keywords (refer to Table 4). In the 'Reproducibility' cluster, the focus is on reproducibility, reliability, and availability of data. The exploration of factors contributing to the reproducibility crisis includes strong publication bias and selective publication of journals. In the 'Statistics' cluster, researchers aim to mitigate the reproducibility crisis by optimizing statistical methods and applications, with a focus on Bayesian statistics, hypothesis testing, and p-values. In the 'Replication and Credibility' cluster, researchers propose improvements such as pre-registration, p-value adjustment, and researcher incentives to reduce or even solve the reproducibility crisis. The clusters 'Open Science and Crisis' and 'Open Data and Meta-Science' are a continuation of the 'Ways to address the repeatability crisis', where scholars expect to create open science centers and open science framework platforms to address the crisis. The 'Methodology in Psychology' cluster is a single-disciplinary study of Psychology, which is an important element in the study of the reproducibility crisis.

The heat map in Figure 6 reflects the research intensity of the keywords, with darker colors indicating higher research intensity and lighter colors indicating lower research intensity. In the field of reproducibility crisis research, topics such as publication bias towards journals, researcher incentive systems, statistical methods, and p-value limits have become hot topics of research, with a focus on the main disciplines of psychology, methodology, ecology, and open science/meta-science.

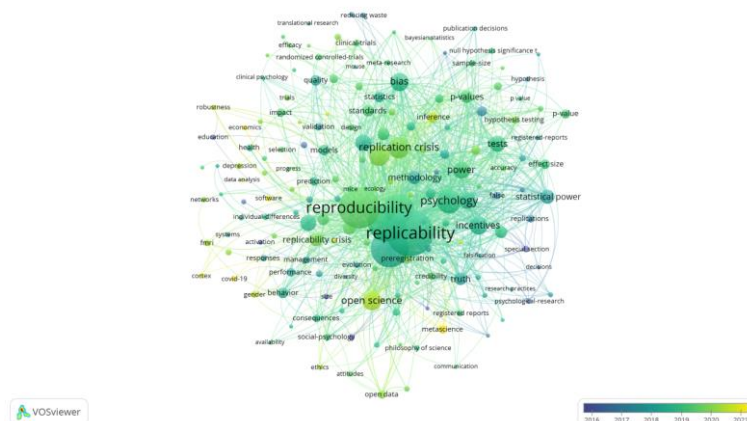


Figure 7: Reproducibility crisis keyword temporal migration

5. Conclusion

This paper employs a bibliometric approach to analyze 720 reproducible crisis papers in the Web of Science core database, using VOS software to examine posting chronological changes, posting authors, posting institutions, posting disciplines, posting journals, and research hotspots. The study reveals several key findings.

Firstly, the number of articles published on the reproducibility crisis has been increasing year by year, indicating a growing research intensity. This trend may be related to the increased number of papers published worldwide and the increased attention from the academic community towards the reproducibility crisis phenomenon and related research.

Secondly, the study identifies a stable collaborative group of researchers on the reproducibility crisis, with Wagenmakers, Eric-Jan of the University of Amsterdam, Krueger RF of the State University of New York (SUNY) Stony Brook as the main authors. These researchers, mostly based in the US and Europe, have formed several research groups with Krueger, RF, van Ravenzwaaij, Don, and others as their cores.

Thirdly, the University of California system is the most active publishing institution in the field of reproducible crisis research, with the United States dominating in the number of publications, institutions, authors, and level of influence. European countries such as Germany, the United Kingdom, and the Netherlands also show outstanding performance. This dominance may be attributed to the scientific and technological strength of these countries and their earlier intervention and wider research span in the field of reproducibility crisis research.

Fourthly, the reproducibility crisis has spread from the field of psychology to other disciplines such as Biochemistry Molecular Biology, Biology, History, and Philosophy of Science, indicating a gradual permeation of the crisis into all fields.

Fifthly, the most published journal in the field of reproducible crisis research is *Frontiers in Psychology*, followed by other journals in the Q1 division with high impact factors. *Advances in Methods and Practices in Psychological Science* has the highest impact factor, indicating that research on reproducibility crises has received significant attention in the academic community.

Lastly, the research hotspots include Reproducibility, Factors that lead to a repeatability crisis, Statistics, Replication and Credibility, Ways to address the repeatability crisis, Open science and Crisis, Methodology in Psychology, Open data, and Meta-Science. Recent changes in research direction in disciplines closely related to the reproducibility crisis, such as psychology, have also influenced the study of the crisis, as have major social events such as the COVID-19 pandemic.

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