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Expert Recommended Biomedical Journal Articles: Their Retractions or Corrections, and Post-retraction Citing

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Abstract

Faculty Opinions has provided recommendations of important biomedical publications by domain experts (FMs) since 2001. The purpose of this study is two-fold: 1) identify the characteristics of the expert-recommended articles that were subsequently retracted; 2) investigate what happened after retraction. We examined a set of 232 recommended, later retracted or corrected articles. These articles were classified as New Finding (43%), Interesting Hypothesis (16%), etc. More than 71% of the articles acknowledged funding support; the NIH (US) was a top funder (64%). The top reasons for retractions were *Errors* of various types (28%); *Falsification/fabrication* of data, image, or results (20%); *Unreliable* data, image, or results (16%); and *Results* not reproducible (16%). Retractions took from less than two months to almost 14 years. Only 15 % of recommendations were withdrawn either after dissents were made by other FMs or after retractions. Most of the retracted articles continue to be cited post-retraction, especially those published in *Nature, Science,* and *Cell*. Significant positive correlations were observed between post-retraction citations and pre-retraction citations, between post-retraction citations and peak citations, and between post-retraction citations and the post-retraction citing span. A significant negative correlation was also observed between the post-retraction citing span and years taken to reach peak citations. Literature recommendation systems need to update the changing status of the recommended articles in a timely manner; invite the recommending experts to update their recommendations; and provide a personalized mechanism to alert users who have accessed the recommended articles on their subsequent retractions, concerns, or corrections.

1. Introduction

White [1] reports that peer-reviewed publications in science and engineering (S&E) grew about 4% annually from 2008 to 2018. The 2018 publications in the health sciences and the biological & biomedical sciences counted for about 36% of the world's 2,555,959 S&E publications in that year (Table S5A-17). The information explosion has been observed since the mid-20th century. To help scientists and researchers overcome information overload, Faculty Opinions[1] provides a platform for peer-nominated domain experts, named Faculty Members (FMs), to recommend publications of importance in their fields. Currently, more than 8,000 FMs recommend approximately 8,000 publications yearly.

With the rapid growth of biomedical publications, the quality of the published articles has been a serious concern. At a recent conference hosted by the Wellcome Genome Campus, the concern was discussed: "publishing poor-quality studies can (and should) lead to retractions from the literature." [2] In Faculty Opinions, if a recommended article is retracted, the record will have a warning sign: "Since being recommended, this article has been retracted" or an editorial note: "Since being evaluated, an Erratum has been added to this article ....." This set of retracted articles represents a unique phenomenon in that the articles were peer-reviewed before publication and evaluated by the recommending FMs. Retraction of a published biomedical paper can be detrimental because falsified results or errors can mislead the research and medical communities resulting in life-and-death consequences or a domino effect on other papers that cited the retracted paper. Marret et al. [3] demonstrated the susceptibility of systematic reviews and meta-analyses to fraudulent data by analyzing a set of fraudulent publications of a single author. This study will observe the retracted or corrected articles retrieved from Faculty Opinions to address the following questions:

1. Which recommended articles were subsequently retracted or corrected?
2. What are the characteristics of these retracted or corrected articles?
3. Why were the articles retracted or corrected?
4. How did FMs recommend these articles? Did they later withdraw recommendations?
5. To what extent are these articles cited post-retraction?

The phenomenon of a growing number of retractions of publications is a serious problem of the current biomedical literature ecosystem because of the unpredictable impact and waste of resources. Although neither peer reviewers nor FMs could catch all the errors or fraud in the manuscripts/papers they evaluated, a better understanding of the factors contributing to the continued use of the retracted publications is important for information science. The goal of this study is two-fold: 1) identify the characteristics of the expert-recommended articles that were subsequently retracted; 2) investigate these articles' post-retraction situations--if their recommendations were withdrawn and how they were cited.

[1] Formally known as F1000Prime in 2009 after merging F1000 Biology (launched in 2002 by F1000 Ltd) and F1000 Medicine (launched in 2006 also by F1000 Ltd). Faculty Opinions became a rebrand of F1000Prime on April 12, 2020.

2. Literature review

The nature and effect of retractions in biomedical publications have been examined from the perspectives of information science and biomedical research.

2.1. Increase in retraction of biomedical publications

2.1.1. Growing number (percentage). Grieneisen and Zhang [4] retrieved 4,449 retracted scholarly publications (from 1928 to 2011) from Web of Science and found that the percentages of retractions in Medicine, Life Science, and Chemistry were higher than projections based on publications (p. 8). Singh, et al. [5] analyzed 2,343 retracted biomedical articles between 2004 and 2013 to illustrate the time-series data (Table 1); there was a steady increase from 69 to 402 for the ten years. Using these data, we drew a visual plot and the trendline shows a strong linear relationship ($y=41.3636x + 6.8$ and $R^2=0.9596$). At the individual author's level, one author's 172 articles were retracted due to fabricated data [6] and another author's 96 articles were retracted due to research misconduct [7].

2.1.2. Crisis-related topic. When CoViD-19 became a global pandemic, "scientists published well over 100,000 articles about the coronavirus in 2020." [8] Retraction Watch listed 188 retracted CoViD-19 papers and seven papers as Expressions of concern as of 10/30/2021 [9].

2.1.3. Growing rate of retractions. An increased rate of retractions has been reported in medical fields, such as oncology [10] and perioperative medicine [11]. Wager and Williams [12] analyzed data from Medline and found that "the proportion of retractions has increased tenfold from 0.002% in the early 1980s to 0.02% in 2005-2009." (p. 568) Rapani et al. [13] conducted a systematic review of retracted dental publications divided into two five-year periods: retractions increased by 47% in 2014-2018 compared to 2009-2013. Ozair et al. [14] reported a rapid increase in retractions in the field of neurology from 17% in 2010 to 56% in 2016-2020. Gaudino et al. [15] analyzed 5,209 biomedical articles published from January 1923 through July 2020 and retracted from January 1971 through August 2020; they found that the annual rate of retracted articles increased from 1980 to 2015 but decreased after 2015. However, the authors did not explain the reasons for this trend.

2.2. Effects of retractions

2.2.1. On medical practice. Steen [16] evaluated 788 retracted papers from 2000 to 2010 and focused on 180 primary papers reporting research involving humans. The 180 primary studies had 851 secondary studies drawing ideas from a primary study. These primary studies with retracted papers treated 9,189 patients and the secondary studies treated 70,501 patients. The results suggest that retracted studies put many more patients at risk in addition to the participants in their studies. The now retracted study that claimed that the MMR vaccine was related to autism led to a drop in vaccinations and subsequently measles outbreaks [17].

2.2.2. Waste of resources. Many research projects were funded. Stern et al. [18] examined 149 papers retracted due to misconduct (1992-2012) that received approximately $58 million in direct funding from the NIH, a mean of $392,582 (SD $423,256) in indirect costs per retracted article. Other financial costs such as investigations could reach $2 million per case [19].

2.2.3. Impact on citing papers (authors). Papers citing retracted papers are often subject to retractions. Systematic reviews of randomized controlled trials (RCT) are vulnerable to published studies of falsification of data, concealment of treatment, overestimation of the benefit of a treatment, or duplicated publications. In a systematic review and meta-analysis, Zarychanski et al. [20] reached a different conclusion from the original conclusion "after exclusion of 7 trials performed by an investigator whose research has been retracted." (p. 687) Marret et al. [3] analyzed the systematic and meta-analyses articles that cited the retracted RCT papers of an author and found that some results would be significantly changed. In a study of 100 authors with multiple retractions, Mistry, Grey, and Bolland [21] found that authors' publication rates declined rapidly after their first retraction.

2.3. Characteristics of retracted articles

2.3.1. Types of documents. Hot topics such as CoViD-19 [8, 22] tended to have more retractions. Publication types such as original research [23], article's prominence, early citation, and author's prolificacy or institutional status [24] have been found to correlate with retractions.

2.3.2. Prolific authors. Grieneisen and Zhang [4] found that "Fifteen prolific individuals accounted for more than half of all retractions due to alleged research misconduct." (p. 1) and the "top 'repeated offenders' counted for 52% of the world's retractions due to alleged research misconduct" (Table 4, p. 10). Prolific authors fabricated data [6, 7] which resulted in mass retractions of their publications. A once-esteemed pain researcher was convicted of data fabrication in 21 studies resulting in massive retractions of his articles and reports [25].

2.3.3. Venues. Fang and Casadevall [26] investigated the relationship between Journal Impact Factor (JIF) and retraction index (the ratio of retractions and published articles between 2001 and 2010) and found a strong positive correlation for 17 journals (*NEJM*, *Science*, *Nature*, *Cell*, *Lancet*, *J Exp Med*, etc.). JIF was highly associated with retractions for fraud or error, but not associated with plagiarism or duplicate publication.

2.3.4. Authors' countries. Ozair et al. [14] found that retractions were highest by authors from the United States (28%), followed by China (22%) and Japan (16%). Fang et al. [27] found that the country origin of the authors was associated with the types of retractions: the USA, Germany, Japan, and China accounted for three-quarters of retractions due to fraud or suspected fraud. China and India had more cases of plagiarism. (Note: the authors of this paper published a correction of Table 3, which we do not use [28]).

A recent study [29] analyzed the first author's country origin of 621 retracted OA articles: 199 from China, 83 from India, 75 from the USA, 50 from Iran, and 25 from Italy. Retracted articles from China and Iran were mostly due to fake peer reviews, while those from the USA were mostly because of error and fraud.

2.4. Reasons for retractions or corrections

Misconduct retractions (including plagiarism, duplicate publication, data fabrication, and ethical issues) counted for 45% of Medline retractions between 1988-2008 [12]. Budd et al. [30] categorized 2,491 retracted articles using a schema of 18 reasons and found that 65% of retractions were due to misconduct (p. 5); they point out that "misconduct is a serious problem and one that contaminates the literature." (p. 4) The study of retracted articles from PubMed between 2000 and 2010 by Steen [31] reports that retractions due to errors (74%) were more common than fraud (27%) but that ambiguous reasons counted for 18%. From the data [6] (Table 2), we derived the percentages for misconduct retractions (including plagiarism, duplicate publication, data fabrication, and ethical issues) and mistake retractions (honest errors), respectively: 55% vs 31% for 2004-2008 and 61% vs. 28% for 2009-2013. Grieneisen and Zhang [4] found that out of the 4,449 retracted papers, 3,621 were retracted because of the following reasons: "distrust data (25%), plagiarism (22%), research misconduct (fraudulent or fabricated data) (20%), and duplicate publication (16%)" (p. 9). Fang et al. [27] analyzed 2,047 retracted articles from PubMed and found that 67% of retractions were due to misconduct and 21.3% were attributable to error. These results were corroborated by a later study [32] that analyzed 1,082 retracted papers from PubMed: misconduct retractions counted for 65%. From the analysis of the 621 retracted OA journal articles found from PubMed, Wang et al. [29] found the retractions were because of "error (22%), plagiarism (21%), duplicate publication (15%), fraud/suspected fraud (14%), and faked peer-review process (14%)" (p. 858). They also found significant increases in errors and plagiarism in 2008-2012 and 2013-2017 (p. 859). The faked peer review became a new type of retraction in the OA era.

2.5. Post-retraction citing

2.5.1. How were retracted papers cited? Budd et al. [33] analyzed 235 retracted biomedical journal papers between 1966 and 1996 from Medline. These papers were cited 2,034 times after retractions. Wright's dissertation [34] analyzed 53 retracted biomedical articles published between 1964 and 1984; she found significantly fewer post-retraction citations based on the predicted number of citations using the Griffith Aging Factor. Hagberg [35] tracked 10 biomedical research publications retracted in 2005 and claimed that "the present data clearly demonstrate absolutely no effect of retraction on the subsequent citation histories of these nine retracted manuscripts." (p. 1390) Bornemann-Cimenti et al. [25] analyzed post-retraction citations of a researcher's publications retracted due to data fabrication; they report that retracted articles were still cited five years after retractions. For RCT papers, retractions were effective in reducing citations [36].

2.5.2. Did citing papers note retractions? Budd et al. [30, 33] found that only 4% of the post-retraction citing papers mentioned retractions; 96% cited positively; and review articles

were better in acknowledging retractions (only one out of eight did not mention retraction). Wright [34] found that 90% of the post-retraction citing articles cited the retracted articles as valid. Self-citations of the retracted articles did not mention the retractions [30, 31]. Theis-Mahon and Bakker [37] retrieved retracted dentistry papers from Retraction Watch; they found that the 81 retracted dentistry publications were cited post-retraction in 685 publications, of which 69% cited positively and only 5% noted the retraction status. Similar findings by [38] reported that fewer citing papers (<5%) indicated any awareness of the cited article having been retracted. Bornemann-Cimenti et al. [25] found that only one-quarter of the citing articles indicated the retraction due to data fabrication (p. 1071). Rapani et al. [13] found that 89.6% of post-retraction citations to the retracted dental articles did not mention the retraction or data reliability. Schneider et al. [39] examined the post-retraction citations of a falsified clinical trial published in 2005 and retracted in 2008. Of the 112 citing papers, 96% did not mention the retraction. Bar-Ilan and Halevi [40] examined articles retracted in 2014 that received more than 10 citations between January 2015 and March 2016; they found that the majority of the 238 citations of the retracted articles were positive even though the retractions were due to ethical misconduct, data fabrication, and false reports.

2.5.3. Retracted papers were cited as valid. Asking why so many authors made positive citations of retracted papers, Budd et al. [30] speculated that some authors were citing from the citations in published papers instead of searching the databases where retractions were clearly indicated (p. 7). Pfeifer and Snodgrass [41] observed that "Methods currently in place to remove invalid literature from use appear to be grossly inadequate. Regardless of strides made in controlling fraud, error is generally considered an inherent and inevitable aspect of research, and efficient removal of invalid information from the literature would serve science well." (p. 1423)

3. Methods

A retraction is defined as “a mechanism for correcting the literature and alerting readers to articles that contain such seriously flawed or erroneous content or data that their findings and conclusions cannot be relied upon.” [42]

3.1. Datasets and computational tools

Searches of Faculty Opinions were first conducted on 5/19/2020 and repeated on 6/15/2020. A total of 232 recommended articles were published between 11/1/2001 and 5/22/2020 with the editorial notes about the article's status. The final dataset includes 209 retracted articles (90%) and 23 articles (10%) as Corrigendum (16), Erratum (4); Addendum (1), Concerned (1), and Correction (1). Some articles have two editorial notes: one about the article's status and one about the recommendation's withdrawal.

A recommendation (Figure 1) includes a rating: good (1-star), very good (2-star), or exceptional (3-star), and an optional one or more categories (Classified_as) and a commentary (also optional). Any FM can add a “Dissent” commentary to a recommended article. Dissent commentary is a citable entity with a unique doi but which does not rate the

article. A Python program using Beautiful Soup was written to scrape relevant data elements into two structured output files, one for articles and one for recommendations.

As Figure 1 shows, the recommended article has two new scores introduced after Faculty Opinions succeeded F1000Prime: *Relative citation ratio* is from iCite by the NIH; *Weighted sum of stars* is a composite measure, but the formula for this score is not revealed (https://facultyopinions.com/blog/meet-the-new-faculty-opinions-score/ dated 4/20/2021; re-accessed on 9/12/2021). Both scores were updated periodically.

For each retracted or corrected article, the data from Faculty Opinions were collected; the original article was followed to track retraction reasons and retraction date.

Advanced searches using doi in Web of Science (WoS) generated two output files, one with citation counts by year of all 232 retracted or corrected articles; one with full bibliographic records of the 232 articles (including authors' affiliations, funding agencies, and WoS categories). For post-retraction citing, each retracted article is searched to generate an output file including all post-retraction citing articles; for OA citing articles, a link from WoS provides direct access to the article to examine how the article is referenced. A relational database was built to integrate data from the above sources (Appendix B).

3.2. Analysis

Statistical analysis provides a big picture of the 232 articles and their recommendations based on the data from Faculty Opinions. Post-retraction citations were derived by counting from the third year after the retraction year to allow a longer delay than one year by [30, 43]. Thus, only papers retracted in 2018 or earlier were included, resulting in 174 of the 232 articles (excluding corrected articles) for analysis of post-retraction citations by 2020. Citation analysis focuses on post-retraction citations and factors such as derived variables including 1) time took to retract, 2) post-retraction citing span (number of years after retraction before no citations), 3) number of peak citations (the article received the most citations in a specific year), 4) number of years to reach peak citations (the year with the most citations), 5) retraction before or after peak citation year.

Nonparametric tests of correlations between

- post-retraction citations and pre-retraction citations
- post-retraction citations and peak citations
- post-retraction citations and time taken to retract
- post-retraction citations and post-retraction citing span
- post-retraction citations span and years reached peak citations
- differences for articles retracted before or after peak citation year

4. Results and discussion

Based on COPE Retraction guidelines [42], retracted articles are different from the corrected articles. The former are considered invalid, but the latter are correctable by a subsequent article or notice.

4.1. Which recommended articles were subsequently retracted or corrected?

Table 1 shows that more recommended articles were retracted than corrected, but corrected articles received more citations based on means.

Table 1. Descriptive statistics of retracted and corrected articles

Article's Status	Total FMs (dissent included)	Total Stars	Weighted sum of stars [1]	Score [1]	Total Citations	Post-Retract Cites
Retracted (n=209; 90%)						
Mean	2	3	4	17	136	30(22%)
SD	2	3	4	19	214	48
Median	1	2	2	9.5	77	16
Range	1 - *14*	1 – *28*	1 – 35	5 - 163	0 – 2407	0 – 338
Corrected (n=23; 10%)						
Mean	2	4	4	20	393	208 (53%)
SD	1	4	4	19	376	307
Median	1	2	2	10	248	66
Range	1 - *5*	1 – *14*	1 – 18	5 – 84	45 - 1460	10 -1282

[1] Two measures from Faculty Opinions (See Figure 1)

The top-recommended articles in our dataset were recommended by at least five FMs (Table 2). Articles were ranked by the total number of FMs and total stars [44, 45]. (This study did not use the new measures, Score and Weighted sum of stars by Faculty Opinions, because they were periodically updated.) Published in high-impact journals--*Nature*, *Science, The Journal of Experimental Medicine (JEM)*, *New England Journal of Medicine (NEJM)*, and *Cell*--these articles were retracted from less than five months to more than 15 years after publication or corrected from one to ten years after publication.

[Table 2 in the landscape is placed at the end of the paper]

The top-7 *Science* article (highlighted) needs a close examination. First, the publication date in Faculty Opinions (11/1/2002) was different from the article's webpage publication date (9/26/2002), marking a discrepancy between print and online versions. Second, the URL to this article's notice of partial retraction was invalid (the link returned a "404" message). Third, for the seven recommendations, six were posted after the retraction date. Fourth, the six post-retraction recommending FMs did not specifically mention the retracted parts of the article but three FMs classified as Controversial. The timeline of the seven recommendations is of interest: 1) the first recommendation was posted two weeks after the publication date and assigned 2-star and Confirmation; 2) the article was partially retracted by the authors 15 months after publication; 3) the six post-retraction

recommendations were posted from 11 to 83 days. These post-retraction recommendations assigned 1-star (4), 2-star (1), and 3-star (1) and classified as New Finding (4), Controversial (3), Confirmation (1), and Interesting Hypothesis (1). This article's webpage at https://www.science.org/doi/10.1126/science.1076185 does not have a note on the partial retraction, but the links (Cited by) include the leading authors' new article entitled "Retraction of an interpretation," published by *Science* on 1/23/2004; from the citation record (with References), it is not clear which article the retraction was about. For *Science*, either the article or the retracton notice are OA, thus users need a subscription, or purchase for access.

This case raised a further question regarding whether all retracted articles that had been recommended were flagged in Faculty Opinions. Searching the Retraction Watch database [43] for articles published in the top journals (Table 3) that were retracted from 1/1/2021 through 10/31/2021, we found 256 retracted articles, of which, five articles were recommended in Faculty Opinions. Only three articles were flagged as being retracted (plus an Editorial Note with a link to the retraction notice); they were published in *Nature Chemical Biology* (published on 10/5/2020; retracted 6/29/2021), the *Journal of Allergy and Clinical Immunology* (published on 4/15/2015; retracted 4/15/2021), and the *Journal of Biological Chemistry* (pdf dated 3/25/2011; retracted 11/23/2020), respectively.

As of 11/27/2021, two recommended articles, a *Nature* article (10.1038/s41586-020-03074-x) retracted on 9/27/2021 and a *Journal of Cancer Cell* article (10.1016/j.ccr.2014.03.009) corrected on 3/8/2021, still do not have editorial notes on retraction and correction. We are periodically checking these two because of a lack of a personalized auto-alert function on selected articles in Faculty Opinions.

In addition to a time lag for posting the editorial notes, the articles of an Expression of Concern or Correction do not have a visible alert flag as retracted articles (see Figure 1), although the editorial note occurs before each recommendation commentary.

Summary. The recommended articles that were subsequently retracted were published in top journals of the fields. The time lags for retractions or corrections by the journals varied widely, which could affect the post-retraction citing. The delay in recommendation systems to alert retractions or corrections also contributes to post-retraction citing. It also sets a barrier for reducing the negative impact of retracted publications if publishers charge for retracted papers and their notices.

4.2. The characteristics of the retracted or corrected articles

The 232 retracted articles were published in 74 journals (Table 3). The five top journals include *Nature*, *Science*, *Cell*, *Journal of Biological Chemistry*, and *Proceedings of the National Academy of Sciences of the USA*. These journals are published by Springer Nature, the American Association for Advancement of Science, Elsevier, and the National Academy of Sciences.

Table 3. The journals by the number of retracted articles

Journal	Articles	Percentage
Nature	34	15%
Science	24	10%
Cell	20	9%
Journal of Biological Chemistry	17	7%
Proceedings of the National Academy of Sciences (USA)	16	7%
Journal of Clinical Investigation	7	3%
Journal of Neuroscience	6	3%
Molecular Cell	6	3%
Anesthesia and Analgesia	5	2%
Nature Medicine	4	2%
New England Journal of Medicine	4	2%
Blood	3	>1%
Diabetes	3	>1%
Immunity	3	>1%
Journal of Experimental Medicine	3	>1%
Nature Immunology	3	>1%
PLoS ONE	3	>1%

The rest of 57 journals for 71 articles: 14 had two articles and 43 had one article (31%)

The 232 retracted articles are published by 1,881 authors from 34 countries (Table 4). Nearly half of the authors were from affiliations in the USA. Analyzing authorship, we found that an average of eight co-authors per article ranging from a single author to 27 co-authors. Only three articles were single-authored. Seven co-authors counted for 12%, five co-authors counted for 11%, and four co-authors 9%. However, most authors (94%) participated in one article; only one author occurred in eight articles (0.1%).

Table 4. Top 10 Countries of Authors' Affiliations [1]

Country	Frequency	Percentage
USA	469	48.0%
France	52	5.3%
Germany	50	5.1%
Spain	50	5.1%
England	43	4.4%
China	38	3.9%
Japan	38	3.9%
Canada	25	2.6%
South Korea	21	2.2%
Italy	19	1.9%
Switzerland	19	1.9%
Israel	15	1.5%
Singapore	15	1.5%
Netherlands	14	1.4%
Other 20 countries (see note)[2]	110	11.3%

[1] For articles with multiple authors from the same affiliation, the affiliation is counted only once.
[2] In descending order by count (from 13 to 1): Egypt, Brazil, India, Scotland, Ireland, Denmark, Iran, Taiwan, Tunisia, Australia, Finland, Belgium, Sweden, Argentina, Wales, Austria, South Africa, Portugal, Luxembourg, and the Czech Republic.

Funding acknowledgments occurred in 165 articles (71%). The 246 funders include government agencies (e.g., German Research Foundation), charitable trusts (e.g., Leona M. and Harry B. Helmsley Charitable Trust), or companies (e.g., Pfizer, AstraZeneca, etc.). Because the WoS full bibliographic records include only the names of the funding agencies, not the amount of funding, ranking is based on the number of funding sources at the top level of the organization (e.g., NIH represents many individually named Institutes). The top funders are in Table 5.

Table 5. Top funders of the 165 articles' research

Funding Source	Articles	Percent
National Institutes of Health, USA (NIH)	106	64%
Ministry of Education, Culture, Sports, Science & Technology, Japan (MEXT)	12	7%
Wellcome Trust, UK	10	6%
European Research Council (ERC)	9	<6%
National Natural Science Foundation, China (NSFC)	7	4%
Swiss National Science Foundation, Switzerland (SNSF)	5	3%
National Science Foundation, USA (NSF)	5	3%
Crohn's & Colitis Foundation of America, USA (CCFA)	5	3%

The remaining 238 funders occurred in 4 articles or less.

The articles funded by more sources were also higher in co-authorship. They were published in top journals: *New England Journal of Medicine*, *Nature*, *Cell*, *Science*, and *Journal of Experimental Medicine* (Table 6).

Table 6. Top funded articles

Article	Funders	Co-authored	Status
10.1056/NEJMoa1712231	18	10	Retracted
10.1038/nature12745	14	27	Corrigendum
10.1038/nature12587	10	26	Corrigendum
10.1038/nature07409	10	15	Retracted
10.1016/j.cell.2012.02.051	10	18	Retracted
10.1126/science.1179052	9	13	Retracted
10.1084/jem.20121486	8	15	Retracted

Summary. The top-recommended articles, although being retracted subsequently, were published in top journals by multiple authors from countries that funded these research projects. The NIH (US) funded most of the articles' research. These resources are lost to errors and frauds. The additional cost of unproductive research by other researchers who have based their work on the retracted publications must also be considered.

4.3. Reasons for retractions and corrections

Most retraction or correction notices identified reasons except for seven articles in the *Journal of Biological Chemistry* withdrawn by the authors between 1/4/2008 and 1/26/2015. Adopting the schema from [46], the top reasons for retractions or corrections

were 1) Error in Data, Image, Analyses, Methods, Results, or Text; 2) Falsification/Fabrication of Data, Image, or Results; 3) Unreliable Data, Image, or Results; and 4) Results not Reproducible. Two authors retracted their papers because their papers cited retracted papers. (Table 7)

A case should be noted: the paper that falsified data was corrected instead of retracted (the shaded cell in Table 7) (https://www.pnas.org/content/115/14/E3325). Although the committee concluded that the erroneous Fig. 2D was intentional, it allowed a correction because it "does not impact the interpretation of the data." We classified this paper as both *Falsification of image* and *Error in image* but only treated it as a corrected paper.

Table 7. Reasons for retraction and frequency

Retraction Reasons	Retracted	Corrected
Error in Data, Image, Analyses, Methods, Results, or Text	74 (28%)	13 (5%)
Falsification/Fabrication of Data, Image, or Results	53 (20%)	*1*[1] *(<1%)*
Unreliable Data, Image, or Results	42 (16%)	8 (3%)
Results not Reproducible	41 (16%)	
Lack of IRB/IACUC Approval	7 (3%)	
Self-plagiarism	5 (2%)	
Plagiarism of Article, Data, Image, or Text	4 (2%)	
Ethical Violations by Author	3 (1%)	
Cites Retracted Work	*2* (1%)	
Misconduct – Official Investigation/Finding	1 (<1%)	
Legal Reasons/Legal Threats	1 (<1%)	
Informed/Patient Consent – None/Withdrawn	1 (<1%)	1 (<1%)

[1] See text for the explanation of why this paper was corrected, not retracted

Summary. Retractions due to these serious problems not only contaminate scientific literature but also have some unimaginable long-term effects on science and medical practice due to their continued use as valid scientific findings. Further more, it is problematic when neither authors nor journals provide reasons for retractions.

4.4. How FMs recommended and dissented the articles and withdrew their recommendations

The 232 retracted articles received a total of 410 recommendations and eight dissents from 371 FMs whose affiliations are in 25 countries: the USA counted for 56% followed by the UK (>8%), Germany (>6%), France (>4%), Canada (<4%), Australia (<4%), Japan (>3%) and 18 other countries (15%).

Some recommendations were made as soon as an article was online, resulting in the recommendations posted before the official publication date. The longest time lag between publication and recommendation is nine and a half years. Surprisingly, some recommendations were posted from two to 306 days after the retraction/correction dates. (See 4.1 to see the *Science* article that received six post-retraction recommendations.)

The majority of the articles were recommended by one FM (62%). These single recommendation articles were rated as follows: 19 got 3-star (13%); 63 got 2-star (44%); and 62 got 1-star (43%). For the articles recommended by multiple FMs, the data show

varied inter-rater agreements. For example, 52 articles were recommended by two FMs: only one article was rated 3-star by both FMs (2%); 14 articles got 2-star from both (27%); and 11 artciles got 1-star from both (21%). The other 26 articles had mixed ratings: 1-star and 3-star (8%), 1-star and 2-star (31%); and 2-star and 3-star (12%). The plot of the articles, ranked by the recommendations (stars and FMs), shows two long-tail plots (Figure 2). Because of the skewed distributions, the median for recommendation is one and for rating is 2-star (Table 1). The top-recommended article had a total of 28 stars from 13 FMs, which also had one dissent (Table 2).

FMs assigned less than two categories per recommendation. On average, there are less than two categories per article. More than 50% of recommendations classified the articles as New Finding (Table 8).

Table 8. Categories occurred in recommendations [1] and articles [2]

Category	in Recommendations [1]	assigned to Articles [2]
New Finding	321 (50%)	186 (43%)
Interesting Hypothesis	83 (13%)	69 (16%)
Technical Advance	56 (9%)	35 (8%)
Novel Drug Target	55 (9%)	39 (9%)
Confirmation	51 (8%)	41 (10%)
Controversial	32 (5%)	26 (6%)
Good for Teaching	28 (4%)	24 (6%)
Refutation	3 (<1%)	3 (<1%)
Clinical Trial: Non-RCT	2 (<1%)	2 (<1%)
Negative / Null Results	2 (<1%)	2 (<1%)
Review / Commentary	2 (<1%)	2 (<1%)
Changes clinical practice	1 (<1%)	1 (<1%)
Total	*636 (100%)*	*430 (100%)*

[1] A FM may assign multiple categories to an article; six recommendations did not assign a category.

[2] An article might be assigned the same category by multiple FMs; this category was only counted once; one article did not have any assigned category.

Dissenting and withdrawing recommendations. FMs posted dissents to disagree with the recommendations. Three FMs dissented two recommended *Science* articles, and four FMs each dissented a recommended article in *Genome Biology*, *Nature*, *Nature Medicine*, and *Proceedings of the National Academy of Science*, respectively. The *Science* article (10.1126/science.1174094), received two dissents (one posted on the same day as the recommendation and the other eight days later), and was retracted one year and a month after publication, but one recommendation has not been withdrawn. For the top *Nature* article in Table 2, of the 13 FMs six withdrew recommendations after the dissent posted on 3/11/2014, and the other seven withdrew after its retraction on 7/2/2014. But, for the top-2 *Science* article retracted on 12/23/2011, none of the nine recommendations was withdrawn.

Of the 410 recommendations posted between 11/22/2001 and 5/27/2020, only 61 (15%) were withdrawn between 3/20/2014 and 6/8/2020. The 61 withdrawn recommendations recommended 44 articles that were published between 8/27/2004 and

5/22/2020 and retracted between 4/12/2014 and 6/5/2020. The remaining 349 recommendations (85%) of 207 articles were not withdrawn. Some FMs withdrew their recommendations following a dissent by another FM or an Expression of Concern about the article was published. In one case, a *Lancet* article was under investigation upon which the journal published an Expression of Concern on 4/12/2014. It took nearly 5 years to retract this article on 3/16/2019 after the Expression of Concern (https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(19)30542-2/fulltext)

Summary. Ratings by FMs show their tendency on a midpoint of 2-star ratings but less overlap on ratings by multiple FMs on the same article. Although varied in assigning categories, FMs tended to recommend articles with new findings. After the articles were retracted, dissented, or noted with an expression of concern, not only were most recommendations not withdrawn but also a few new recommendations were added.

Questions remain as to why no recommendation was withdrawn before 2014 and why only a small percentage of the recommendations of retracted papers were withdrawn by FMs. It is possible that either FMs were unaware of the retractions or corrections, or they wanted to keep their recommendations. In cases that the editorial notes on retractions or corrections took long time to be added to the recommended articles, the FMs who withdrew their recommendations quickly after the retractions were likely be alerted the retractions by other sources.

4.5. Post-retraction citing

In the final dataset (Table 9), excluding the 23 corrected articles and nine articles without post-retraction citations, there are 174 articles, published between 2004 and 2018 that were retracted between 2006 and 2018. There are 4,055 post-retraction citations between 2006 and 2020, which is about 17% of the total citations to the 174 articles. Below are the results of *Spearman's rho* tests of correlations between

- post-retraction citations and pre-retraction citations (.527; p <.001)
- post-retraction citations and peak citations (.636; p <.001)
- post-retraction citations and time taken to retract (-.070; negative but not significant)
- post-retraction citations and post-retraction citing span (.497; p < .001)
- post-retraction citing span and years reached peak citations (-.652; p <.001)

These results indicate that the articles that had more pre-retraction citations also had more post-retraction citations; those that had more peak citations also had more post-retraction citations; and those that had a longer post-retraction citing span also had more post-retraction citations. The association between time reached peak citations and post-retraction citing span is reversed.

Table 9. Post-retraction citations (n=4,055) to the retracted articles (n=174)

	Time took to Retract	Post-retraction Cites (%)	Post-retraction Citing Span (Years)	Peak Cites	Years Reached Peak Cites
Median	40 months	12	6	21	2
Mean	47 months	23	6	30	2
SD	36 months	38	3	39	2
Min	1.7 months	1	2	2	Immediacy [1]
Max	13.72 years	375	15	402	9

[1] Six articles had peak cites in their publication year; their total citations ranged between 3 and 153; their post-retraction cites ranged between 1 and 36.

In Table 10, the articles were grouped by the peak-cites year (the year the article reached highest citations) to test citation differences. The nonparametric tests (Mann-Whitney Test) observed no significant differences in post-retraction citations between G_1 and G_{2+3} ($U=3554.5$, $p = .834$), although the articles retracted before the peak-cites year (G_1) have greater pre-retraction citations ($U=1570.5$; $p < .001$), higher peak-cites ($U= 2616.5$; $p < .005$) and took longer to retract ($U=634.5$; $p < .001$) than the articles retracted on or after the peak-cites year (G_{2+3}).

Table 10. Retraction year and the peak-cites year

Retracted	Before the Peak-Cites Year (n=105) [G_1]		On the Peak-Cites Year (61) [G_2]		After the Peak-Cites Year (n=8) [G_3]	
Cites	Pre-retraction	Post-retraction	Pre-retraction	Post-retraction	Pre-retraction	Post-retraction
Median	88	13	34	10	15	13
Mean	155	20	62	25	19	29
SD	254	28	93	51	17	39
Min	11	1	2	1	3	1
Max	2,360	200	573	375	46	116

The time-series plots show a visible decline in post-retraction citations starting from 2016 (also a spike point) and a steady growth in retractions over the 15 years (Figure 3). Although the trend for citations dropped from 2019, the data cannot explain the unusual high numbers in post-retraction citations for the 2016-2018; what factors contributed to this trend?

We investigated the post-retraction citing articles to five highly-cited retracted articles to discover how the retractions were noted in the texts or references. Out of the 487 post-retraction citing articles, only 12 acknowledged the retraction and two cited both the retracted article and the retraction notice.

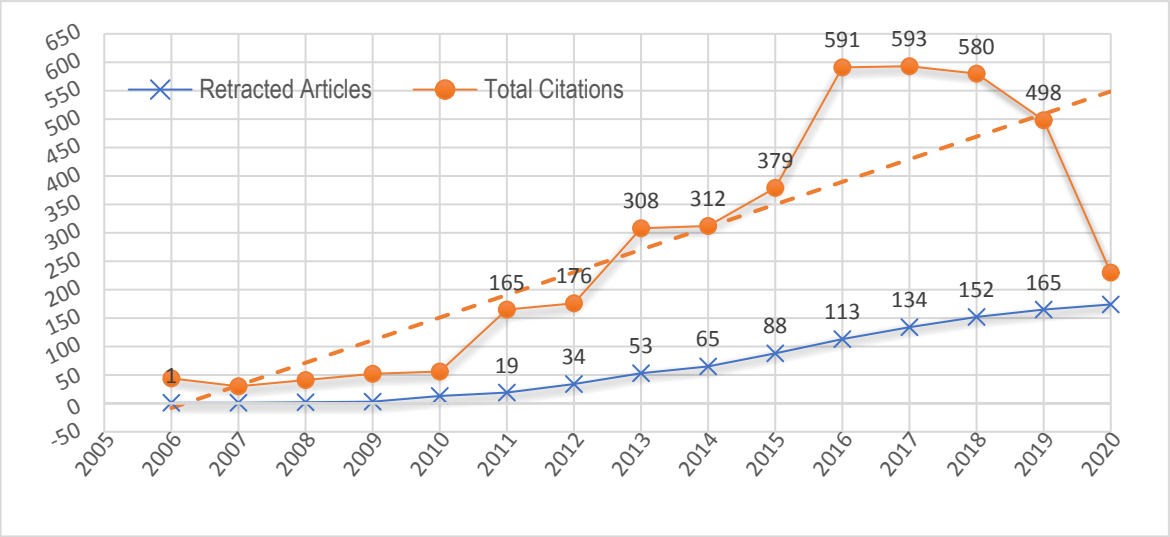

Figure 3. Post-retraction citations of the retracted articles each year

Summary. The results suggest that retractions did not change the trend of the articles' citations as they continue to grow to reach the peak-cites post retraction. Although the effect of the time taken to retract on post-retraction citations was not significant, but only slightly reversed citations, the decline in citations could also be a factor of citation obsolescence. The visible increase in post-retraction citations between 2016 and 2018 needs further investigation. As information-seeking research has reported, it is likely that citing authors have missed the retraction notices because scientists rarely search the databases or recheck the journals for updates on the articles they have alreadt collected and read. It is also possible that the authors cited the retracted articles from tertiary sources such as references of papers.

4.6. Can errors be avoided in publications?

The few honest errors, later corrected, should be prevented. Benchimol et al. [47] made "an appeal to authors, publishers, editors, and peer reviewers to endorse and effectively implement the correct reporting guidelines in their submission and evaluation of manuscripts." (p. 1419) Facing high pressure to publish, scientists are measured on productivity metrics. However, "when a measure becomes a target, it ceases to be a good measure." [48, p. 208] It was more than 20 years ago that Pfeifer and Snodgrass [41] pointed the lack of adequate methods to remove invalid literature from use. Today, the situation remains serious and "improvements are needed from publishers, bibliographic databases, and citation management software to ensure that retracted articles are accurately documented." [49]

5. Conclusions

Based on the findings, this study suggests that expert recommendation systems such as Faculty Opinions implement strategies and methods to 1) notify all recommending FMs as

soon as possible about the subsequent retractions; 2) invite FMs to revise or amend their recommendations on what is still valid and what were flaws or errors; 3) shorten the time-lag in adding editorial notes about the retractions using multiple sources such as data from the Retraction Watch database; and 4) alert the users who have accessed the recommendations before the articles' retractions. It is also important that publishers should make retracted articles and their notices of retractions more transparent and open access to facilitate corrections of invalid literature.

6. Acknowledgment

[to be added]

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Appendix A. Retraction Watch defined reasons adopted and found in this study [1] [44]

Reason	Description
• Cites Retracted Work	• A retracted item is used in citations or referencing
• Error in Data, Image, Analyses, Methods, Results, or Text	• A mistake made in the data, or preparation or printing of an image, in the evaluation of the data or calculations, or experimental protocol, or determining results or establishing conclusions, or written portion
• Ethical Violations by Author	• When an author performs an action contrary to accepted standards of behavior.
• Falsification/Fabrication of Data, Image, or Results	• Intentional changes to data, an image, or results so that it is not representative of the actual finding
• Informed/Patient Consent – None/Withdrawn	• When the full risks and benefits from being in an experiment are not provided to and accepted by the participant, or the participant chooses to later recant their approval
• Lack of IRB/IACUC Approval	• Failure to obtain consent from the institutional ethical review board overseeing human or animal experimentation prior to initiation of study, or failure to provide proof of such
• Legal Reasons/Legal Threats	• Actions taken to avoid or foster litigation
• Misconduct – Official Investigation/Finding	• Finding of misconduct after investigation by incorporated company, institution, or governmental agency
• Plagiarism of Article, Data, Image, or Text	• Used when an entire published item, or undefined sections of it, and not written by one or all authors of the original article, are repeated in the original article without appropriate citation. (this definition also applied to data, image, and text)
• Results Not Reproducible	• Experiments conducted, using the same materials and methods, that fail to replicate the finding of the original article
• Self-plagiarism	• Duplicate a published item, or undefined sections of it, written by one or all authors of the original article, are repeated in the original article without appropriate citation.
• Unreliable Data, Image, or Results	• The accuracy or validity of the data, image, or results is questionable

[1] A set of granular reasons of the same nature such as the four types of Plagiarism (article, data, image, or text) aggregated as one

Appendix B. Data Model

RETRACTED_ARTICLES (**Retract_doi**, Title, (Metrics), {(Author, Affiliation)}, Journal, PublicationDate, RetractDate, [PreRetractCites], [PeekCites], [PeekCitesYear], [PostRetractCites], [PostRetractCitingSpan], {Funding}, {*Reason}*)
RETRACTION_REASONS (**Reason**, Description)
RECOMMENDATIONS (**RecomendID**, *Retract_doi*, (FM, Affiliation), RecommendDate, RatingStar, {Classified_as}, Commentary, WithdrawnDate)
CITATIONS (***Retract_doi***, TotalCites, (2001, ..., 2020))
POST_RETRACT_CITATIONS (**Citing_doi**, ***Retract_doi***, mentioned_retracton, cited_retraction_notice)

Database structure to integrate data from multiple sources. This model uses text notation for the data model. Relations are named using the upper case with underlined bold attribute as PK, underlined *italicized* attributes as FK, underlined *bold italicized* for an attribute that is both PK and FK, round brackets ( ) for composite attributes, curly brackets { } for multi-valued attributes, and square brackets [ ] for derived values). When multiple authors of an article are from the same affiliation, for this article, this affiliation is counted only once. Because of varied formats in names, an organization's country is the only unambiguous element. For Dissent entries, it is a record in RECOMMENDATION, but the value for Star is "0" because no rating was associated with dissent entries.

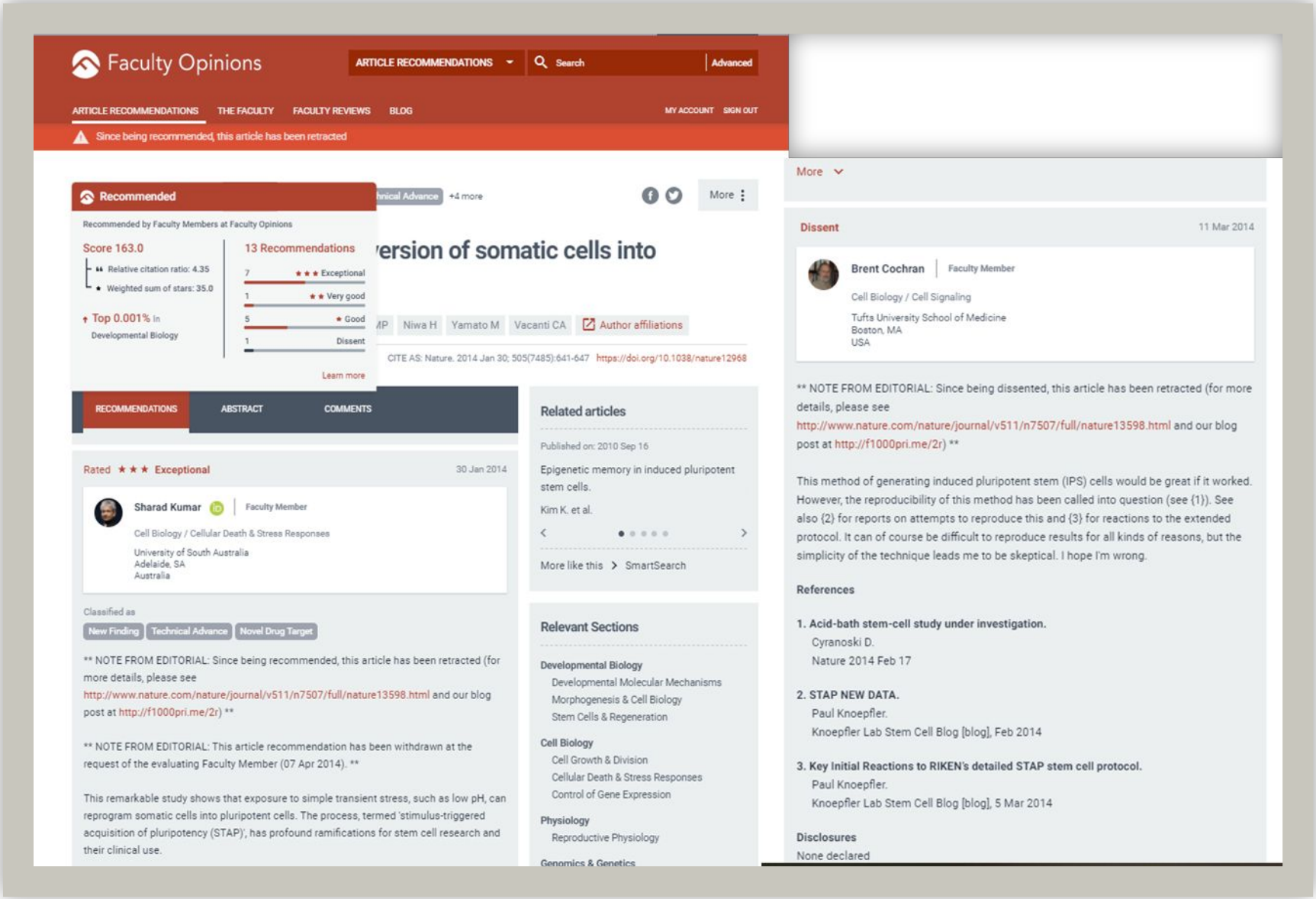

Figure 1. Partial screenshot of a retracted article (Dissent is included; not all recommendations are included)

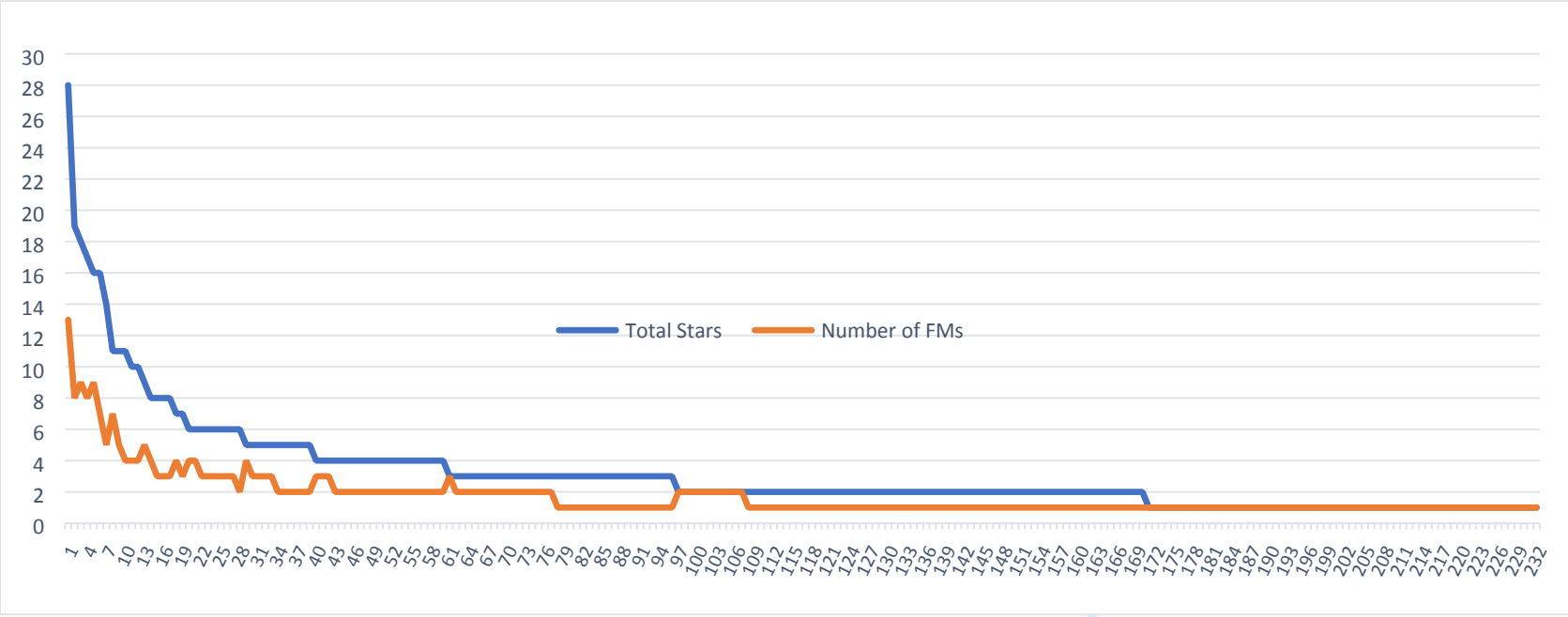

Figure 2. The 232 ranked articles by total stars and number of recommending FMs

Table 2. Top recommended articles measured by Total recommending RMs and total Stars.

Article doi (leading 10.)	Pub Date	Total FMs[1]	Total Dissents	Dissent date	Total Stars	Weighted Sum Stars	Score	Total Cites	Post-Retract Cites (%)	Retract/ correct Date
1038/nature12968	1/30/2014	13	1	3/11/2014	28	35	163.1	153	28 (18.30)	7/2/2014
1126/science.1179052	10/23/2009	9	1	11/18/2009	18	21	98.4	400	85 (21.25)	12/23/2011
1084/jem.20100730	7/4/2011	9			16	16	74.5	49	22 (44.90)	11/21/2011
1038/nature07199	8/14/2008	8			19	22	102.4	20	3 (15.00)	4/8/2010
1056/NEJMoa1200303	4/4/2003	8			17	20	99.4	2407	47 (1.95)	6/21/2018
1016/j.cell.2013.04.008	5/9/2013	7			16	20	93.8	321	23 (7.17)	1/12/2017
1126/science.1076185	9/26/2002	7			11	12	56.3	378	180 (47.62)	1/23/2004
1038/nature12587	*10/3/2013*	*5*			*14*	*18*	*84.3*	*344*	*103 (29.94)*	*4/1/2015*
1126/science.1126088	*4/21/2006*	*5*			*11*	*12*	*57.1*	*1072*	*196 (18.28)*	*1/22/2016*
1038/nature04836	7/6/2006	5			9	10	46.8	202	69 (34.16)	1/31/2008

[1] Not including dissent FM; the italicized articles were corrected.

Expert Recommended Biomedical Journal Articles: Their Retractions or Corrections, and Post-retraction Citing

Abstract

Faculty Opinions (formerly as F1000Prime) provides recommendations of important biomedical publications by domain experts (FMs) since 2001. This study examined the set of 232 recommended articles that were later retracted or corrected. These articles were recommended as New Finding (43.26%), Interesting Hypothesis (16.05%), etc. The research produced these articles also received various funding support; mostly from NIH. The top reasons for retractions were Errors of various types (28,03%); Falsification/fabrication of data, image, or results (20.08%); Unreliable data, image, or results (15.91%); Results not reproducible (15.53%). Retractions took from less than two months to almost 14 years. Only 14.88 % of recommendations were withdrawn either after dissents made by other FMs or retractions. Most of the retracted articles continue to be cited post-retractions; especially those published in *Nature, Science,* and *Cell*. Significant positive correlations were observed between post-retraction cites and pre-retraction cites, between post-retraction cites and peak cites, and between post-retraction cites and post-retraction citing span. A significant negative correlation was also observed between post-retraction citing span and years taken to reach peak cites. To improve the efficacy of retraction, journals, databases, expert recommendation systems, and authors have shared responsibilities to ensure scientific literature is valid and retracted or corrected articles are cited adequately. Further studies need to investigate how post-retraction citing authors cited the retracted articles and the nature of these references to understand the long-term effect of retraction.

1. Introduction

White [1] reports that peer-reviewed publications in science and engineering (S&E) grew about 4% annually from 2008 to 2018. The 2018 publications in health sciences, and biological & biomedical sciences counted for about 36% of the world's 2,555,959 S&E publications in that year (Table S5A-17). The information explosion has been observed since the mid-20th-century. To help scientists and researchers overcome information overload, Faculty Opinions[1] provides a platform for peer-nominated domain experts, named Faculty Members (FMs), to recommend publications of importance in their fields. Currently, more than 8,000 FMs recommend approximately 8,000 publications yearly.

With the rapid growth of biomedical publications, the quality of the published articles has been a serious concern. At a recent conference hosted by the Wellcome Genome Campus, the concern was discussed: "publishing poor-quality studies can (and should) lead to retractions from the literature." [2] In Faculty Opinions, if a recommended article is

[1] Formally known as F1000Prime in 2009 after merging F1000 Biology (launched in 2002 by F1000 Ltd) and F1000 Medicine (launched in 2006 also by F1000 Ltd). Faculty Opinions as a rebrand of F1000Prime on April 12, 2020.

retracted, the record will have a warning sign: "Since being recommended, this article has been retracted" or an editorial note: "Since being evaluated, an Erratum has been added to this article ....." This set of retracted articles represents a unique phenomenon in that the articles were peer-reviewed before publication and evaluated by the recommending FMs. Retraction of a published biomedical paper can be detrimental because the falsified results or errors can mislead the research and medical communities resulting in life-death consequences or a domino effect on other papers that cited the retracted paper. Marret et al. [3] demonstrated the susceptibility of systematic reviews and meta-analyses to fraudulent data by analyzing a set of fraud publications of a single author. This study will observe the retracted or corrected articles retrieved from Faculty Opinions to address the following questions:

1. Which recommended articles were retracted or corrected?
2. What are the characteristics of these retracted or corrected articles?
3. Why were the articles retracted or corrected?
4. How FMs recommended these articles? Did they later withdraw recommendations?
5. To what extent are these articles cited post-retraction?

2. Literature review

The nature and effect of retractions in biomedical publications have been examined from the perspectives of information science or biomedical research.

2.1. Increasing in retraction of biomedical publications

Wager and Williams [4] analyzed data from Medline to show that the proportion of retractions has increased tenfold from 0.002% in 1980-1984 to more than 0.02% in 2005-2009. Grieneisen and Zhang [5] retrieved 4,449 retracted scholarly publications (from 1928 to 2011) from Web of Science and found that the percentages in Medicine, Life Science, and Chemistry were higher than projections based on publications (p. 8). Singh, et al. [6] analyzed 2,343 retracted biomedical articles between 2004 and 2013 to illustrate the time-series data (Table 1); there was a steady increase from 69 to 402 for the ten years. Using these data, we drew a visual plot and the trendline shows a strong linear relationship ($y=41.3636x + 6.8$ and $R^2=0.9596$). At the individual author's level, an author's 172 articles were retracted due to fabricated data [7] and another author's 96 articles were retracted due to research misconduct [8]. When CoViD-19 became a global pandemic, "scientists published well over 100,000 articles about the coronavirus in 2020." [9] Retraction Watch listed 131 retracted CoViD-19 papers as of July 25, 2021 [10]. Rapani et al. [11] conducted a systematic review of retracted dental publications divided into two five-year periods: retractions increased by 47% in 2014-2018 compared to in 2009-2013. Gaudino et al. [12] analyzed 5,209 biomedical articles published from January 1923 through July 2020 and retracted from January 1971 through August 2020. The annual rate of retracted articles increased from 1980 to 2015 but decreased after 2015. The authors did not study the explanations for this trend. Ozair et al. [13] reported a rapid increase in retractions in the field of neurology from 16.9% by 2010 to 56% for 2016-2020; retractions were highest from United States (28.8%), followed by China (22.4%) and Japan (16.3%); the majority were retracted due to various types of research misconduct. Increased rate of retractions

has been reported in other medical fields, such as oncology [14] and perioperative medicine [15].

2.2. Effects of retractions

Steen [16] evaluated 788 retracted papers from 2000 to 2010 and focused on 180 primary papers reporting research involving humans. The 180 primary studies had 851 secondary studies drawing ideas from a primary study. These primary studies with retracted papers treated 9,189 patients and the secondary studies treated 70,501 patients. The results suggest that retracted studies put many more patients at risk in addition to the patients in their studies. The claim of the MMR vaccine was related to autism led to a drop in vaccinations and subsequently measles outbreaks [17]. Many research projects were funded. Stern et al. [18] examined 149 retracted papers due to misconduct (1992-2012) that received $58,494,718.60 in total funding (average $392,582 per retracted article). The additional cost of unproductive research by other researchers who have based their work on the retracted publications must also be considered. In addition, papers citing retracted papers are often subject to retractions. Systematic reviews of randomized controlled trials are vulnerable to published studies of falsification of data, concealment of treatment, overestimation of the benefit of a treatment, and duplicated publications. In a systematic review and meta-analysis, Zarychanski et al. [19] reached a different conclusion from the original conclusion "after exclusion of 7 trials performed by an investigator whose research has been retracted." (p. 687) Marret et al. [3] analyzed the systematic and meta-analyses articles that cited the retracted RCT papers of an author and found that some results would be significantly changed. In a study of 100 authors with multiple retractions, Mistry, Grey, and Bolland [20] found that authors' publication rates declined rapidly after their first retraction.

2.3. Characteristics of retracted publications

Hot topics such as CoViD-19 [9, 21] tended to have more retractions. Publication types such as original research [22], article's prominence, early citation, and author's prolificacy or institutional status [23] have been found correlated with retractions. Grieneisen and Zhang [5] found that "Fifteen prolific individuals accounted for more than half of all retractions due to alleged research misconduct." (p. 1) and the "top 'repeated offenders' counted for 52% of the world's retractions due to alleged research misconduct" (Table 4, p. 10). Prolific authors fabricated data [7, 8] and resulted in mass retractions of their publications. A once estimated pain researcher was convicted of data fabrication in 21 studies resulting in massive retractions of his articles and reports [24]. Fang and Casadevall [25] investigated the relationship between Journal Impact Factor (JIF) and retraction index (the ratio of retractions and published articles between 2001 and 2010) and found a strong positive correlation for 17 journals (*NEJM*, *Science*, *Nature*, *Cell*, *Lancet*, *J Exp Med*, etc.). Fang et al. [26] found that the country origin of the authors was associated with the types of retractions: USA, Germany, Japan, and China accounted for three-quarters of retractions due to fraud or suspected fraud. China and India had more cases of plagiarism. JIF was highly associated with retractions for fraud or error, but not associated with plagiarism or duplicate publication. (This paper's author published a correction of Table 3, which this

paper does not use [27]) A recent study [28] analyzed the first author's country origin of 621 retracted OA articles: 199 from China, 83 from India, 75 from the USA, 50 from Iran, and 25 from Italy. Retracted articles from China and Iran were mostly due to fake peer reviews, while those from USA were mostly because of error and fraud.

2.4. Reasons for retractions or corrections

Misconduct retractions (including plagiarism, duplicate publication, data fabrication, and ethical issues) were counted for 45% of Medline retractions 1988-2008 [4]. In another study of retracted articles from PubMed between 2000 and 2010, Steen [29] reports that papers retracted due to errors (73.5%) were more than fraud (26.6%) but ambiguous reasons counted for 18.1%. From the data [6] (Table 2), we derived the percentages for misconduct retractions (including plagiarism, duplicate publication, data fabrication, and ethical issues) and mistake retractions (honest errors), respectively: 55% vs 31% for 2004-2008 and 61% vs. 28% for 2009-2013. Grieneisen and Zhang [5] found that out of the 4,449 retracted papers, 3,621 were retracted because of the following reasons: distrust data (25%), plagiarism (22%), research misconduct (fraudulent or fabricated data) (20%), and duplicate publication (16%) (p. 9). Fang et al. [26] analyzed 2,047 retracted articles from PubMed and found that 67.4% of retractions were due to misconduct and 21.3% were attributable to error. These results were corroborated by a later study [30] that analyzed 1,082 retracted papers from PubMed: misconduct retractions counted for 65.3%. From the analysis of the 621 retracted OA journal articles searched from PubMed, Wang et al. [28] found the retractions were because of error (22%), plagiarism (21%), duplicate publication (15%), fraud/suspected fraud (14%), and faked peer-review process (14%) (p. 858). They also found significant increases for the three 5-year intervals (2003-2007, 2008-20012, and 2013-2017), most visibly for error and plagiarism in the last two intervals (p. 859). Faked peer review became a new type of retraction in the OA era.

2.5. Post-retraction citing

Budd et al. [31] analyzed 235 retracted biomedical journal papers from Medline between 1966 and 1996. These papers were cited 2,034 times after retractions (counted from two years after). For the post-retraction citations, only 6.4% of the 299 citing papers in Abridged Index Medicus (AIM) journals acknowledged the retraction, and 7.7% of the 1,594 non-AIM citing papers acknowledged the retraction. Most citations occurred in the Introduction and Discussion sections, and the majority made explicitly or implicitly positive mentioning (93.7% for AIM citing papers and 92.2% for non-AIM citing papers). (Table 2, p. 441). They also zoomed in on the eight review articles cited after retractions: the only one mentioned retraction. Theis-Mahon and Bakker [32] retrieved dentistry retracted papers from Retraction Watch to observe post-retraction citing; they found that the 81 retracted dentistry publications were cited in 685 publications, of which only 5.4% noted the retraction status and 69.3% were positive; the randomized controlled trials were more likely to be cited. Wright's dissertation [33] analyzed 53 retracted biomedical articles to address two questions: if citations dropped post-retraction; if the citing papers referred to the post-retracted articles adequately. She found significantly fewer post-retraction citations, but 90% of the post-retraction citing articles cited the retracted articles as valid.

Further, self-citations to the retracted articles ignored the retraction. Another study [34] reports that fewer citing papers (<5%) indicated any awareness of the cited article having been retracted. Bar-Ilan and Halevi [35] retrieved 987 articles retracted in 2014 from ScienceDirect to examine post-retraction citations. They included the retracted articles that received more than 10 citations between January 2015 and March 2016, resulting in 238 citing documents. They found that majority of the citations to the retracted articles were positive even though the retractions were due to ethical misconduct, data fabrication, and false reports. Hagberg [36] tracked 10 biomedical research publications retracted in 2005 to assess the impact of these papers. The study found "the present data clearly demonstrate absolutely no effect of retraction on the subsequent citation histories of these nine retracted manuscripts" (p. 1390), and some citing articles failed to mention the retractions (p. 1386). Bornemann-Cimenti et al. [24] analyzed post-retraction citations to a researcher's publications retracted due to data fabrication; they report that retracted articles were still cited 5 years after retractions and only one-quarter of the citing articles indicated the retraction status (p. 1071). Rapani et al. [11] found that 89.6% of post-retraction citations to the retracted dental articles did not mention the retraction or data reliability. Schneider et al. [37] examined in depth the post-retraction citations to a 2008 retracted falsified clinical trial published in 2005. They found that 107 of the 112 (96%) direct citations did not mention the retraction and the 152 second-generation citations to the 35 direct citations did not mention the retraction. Post-retraction citing may be related to factors such as the scale of the retractions and media attention. For randomized controlled trials, retractions were effective in reducing citations [38]. Another study [39] also observed that retraction affected citations to retracted papers as compared with matching non-retracted papers.

3. Methods

A retraction is defined as “a mechanism for correcting the literature and alerting readers to articles that contain such seriously flawed or erroneous content or data that their findings and conclusions cannot be relied upon.” [40]

3.1. Datasets and computational tools

Searches of Faculty Opinions were conducted on May 19 and June 15, 2020, resulting in 232 recommended articles published between 11/1/2001 and 5/22/2020 with the editorial notes about retraction or correction: 209 articles (90%) were retracted and 23 (10%) were corrected as Corrigendum (16), Erratum (4); Addendum, Concerned, and Correction, respectively. There are two editorial notes: one for the article's retraction; one for the recommendation's withdrawal. A recommendation includes a rating: good (1-star), very good (2-star), or exceptional (3-star), and optional one or more categories (Classified_as) and a commentary. Any FM can add a “Dissent” commentary to a recommended article. Dissent commentary is a citable entity with a unique doi but does not rate the article (Figure 1). A Python program using Beautiful Soup was written to scrape relevant data elements into two structured output files, one for articles and one for recommendations.

As Figure 1 shows, the recommended article has two new scores introduced after Faculty Opinions succeeded F1000Prime: *Relative citation ratio* is from iCite by NIH; *Weighted sum of stars* according to this post: "The model was trained using proprietary data for more than 180,000 articles manually labelled [sic labeled] by Faculty Opinions team for the past 20 years." (https://facultyopinions.com/blog/meet-the-new-faculty-opinions-score/ dated April 20, 2021; reaccessed on September 12, 2021). A PHP program using Puppeteer was written and ran on May 17, 2021, to get these scores.

For each retracted or corrected article, the original article and notice on the retraction date and reason were collected. Reasons adopted the Retraction Watch's schema (Appendix A).

Advanced searches using doi in Web of Science (WoS) generated two output files, one with citation counts by year of all 232 retracted articles; one with full bibliographic records of the 232 retracted articles (including authors' affiliations, funding agencies, and WoS categories). For post-retraction citing, each retracted article is searched to generate an output file including all post-retraction citing articles; for OA citing articles, a link from Web of Science provides direct access to the article. A relational database was built to integrate data from the above sources (Appendix B).

3.2. Analysis

Descriptive statistics provide a big picture of the 232 articles and their recommendations based on the data from Faculty Opinions. Post-retraction citations were derived by counting from one year after the retraction year as [41]. Thus, all 2019 retracted papers were not included in the analysis. Therefore, 174 of the 232 articles retracted in 2018 or earlier (excluding corrected articles) were cited post-retraction as of 2020. The analyses differentiate correction from retraction in some contexts, such as reasons and citations.

Citation analysis focuses on post-retraction cites and factors as derived variables including 1) time took to retract, 2) post-retraction citing span (number of years after retraction before no cite), 3) number of peak cites (the article received most citations in a specific year), 4) number of years to reach peak citations (the year with the most cites), 5) retraction before or after peak citation year.

Nonparametric tests of correlations between

- post-retraction cites and pre-retraction cites
- post-retraction cites and peak cites
- post-retraction cites and time took to retract
- post-retraction cites and post-retraction citing span
- post-retraction citing span and years reached peak cites
- differences for articles retracted before or after peak citation year

4. Results

Based on COPE Retraction guidelines [40], retracted articles are different from the corrected articles. They should be treated differently.

4.1. Which recommended articles were retracted or corrected?

The recommendations to retracted articles vs corrected articles are summarized in Table 1. More articles were retracted than corrected. The highly recommended articles are in the retraction group. Although these retracted articles continue to receive citations, this group received fewer citations after retraction than the corrected articles.

Table 1. Descriptive statistics of retracted and corrected articles

Article's Status	Total FMs (dissent included)	Total Stars	Weighted sum of stars [1]	Score [1]	Total Citations	Post-Retract Cites
Retracted (n=209; 90.09%)						
Mean	1.8	3.2	3.5	16.6	135.8	29.8
SD	1.6	3.4	4.1	19.4	213.5	47.5
Median	1	2	2	9.5	77	16
Range	1 - *14*	1 – *28*	1 – 35	4.7 - 163.1	0 – 2407	0 – 338
Corrected (n=23; 9.91%)						
Mean	1.9	3.6	4.0	19.5	393.2	208.4
SD	1.3	4.0	4.0	18.8	376.4	306.7
Median	1	2	2	10.3	248	66
Range	1 - *5*	1 – *14*	1 – 18	4.7 – 84.3	45 - 1460	10 -1282

[1] Two measures from Faculty Opinions (See Figure 1)

The top 10 recommended retracted/corrected articles (Table 2) were published in prestigious journals: *Nature*, *Science, The Journal of Experimental Medicine*, *New England Journal of Medicine*, and *Cell.* After publications, these articles were retracted between 4.67 months and 15.22 years or corrected between 1.49 and 9.76 years. The top 7 *Science* article published on 11/1/2002 and retracted on 1/23/2004 got the highest percentage of post-retraction cites (47.62%); further, six of the seven FMs posted recommendations after the retraction date, which will be discussed in Section 5.

As mentioned in 2.1, Faculty Opinions introduced two new measures, Score and Weighted sum of stars and they are periodically updated. For this study, we ranked the articles according to the strategy [42,43]. Based on the new measures, the top 1 article will remain top 1, but the top 2 would become top 3 by Weighted sum of stars and top-4 by Score.

[Table 2 in the landscape is placed at the end of the paper]

4.2. The characteristics of the retracted or corrected articles

The 232 retracted articles were published in 74 journals (Table 3) with 1,881 authors from 34 countries. The top journals are *Nature*, *Science*, *Cell*, *Journal of Biological Chemistry*, and *Proceedings of the National Academy of Sciences of (USA)*. For co-authorship, seven co-authors counted for 27 (12%), five co-authors counted for 25 (11%), and four co-authors 20 (9%), etc. Only three articles were single-authored; the highest co-authorship was 27 co-authors. Of the 1,881 authors, the majority 1759 (93.51%) participated in one article; 108 (5.74%) in two articles; 10 (0.53%) in three articles; three in four articles (0.16%), and

one in eight articles (0.05%). The countries based on authors' affiliations (Table 4) show that 15 countries are on the top 10 list (with ties); a majority of the articles were by authors from affiliations in the USA.

Table 3. The journals by the number of retracted articles

Journal	Articles	Percentage
Nature	34	14.66%
Science	24	10.34%
Cell	20	8.62%
Journal of Biological Chemistry	17	7.33%
Proceedings of the National Academy of Sciences (USA)	16	6.90%
Journal of Clinical Investigation	7	3.02%
Journal of Neuroscience	6	2.59%
Molecular Cell	6	2.59%
Anesthesia and Analgesia	5	2.16%
Nature Medicine	4	1.72%
New England Journal of Medicine	4	1.72%
Blood	3	1.29%
Diabetes	3	1.29%
Immunity	3	1.29%
Journal of Experimental Medicine	3	1.29%
Nature Immunology	3	1.29%
PLoS ONE	3	1.29%

The rest of 57 journals for 71 articles: 14 had two articles and 43 had one article (30.60%)

Table 4. Top 10 Countries of Authors' Affiliations [1]

Country	Frequency	Percentage
USA	469	47.96%
France	52	5.32%
Germany	50	5.11%
Spain	50	5.11%
England	43	4.40%
China	38	3.89%
Japan	38	3.89%
Canada	25	2.56%
South Korea	21	2.15%
Italy	19	1.94%
Switzerland	19	1.94%
Israel	15	1.53%
Singapore	15	1.53%
Netherlands	14	1.43%
Other 20 countries (see note)[2]	110	11.25%

[1] For articles with multiple authors from the same affiliation, the affiliation is counted only once.
[2] In descending order by count (from 13 to 1): Egypt, Brazil, India, Scotland, Ireland, Denmark, Iran, Taiwan, Tunisia, Australia, Finland, Belgium, Sweden, Argentina, Wales, Austria, South Africa, Portugal, Luxembourg, and the Czech Republic

Funding acknowledgments occurred in 165 articles (71.12%) about 246 founders including government agencies, associations (e.g., German Research Foundation),

charitable trusts (e.g., Leona M. and Harry B. Helmsley Charitable Trust), or companies (e.g., Pfizer, AstraZeneca, etc.). The WoS full bibliographic records include only the names of the funding agencies, not the number of funds. Thus, we only count the number of funding sources at the top level of the organization (e.g., NIH represents any of them individually named Institute in the National Institutes of Health). A total of 106 articles acknowledged NIH as the funding source (Table 5). The 11 articles in Table 6 received funds from at least 8 different sources. The authorship of the highly funded articles shows greater than average co-authors (Mean= 8 co-authors for the 232 articles) and published in top journals, *Nature*, *New England Journal of Medicine*, and *Cell* (Table 6).

Table 5. Top funders of the 165 articles' research

Funding Source	Articles	Percent
Nationals Institutes of Health, USA (NIH)	106	64.24%
Ministry of Education, Culture, Sports, Science & Technology, Japan (MEXT)	12	7.27%
Wellcome Trust, UK	10	6.06%
European Research Council (ERC)	9	5.45%
National Natural Science Foundation, China (NSFC)	7	4.24%
Swiss National Science Foundation, Switzerland (SNSF)	5	3.03%
National Science Foundation, USA (NSF)	5	3.03%
Crohn's & Colitis Foundation of America, USA (CCFA)	5	3.03%

The remaining 238 funders occurred in 4 articles or less

Table 6. Top 5 funded articles

Article	Funders	Co-authored	Type
10.1056/NEJMoa1712231	18	10	Retracted
10.1038/nature12745	14	27	Corrigendum
10.1038/nature12587	10	26	Corrigendum
10.1038/nature07409	10	15	Retracted
10.1016/j.cell.2012.02.051	10	18	Retracted

4.3. Reasons caused retractions and corrections

By accessing the journals' retraction or correction notices, we assigned reasons to 225 articles adopting the scheme [44]; the 7 articles published in the *Journal of Biological Chemistry* simply noted the article withdrawn by the authors. The top 4 retractions or corrections (Table 7) were due to 1) Error in Data, Image, Analyses, Methods, Results, or Text; 2) Falsification/Fabrication, Unreliable Data, Image, or Results; 3) Unreliable Data, Image, or Results; 4) Results not Reproducible. The paper falsified data was given a second chance to correct (the shaded cell in Table 7), which we zeroed in the history of the paper (https://www.pnas.org/content/115/14/E3325). Although the committee concluded that the erroneous Fig. 2D was intentional, a correction to it "does not impact the interpretation of the data." We coded this paper as both Falsification image and Error in image. Also in Table 7, two retractions withdrawn by the authors were due to their cited papers were retracted (https://www.nature.com/articles/nature09809; https://www.nature.com/articles/nature09809)

Table 7. Reasons for retraction and frequency

Retraction Reasons	Retracted	Corrected
Error in Data, Image, Analyses, Methods, Results, or Text	74 (28.03%)	13 (4.92%)
Falsification/Fabrication of Data, Image, or Results	53 (20.08%)	1[1] (0.38%)
Unreliable Data, Image, or Results	42 (15.91%)	8 (3.03%)
Results not Reproducible	41 (15.53%)	
Lack of IRB/IACUC Approval	7 (2.65%)	
Self-plagiarism	5 (1.89%)	
Plagiarism of Article, Data, Image, or Text	4 (1.52%)	
Ethical Violations by Author	3 (1.14%)	
Cites Retracted Work	*2* (0.76%)	
Misconduct – Official Investigation/Finding	1 (0.38%)	
Legal Reasons/Legal Threats	1 (0.38%)	
Informed/Patient Consent – None/Withdrawn	1 (0.38%)	1 (0.38%)

[1] See text for the reason why this paper was corrected, not retracted

4.4. How FMs recommended and dissented the articles and withdrew their recommendations

The 232 retracted articles received a total of 410 recommendations and eight dissents from 371 FMs whose affiliations are in 25 countries (USA counted for 56.33% followed by UK 8.09%, Germany 6.20%, France 4.04%, and Canada and Australia each 3.50%). Recommendations were made between 216 days before the publication date, behind the online first date, and 3,413 days after the publication date. Surprisingly, there were 11 recommendations dated after the retraction/correction dates (between 2 and 306 days). These articles, ranked by the recommendations, show two long-tail plots (Figure 2). The majority of the articles were recommended by one FM (144 articles or 62.07%). The top recommended article had a total of 28 stars from 13 FMs, which also had one dissent (without rating). For the 144 one-recommendation articles, 19 got 3-star (13.19%); 63 got 2-star (43.75%); and 62 got 1-star (43.06%). For the articles recommended by more than one FM, the ratings vary. For the 52 2-FM articles, only one got 3-star from both FMs (1.92%); 14 articles got 2-star from both (26.92%); and 11 articles got 1-star from both (21.15%); the other 26 articles had mixed ratings: 1 and 3 (7.69%), 1 and 2 (30.77%); 2 and 3 (11.54%). The grand mean is 1.79 (SD=0.76). The affiliations of the 371 FMs are in 25 countries: USA (209), UK (30), Germany (23), France (15), Australia (13), Canada (13), Japan (12), and the rest 18 countries (56).

Because assigning categories is optional. 6 recommendations and one article had no assigned categories. The 404 recommendations assigned 636 categories to the 231 articles (Table 8). On average, there are 1.56 categories per recommendation and 1.86 categories per article (the same categories from different FMs were consolidated). The top category is New Finding.

Table 8. Categories occurred in recommendations [1] and articles [2]

Category	in Recommendations [1]	assigned to Articles [2]
New Finding	321 (50.47%)	186 (43 26%)
Interesting Hypothesis	83 (13.05%)	69 (16.05%)
Technical Advance	56 (8.81%)	35 (8.14%)
Novel Drug Target	55 (8.65%)	39 (9.07%)
Confirmation	51 (8.02%)	41 (9.53%)
Controversial	32 (5.05%)	26 (6.05%)
Good for Teaching	28 (4.40%)	24 (5.58%)
Refutation	3 (.47%)	3 (.70%)
Clinical Trial: Non-RCT	2 (.31%)	2 (.47%)
Negative / Null Results	2 (.31%)	2 (.47%)
Review / Commentary	2 (.31%)	2 (.47%)
Changes clinical practice	1 (.16%)	1 (.23%)
Total	*636 (100%)*	*430 (100%)*

[1] A FM may assign multiple categories to an article

[2] An article may be assigned the same category by multiple FMs and this category was only counted once

Dissenting and withdrawing recommendations. Dissent posts always followed at least one recommendation. The seven dissented articles were published in *Science* (3) and in *Genome Biology*, *Nature*, *Nature Medicine*, and *Proceedings of the National Academy of Science*, respectively. The *Science* article (10.1126/science.1174094), recommended by one FM (assigned 2-star and classified as Interesting Hypothesis and Controversial), received two dissents (one posted on the same day as the recommendation and the other 8 days later). This article was retracted one year and a month after publication, but the recommendation has not been withdrawn. The two top-recommended articles each also have a dissent (see Table 2). For the top article in *Nature*, six of the 13 FMs withdrew recommendations after the dissent posted on March 11, 2014, and the other seven FMs also withdrew after its retraction on July 2, 2014. The top 2 article in *Science* retracted on December 23, 2011, but none of the nine recommendations was withdrawn. In some cases, withdrawal also happened before the journal's retraction when an investigation of the research started. For example, an FM withdrew a recommendation after the journal had issued an Expression of Concern; the formal retraction of the article only happened 1,794 days after the Expression of Concern. (https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(19)30542-2/fulltext)

Of the 410 recommendations, only 61 (14.88%) were withdrawn between March 20, 2014, and June 8, 2020. These recommendations were about 44 articles that were published between August 27, 2004, and May 22, 2020; retracted between April 12, 2014, and June 5, 2020. The remaining 349 recommendations (85.12%) to 207 articles were not withdrawn. Several recommendations were withdrawn before retractions as a result of another FM's dissent or an investigation of the research. The results show: 1) a very low percentage of recommendation withdrawal; 2) none of the recommendations withdrew before 2014. By zeroing in the 61 withdrawn recommendations to the 44 articles, we observed that 19

articles were recommended by more than one FM; for articles by multiple FMs, only three had all recommendations withdrawn; the other 16 articles had at least one recommendation not withdrawn. Between April 12, 2014, and June 5, 2020, there were 60 retracted articles, none of the recommendations was withdrawn. The data cannot explain why no recommendation was withdrawn before 2014.

4.5. Post-retraction citing

Included in the post-retraction citing analysis are the articles retracted in 2018 or before to allow citation delay. The post-retraction cites included all cites one year after retraction. Thus, for 2018 retracted articles, only citing articles published in 2020 meet the threshold. In the final dataset, there are 174 articles, published between 2004 and 2018, retracted between 2006 and 2018, excluding the 23 corrected articles and nine articles without post-retraction cites. Retraction took place as early as 1.7 months and as late as 13.72 years. The post-retraction cites counted for 4,055, which is 16.89% of the 24,007 citations these articles received. Table 9 summarizes this dataset.

Results of *Spearman's rho* tests of correlations between

- post-retraction cites and pre-retraction cites (.527; p <.001)
- post-retraction cites and peak cites (.636; p <.001)
- post-retraction cites and time taken to retract (-.070; negative but not significant)
- post-retraction cites and post-retraction citing span (.497, p < .001)
- post-retraction citing span and years reached peak cites (-.652; p <.001)

Table 9. Post-retraction citations (n=4,055) to the retracted articles (n=174)

	Time took to Retract (month)	Post-retraction Cites (%)	Post-retraction Citing Span (Years)	Peak Cites	Years Reached Peak Cites
Median	40	11.50	6	21	2
Mean	47.07	22.03 (20.19)	5.85	30.26	2.33
SD	35.55	37.79 (16.36)	2.72	38.87	1.58
Min	1.70	1	2	2	Immediacy [1]
Max	164.67	375	15	402	9

[1] Six articles had peak cites in their publication year; their total citations ranged between 3 and 153; their post-retraction cites ranged between 1 and 36.

To observe differences between articles retracted at different citation life-cycle, the peak citation year was used as the threshold to partition the 174 articles (Table 10). Nonparametric tests (Mann-Whitney Test) found no significant differences in post-retraction cites or total cites between G_2 and G_3 (Table 10) although difference (p <.05) in pre-retraction cites was observed. Since the focus is on the post-retraction citing and G_3 is a small group, G_2 and G_3 are merged to form G_{2+3} (n=69) to compare with G_1 (n=105). Articles retracted before peak citation year (G_1) has significantly greater pre-retraction cites (U=1570.5; p < .001), higher peak cites (U= 2616.5; p < .005) and took longer (more months) to retract (U=634.5; p < .001). There was no significant difference in post-retraction cites between G_1 and G_{2+3} (U=3554.5, p = .834).

Table 10. Retraction year and the peak-cites year

Retracted	Before Peak-Cites Year (n=105) [G_1]		Same Year as Peak-Cites Year (61) [G_2]		After Peak-Cites Year (n=8) [G_3]	
Cites	Pre-retraction	Post-retraction	Pre-retraction	Post-retraction	Pre-retraction	Post-retraction
Median	88	13	34	10	15	13
Mean	154.70	19.99	61.95	24.61	19.00	29.13
SD	253.62	27.57	93.18	50.96	17.05	39.40
Min	11	1	2	1	3	1
Max	2,360	200	573	375	46	116

The two plots represent the number of retracted articles being cited post-retraction and the total cites by year (Figure 3). An increase in citations in 2016 and a decrease in 2019 are visible.

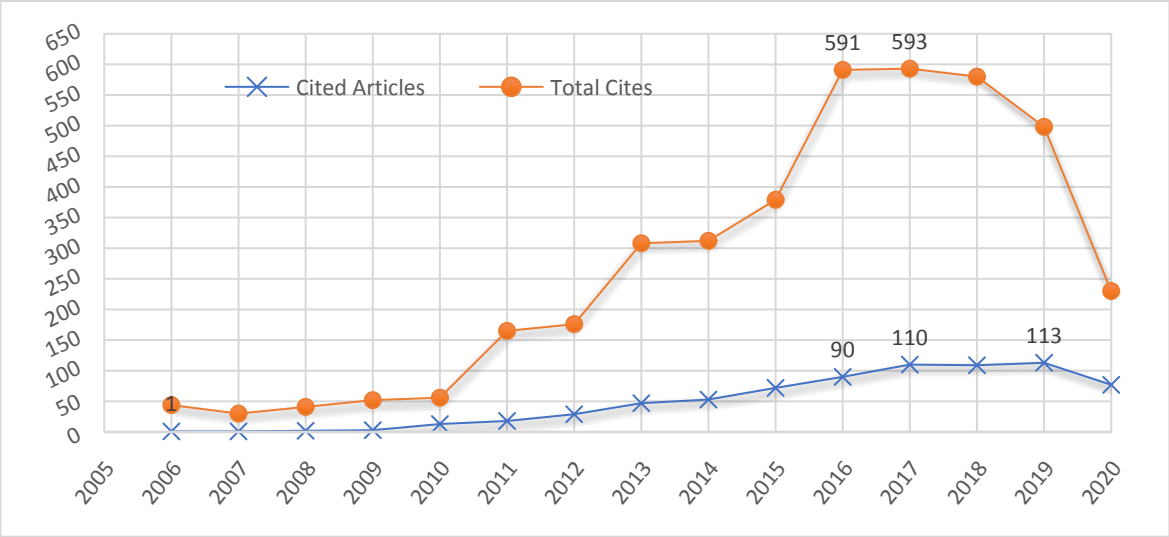

Figure 3. Post-retraction cites of the retracted articles each year

5. Discussion

The results in Section 4 show that the majority of the recommended articles were published in high-impact journals with New Finding. These articles received multiple funding resources (mostly from NIH), involved a high number of co-authors whose affiliations were in the USA. These articles were retracted or corrected mainly because of an *error* in data, image, analysis, methods, results, or text; *falsification/fabrication* of data, image, or results; *unreliable* data, image, or results; and results not *reproducible*. "Retraction reasons should be communicated more clearly to the public." [2] Although the records in Faculty Opinions flag the retracted or corrected articles, and Web of Science also tag "retraction" in Document Type, neither system provides the reasons for retractions. Seven articles from one journal in our dataset only had a note: "This article has been withdrawn by the authors." This is similar to the ambiguous reasons for retraction [18].

The time took to retract a published article ranged from less than 2 months to more than 13 years (Table 9). During this time, articles were cited as valid research outputs and could affect post-retraction citing. The post-retraction cites are positively correlated with pre-retraction cites, peak cites, and post-retraction citing span (Section 4.5). Post-retraction citing spanned 15 years in some cases. Although previous studies show that most biomedical journal articles started to see a decrease in cites after the peak-cite year [42,43], a few articles in this study continue to receive relatively higher cites post retraction. This phenomenon should be zeroed in because the efficacy of retractions was not assured. The top 7 article (Table 2) published in *Science* was a case in point. Published on 1 November 2002, it was recommended by an FM on 15 November 2002 (assigned 2-star, Confirmation). On 23 January 2004, the authors published "Retraction of an Interpretation," which referenced the 2002 article but from the 2002 article, neither a hyperlink to this retraction notice nor a note about this retraction. This could explain why after retraction six FMs recommended this article dated between February 2 and 12, 2004 assigned 1 to 3 stars and additional categories: New Finding (4), Controversial (3), and Interesting Hypothesis (1). Although Faculty Opinions' editorial note has the link to the retraction, the undated link reached 404 (page does not exist). The retraction note's volume and page were in Web of Science search results. This notice is not freely accessible (https://www.science.org/lookup/doi/10.1126/science.303.5657.467b). Without a subscription, the charge is $30 for the article and $30 for the retraction notice.

The other two *Science* articles in Table 2, one retracted (top 2) and one corrected (top 9) are indicated as retracted or corrected in the HTML version. We found that journals handled retractions/corrections differently: 1) both the HTML and pdf versions indicated the correction or retraction with date-stamp; 2) the HTML version had a hyperlink named Related Article (e.g., *Journal of Biological Chemistry*) to a later issue's section "Additions and Corrections" that published one or more notices for retraction or correction; 3) the pdf version article has a "Retracted" watermark (with or without date-stamp) or note on margins; 4) no open access to the retracted articles; 5) no open access to the retraction notes, 6) no reasons for retraction. Open access to the retracted papers was given by many journals although COPE Retraction guidelines [40] only suggest that retraction notices should "Be freely available to all readers (ie, not behind access barriers or available only to subscribers)"; "State the reason(s) for retraction" (p. 3)

We made an exploratory search of the post-retraction citing articles to 5 retracted articles to check if these citing articles noted the retraction in the text or references. Out of the 487 post-retraction citing articles, only 12 acknowledged the retraction and two cited both the retracted article and the retraction notice. A follow-up with a systematic data collection should examine post-retraction citing status. There are several possibilities for citing retracted articles: 1) the authors accessed and collected the article before its retraction, 2) the authors cited the article from tertiary sources such as references of the citing articles, 3) the paper's HTML version did not indicate the retraction.

The questions remain about the small percentage of withdrawals of recommendations to the retracted articles in Faculty Opinions: Were the FMs notified about the retractions when the Editorial Notes were added to their recommendations? Did FMs decide that the nature of the retraction had not changed what they recommended about the article? Could they add a rationale on why they would keep the recommendation as is?

Can some errors be avoided? For the few corrected articles in our dataset, it seems possible to avoid these errors. Benchimol et al. [45] made "an appeal to authors, publishers, editors, and peer reviewers to endorse and effectively implement the correct reporting guidelines in their submission and evaluation of manuscripts." (p. 1419) Facing high pressure to publish, scientists are measured on productivity metrics. However, "when a measure becomes a target, it ceases to be a good measure." [46] It was more than 20 years ago Pfeifer and Snodgrass [47] observed "Methods currently in place to remove invalid literature from use appear to be grossly inadequate. Regardless of strides made in controlling fraud, error is generally considered an inherent and inevitable aspect of research, and efficient removal of invalid information from the literature would serve science well." (p. 1423) Today, the situation remains concerning so that "improvements are needed from publishers, bibliographic databases, and citation management software to ensure that retracted articles are accurately documented." [48]

6. Conclusions and Implications

This study analyzed the retractions of the peer-reviewed and expert-recommended biomedical journal articles. Retractions from scientific literature not only wasted resources but also have a long-term negative impact on the validity of scientific literature. When the post-retraction citing researchers unaware of the fraud or errors, subsequent research is misled. There are several approaches to improve the efficacy of retraction to ensure the validity of scientific literature.

First, journals need to ensure that the retracted articles are clearly and visibly identified; "retracted" should be added to the how-to-cite citations. From the submission of the manuscript to the production of the published paper, there are many opportunities for checking references to notify the authors and reviewers about any cited articles being retracted/corrected. Most importantly, retracted papers and their retraction notices should be open access rather than fee-based.

Second, databases such as PubMed, Web of Science add notes to the retracted articles (with some got missed). These notes only can help users who encounter the retracted articles after the retraction notes were added. Given retractions took longer to process, the users who accessed these articles prior to the retraction should be notified. The expert recommendation systems such as Faculty Opinions need to notify all recommending FMs and the users who accessed these recommendations before articles' retractions about the retractions in addition to adding an editorial note. If an FM decides to keep a recommendation, the FM should justify it for the users who depend on experts' evaluations.

Third, authors are ultimately responsible for conducting rigorous research and following reporting guidelines. For multi-authorships, a contribution statement should include who checked internal validity (on data, images, analyses, results, and interpretations), reporting guidelines, and references. During the galley proof, a final reference rechecking should access the original articles to ensure the cited articles are still valid. This final reference checking is extremely important for systematic review and meta-analyses articles in biomedical literature.

7. Acknowledgement

[to be added]

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Appendix A. Retraction Watch defined reasons adopted and found in this study [1] [44]

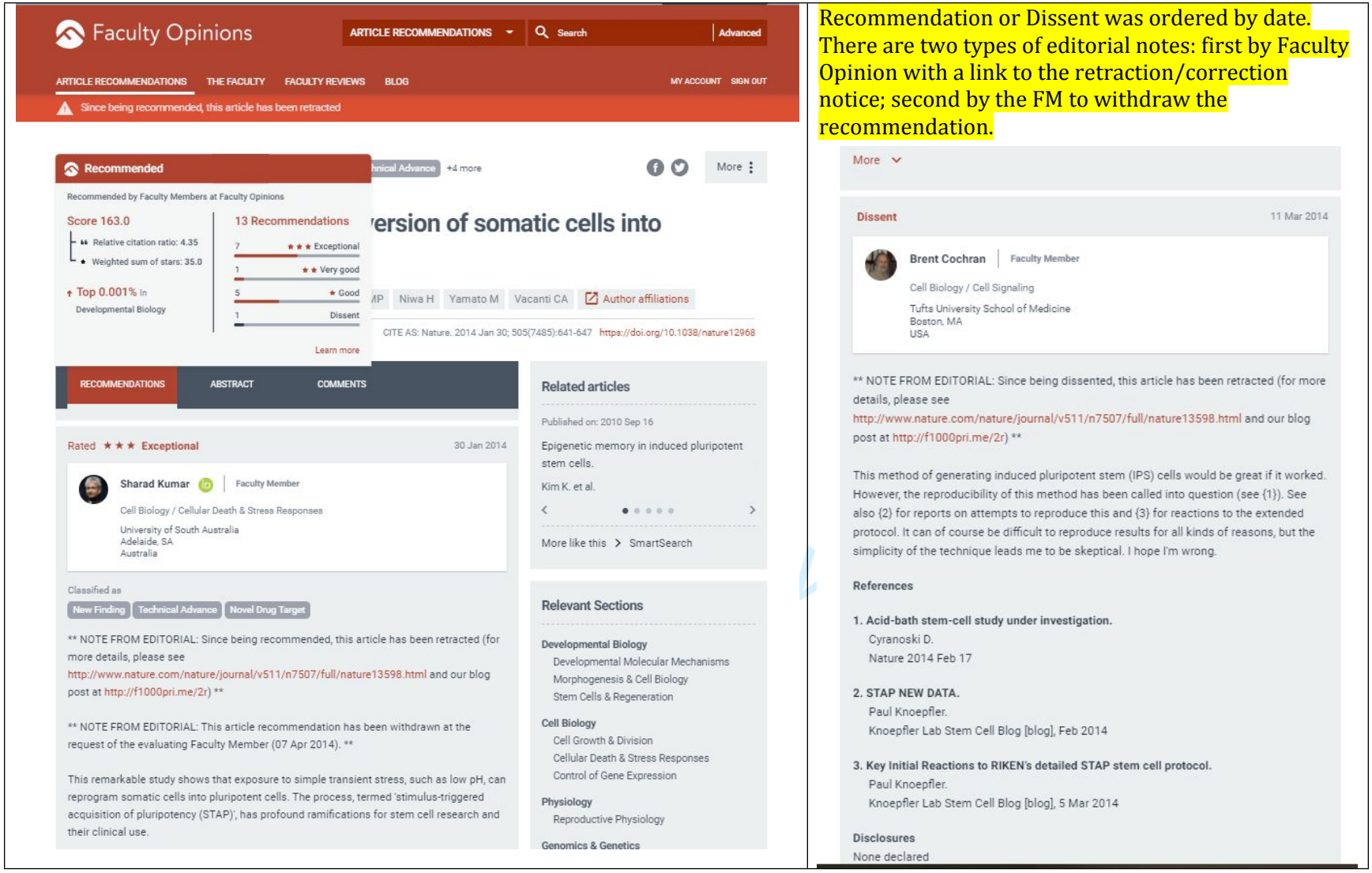
Reason	Description
• Cites Retracted Work	• A retracted item is used in citations or referencing
• Error in Data, Image, Analyses, Methods, Results, or Text	• A mistake made in the data, or preparation or printing of an image, in the evaluation of the data or calculations, or experimental protocol, or determining results or establishing conclusions, or written portion
• Ethical Violations by Author	• When an author performs an action contrary to accepted standards of behavior.
• Falsification/Fabrication of Data, Image, or Results	• Intentional changes to data, an image, or results so that it is not representative of the actual finding
• Informed/Patient Consent – None/Withdrawn	• When the full risks and benefits from being in an experiment are not provided to and accepted by the participant, or the participant chooses to later recant their approval
• Lack of IRB/IACUC Approval	• Failure to obtain consent from the institutional ethical review board overseeing human or animal experimentation prior to initiation of study, or failure to provide proof of such
• Legal Reasons/Legal Threats	• Actions taken to avoid or foster litigation
• Misconduct – Official Investigation/Finding	• Finding of misconduct after investigation by incorporated company, institution of governmental agency
• Plagiarism of Article, Data, Image, or Text	• Used when an entire published item, or undefined sections of it, and not written by one or all authors of the original article, are repeated in the original article without appropriate citation. (this definition also applied to data, image, and text)
• Results Not Reproducible	• Experiments conducted, using the same materials and methods, that fail to replicate the finding of the original article
• Self-plagiarism	• Duplicate a published item, or undefined sections of it, written by one or all authors of the original article, are repeated in the original article without appropriate citation.
• Unreliable Data, Image, or Results	• The accuracy or validity of the data, image, or results is questionable

[1] A set of granular reasons of the same nature such as the four types of Plagiarism (article, data, image, or text) aggregated as one

Appendix B. Data Model

RETRACTED_ARTICLES (**Retract_doi**, Title, (Metrics), {(Author, Affiliation)}, Journal, PublicationDate, RetractDate, [PreRetractCites], [PeekCites], [PeekCitesYear], [PostRetractCites], [PostRetractCitingSpan], {Funding}, {*Reason}*)
RETRACTION_REASONS (**Reason**, Description)
RECOMMENDATIONS (**RecomendID**, *Retract_doi*, (FM, Affiliation), RecommendDate, RatingStar, {Classified_as}, Commentary, WithdrawnDate)
CITATIONS (***Retract_doi***, TotalCites, (2001, ..., 2020))
POST_RETRACT_CITATIONS (**Citing_doi**, ***Retract_doi***, mentioned_retracton, cited_retraction_notice)

Database structure to integrate data from multiple sources. This model uses text notation for the data model. Relations are named using the upper case with underlined bold attribute as PK, underlined *italicized* attributes as FK, underlined *bold italicized* for an attribute that is both PK and FK, round brackets ( ) for composite attributes, curly brackets { } for multi-valued attributes, and square brackets [ ] for derived values). When multiple authors of an article are from the same affiliation, for this article, this affiliation is counted only once. Because of varied formats in names, an organization's country is the only unambiguous element. For Dissent entries, it is a record in RECOMMENDATION, but the value for Star is "0" because no rating was associated with dissent entries.



Recommendation or Dissent was ordered by date. There are two types of editorial notes: first by Faculty Opinion with a link to the retraction/correction notice; second by the FM to withdraw the recommendation.

Figure 1. Partial screenshot of a retracted article (Dissent is included; not all recommendations are included)

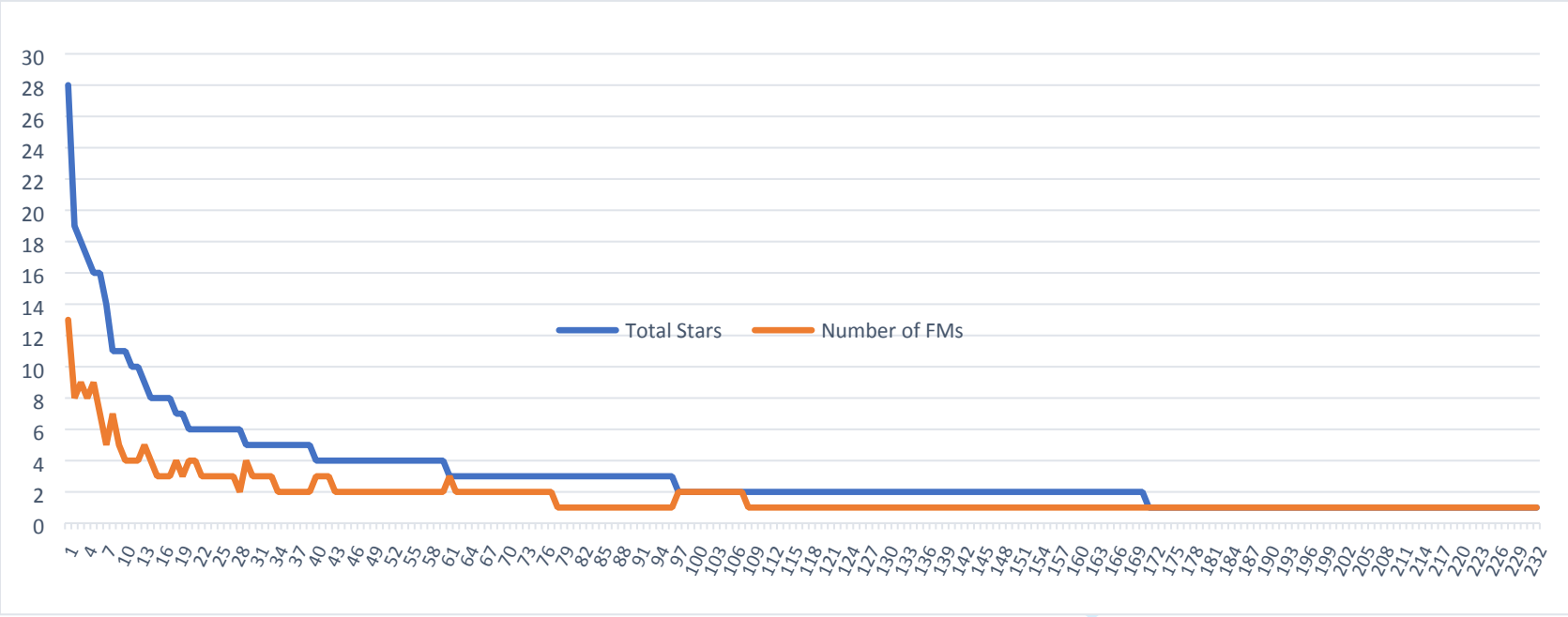


Figure 2. The 232 ranked articles by total stars and number of recommending FMs

Table 2. Top recommended articles measured by Total recommending RMs and total Stars.

Article doi (leading 10.)	Pub Date	Total FMs[1]	Total Dissents	Dissent date	Total Stars	Weighted Sum Stars	Score	Total Cites	Post-Retract Cites (%)	Retract/ correct Date
1038/nature12968	1/30/2014	13	1	3/11/2014	28	35	163.1	153	28 (18.30)	7/2/2014
1126/science.1179052	10/23/2009	9	1	11/18/2009	18	21	98.4	400	85 (21.25)	12/23/2011
1084/jem.20100730	7/4/2011	9			16	16	74.5	49	22 (44.90)	11/21/2011
1038/nature07199	8/14/2008	8			19	22	102.4	20	3 (15.00)	4/8/2010
1056/NEJMoa1200303	4/4/2003	8			17	20	99.4	2407	47 (1.95)	6/21/2018
1016/j.cell.2013.04.008	5/9/2013	7			16	20	93.8	321	23 (7.17)	1/12/2017
1126/science.1076185	11/1/2002	7			11	12	56.3	378	180 (47.62)	1/23/2004
1038/nature12587	*10/3/2013*	*5*			*14*	*18*	*84.3*	*344*	*103 (29.94)*	*4/1/2015*
1126/science.1126088	*4/21/2006*	*5*			*11*	*12*	*57.1*	*1072*	*196 (18.28)*	*1/22/2016*
1038/nature04836	7/6/2006	5			9	10	46.8	202	69 (34.16)	1/31/2008

[1] Not including dissent FM; the italicized articles were corrected