Abstract

This paper provides insight into the changes manuscripts undergo during peer review, the potential reasons for these changes, and the differences between scientific fields. A growing body of literature is assessing the effect of peer review on manuscripts, however much of this research currently focuses on the social and medical sciences. We matched more than 6,000 preprint-publication pairs across multiple fields and quantified the changes in their reference lists. We also quantified the change in references per full-text section for 565 pairs from PLOS journals. In addition, we conducted manual checks of a randomly chosen sample of 98 pairs to validate our results, and undertook a qualitative analysis based on the context of the reference to investigate the potential reasons for reference changes. We found 10 disciplines, mostly in the natural sciences with high levels of removed references. Methods sections undergo the most relative change in the natural sciences, while in the medical and health sciences, the results and discussion sections underwent the most changes. Our qualitative analysis identified issues with our results due to incomplete preprint reference lists. In addition, we deduced 10 themes for changing references during peer review. This analysis suggested that manuscripts in the natural and medical sciences undergo more extensive reframing of the literature used to situate and interpret the results of studies than the social and agricultural sciences, which are further embedded in the existing literature through peer review. Peer review in engineering tends to focus on methodological details. Our results are useful to the body of literature examining the effectiveness of peer review in fulfilling its intended purposes.

Keywords: Peer Review; Preprints; Reference Lists Changes; Peer Review Impact

Introduction

Academic publishing is a social process. Academics do not develop their ideas in isolation, but draw on prior work from other members of the academic community to formulate hypotheses and devise studies. Most of the time, academics then cite these prior works when writing manuscripts to build their arguments and demonstrate where their study belongs in the larger body of academic literature. On the one hand, academics use citations to persuade other members of the academic community of the soundness of their claims (Gilbert, 1977), to agree with previous literature, or to note their differences and potential disagreements (Bruggeman, Traag, & Uitermark, 2012; Murray, 2020). On the other hand, there is evidence that social processes affect which studies are cited beyond the academic merit of a study. Examples include higher rates of self-reference of national colleagues (Khelfaoui, Larrègue, Larivière, & Gingras, 2020) or the tendency for the work of female academics to receive fewer citations than that of their male peers (Maliniak, Powers, & Walter, 2013; Dworkin et al., 2020). Thus, the act of citing prior work is affected by social factors, alongside considerations such as the relevance of the work to the author’s current study and its academic merit. Cumulatively, these citing behaviours can have career implications for academics via their influence on the impact of these previous studies and the reputation of their authors and in the longer term provide a “cumulative advantage” for the previously more cited authors (Merton, 1968) in shape of an upward spiral.

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Furthermore, although academics may author a publication, they do not solely determine a publication’s content. Journal editors and peer reviewers also play key and distinct roles in influencing the content of manuscripts through the academic publication process. Editors screen submitted manuscripts for relevance to the journal’s topical orientation and evidence of misconduct, before tasking peer reviewers with providing their expert opinions on the manuscript’s soundness and contribution to existing knowledge, then applying these insights in a final decision about publishing the manuscript (Hirschauer, 2010). Editors and peer reviewers are individuals working in the same academic system, likely as academics themselves, and are affected by similar factors shaping citing behaviour (Teplitskiy, Acuna, Elamrani-Raoult, Körding, & Evans, 2018). There are social processes at work to determine editorial board memberships (Miniaci & Pezzi, 2020). Editors and reviewers have specific goals, ideas and values of “an ideal scientific contribution”, and editors evaluate academic manuscripts submitted to their journals in the light of these ideals (Hengel, 2017). In a larger scope, this empowers particular academic schools of thought through editorial decisions and strategies (Teplitskiy et al., 2018). It fosters a mainstream line of thought that can in turn penalize novelty and innovative academic work (Hořstra et al., 2020) that would be disruptive to the larger body of literature accepted by a given subset of the community (Wu, Wang, & Evans, 2017). Thus, one or multiple normalizing processes are at work in shaping what subjects should be studied, which prior works should be cited, and how and in which form academic ideas should be expressed to be accepted for publication in mainstream outlets.

Clearly then, the peer review process is a major cornerstone of the academic system. More formally, peer review is broadly agreed upon by the academic community to serve two functions: it should improve the quality of a manuscript as a communication tool, and it should screen studies for academic rigour to identify their shortcomings so that they may be addressed, or reject those studies that are irretrievably flawed (De Vries, Marschall, & Stein, 2009). Nevertheless, peer review could play other less explicit roles for the academic system beyond these two main functions (Hirschauer, 2010). In the context of a growing body of research questioning the effectiveness of peer review in performing these two functions, several studies have investigated the effect peer review has on manuscripts. These have been conducted through diverse means, such as surveys of authors’ experiences with changes requested by peer reviewers (Strang & Siler, 2015), comparing text and referencing changes in manuscripts before and after peer review (Teplitskiy, 2016; Klein, Broadwell, Farb, & Grappone, 2019), assessing post-review manuscripts on, for instance, readability (Hengel, 2017), adherence with reporting guidelines (Hopewell et al., 2014; Carneiro et al., 2020), or multiple aspects of quality as assessed via checklists (Goodman, Berlin, Fletcher, & Fletcher, 1994; Roberts, Fletcher, & Fletcher, 1994) or judged by readers and journal editors (Jefferson, Wager, & Davidoff, 2002).

Many of these studies of changes resulting from peer review have largely focused on the social and medical sciences. Given the different methods and foci of disciplines, the aim of this study was to understand how the peer review process influences manuscripts in different disciplines, as measured through changes in reference lists and the sections most altered between the submitted and published versions. The paper is structured as follows: we first describe previous literature examining the effects of peer review on manuscripts. We then present our data and analytical strategy in methods section, followed by presentation of our results. Finally, we contextualise our findings in relation to previous studies, draw conclusions and discuss the broader impact of our results for the academic system.

Background

Here we first introduce prior studies that had a large scale and quantitative focus on peer review as a field of research. We look also into disciplinary differences in editorial practices. In addition, we summarise the findings of the studies we identified that have assessed the effects of peer review on changes in content of manuscripts.

Batagelj, Ferligoj, & Squazzoni (2017) present a quantitative study of all publications indexed in Web of Science with peer review or refereeing as their subject (e.g., about 23,000 records). They conclude that a new field of research has emerged, i.e., studies of peer review. Using citation networks and main path analysis, they identified 47 publications that can be considered as the most influential studies in this field. They emphasized on three historical periods where social sciences, biomedical journals and more recently specialist journals of science studies have dominated the studies of peer review.
Miniaci & Pezzoni (2020) investigated factors that can affect researchers’ chances for membership in editorial boards of *economics* journals. They found that merit and academic productivity play a role in determining who is selected as a member of the editorial boards, but, after controlling for all merit based factors, they found that there is a social process at work. Former colleagues, proteges and co-authors of the editor in chief have higher chances to be elected as prospective editorial board members.

Hyland & Jiang (2020) studied 850 review note extracts posted on a website from 2014 to mid-2019 which were extremely critical of the reviewed manuscripts and rough in the used language by the reviewers. They highlight the fact that although peer review is a cornerstone of the academic system, still, there is need for editors to control the process and prevent the detrimental aspects of non-constructive reviews. In addition Pranić, Malički, Marušić, Mehmani, & Marušić (2020) found that authors are more satisfied with constructive review notes and editors think these constructive reviews better guide the editorial decision-making process.

Casnici, Grimaldo, Gilbert, & Squazzoni (2017) studied the review data on 915 submissions to a multi-disciplinary journal. They found that reviewers from different disciplinary backgrounds have differing behaviours in their review and they write different review notes. Junior reviewers took less time and used kinder language towards the authors. Nevertheless, they found that multi-disciplinary journals can establish agreements and evaluation standards on good academic work which requires extensive efforts from the editorial board members and editor in chiefs of journals. This will in turn nurture more impactful multi-disciplinary research instead of suppressing it.

Recent studies of the effect of peer review on manuscripts suggests that peer review, at least in the social sciences, disproportionately focuses on its first function – critically analysing the theoretical framing of studies – rather than the second function of ensuring the studies are methodologically valid (Strang & Siler, 2015; Teplitskiy, 2016). Strang & Siler (2015), using a qualitative analysis of articles published in Administrative Science Quarterly between 2005 and 2009 and supported by a survey of the authors, found that the sections of the articles pertaining to the theoretical framing of studies and the interpretation of results were the sections most altered during peer review, while methodological sections were largely unchanged. Papers’ reference lists grew on average by 26% between submitted and published versions, however this was usually not simply a case of adding citations. Reference lists typically underwent extensive change in line with the degree of criticism around framing and interpretation during review, with references removed and added based on the change in interpretation. Teplitskiy (2016) compared manuscripts in quantitative sociology before and after peer review and similarly found that the manuscripts predominantly changed in their theoretical framing of the study, rather than in the methodology or results. These changes were applied to embed results in a theoretical framework and convey a better relation to the body of literature in sociology (Teplitskiy, 2016). However, this focus on theoretical reframing has the potential to redirect authors’ time in reframing studies that are otherwise methodologically sound and acceptable for publishing, and to homogenise research in line with the field’s accepted frameworks or “schools of thought” (Teplitskiy et al., 2018).

In comparison to these studies from the social sciences, an analysis of arXiv and bioRxiv preprints and their published versions, which were predominately in the physics and biology disciplines, found there was very little change in the titles, abstracts or manuscript text between versions. Around 80% of body sections compared between physics preprints and manuscripts were identical or nearly so, and there was only slightly more variability in biology manuscripts (Klein et al., 2019). This suggests that peer review in these disciplines does not have the same focus on theoretical reframing as the social sciences, and indeed perhaps does not substantially add to manuscripts at all, though it may control the methodological soundness. Note that these preprint servers might host specific disciplinary manuscripts and thus conclusions of the studies using only one of these servers might not be generalizable to other disciplines. Furthermore, depositing a preprint on a server prior to publication is highly skewed toward specific disciplines and there are still disciplinary journals that do not allow authors to post preprint versions of manuscripts submitted to their journal.

Another series of studies have examined the effect of peer review on manuscripts in the medical sciences. Goodman et al. (1994) compared pre- and post-peer review medical manuscripts using a checklist of 34 items administered by physicians. They found that peer review modestly improved overall scores of manuscript quality, and 5 individual items significantly improved, pertaining to the generalisability and certainty of results, and the weight authors gave to the results. Another study also found that the readability of medical
manuscripts was slightly improved with peer review, and the median length of articles increased by 2.6% (Roberts et al., 1994). More recently Hopewell et al. (2014) found in a study examining adherence to CONSORT reporting guidelines for clinical trials that peer review was ineffective in detecting deficient reporting of methods and results. This may have extended from the tendency for ensuring adherence to reporting guidelines to fall within the editor’s realm of responsibility, however the peer review process overall generally prompted only a small number of changes in manuscripts. Further, although most changes improved the quality of reporting, there was also a number of cases where review negatively influenced manuscripts by adding unplanned analyses. Carneiro et al. (2020) similarly found peer review marginally increased reporting quality in their sample of bioRxiv preprints and associated publications, but also that 27% of their pairs decreased in reporting quality between versions. Together these studies suggest peer review has mixed effects on medical manuscripts, but generally slightly improves their content.

In addition to changes suggested by well-intentioned reviewers, unethical review practices can also influence manuscripts under development. Such practices include coercive citations wherein the editor or reviewer unnecessarily requests citations to their own work or work from the journal in which the manuscript is under review. Coercive citation is not an uncommon practice by both reviewers and editors. Wilhite & Fong (2012) found that 20% of nearly 7,000 social scientists had been coerced to add citations to their manuscripts and more than 20% of journals in these fields engaged in coercive practices. Meanwhile, nearly a third of all citations that reviewers recommended were to their own works, and requests for citing the reviewer occurred more often when the reviewer recommended the manuscript was accepted or revised than rejected (Thombs et al., 2015). Although, in a much larger sample of nearly 55,000 reviewers, Baas & Fennell (2019) recorded only 0.79% engaged in citation manipulation. As such, reference changes during peer review may reflect a certain degree of unscrupulous peer review practices, in addition to legitimate revisions of the manuscripts.

As the majority of research into the effect of peer review on manuscripts has occurred in the social and medical sciences and academic disciplines have varying methods and foci, in this study we investigate how peer review influences manuscripts and whether there are identifiable differences between disciplines in the effect of peer review. To do this, we match preprints from bibliometric databases to their published form in a sample of more than 6,000 pairs, and then quantify the changes made to reference lists during peer review across multiple disciplines. Further, we identify the sections of publications that undergo the most extensive referencing changes during peer review. This broad examination enables us to identify whether there are any disciplinary effects in changes to manuscripts during peer review, and what those differences are. In addition, we carry out an extensive gold standard validation of preprint-publication pairs through manual controls of the reference list changes and, via a qualitative analysis of the text surrounding referencing changes, we reflect on the potential reasons for the observed changes.

We acknowledge there are limitations to using references as the measurement of the effect of peer review. For instance, changes may be made to the manuscript which do not affect referencing and these changes will not be captured through our method. However, Strang & Siler (2015) observed moderate correlations between the intensity of peer review critiques and the extent of bibliographic changes made between manuscript versions, with more intense criticism typically associated with greater bibliographic change ($r = 0.31-0.59$), suggesting reference changes might be a suitable proxy for the effect of peer review on manuscripts. Further, a key benefit of this approach that warrants its trial is that the use of reference lists instead of resource-intensive content analysis to identify changes affords us the ability to use a much larger sample size than many previous studies. Our mixed-method study, that utilises an automated process to examine a large sample of publications and a qualitative analysis to further interrogate the reasons for referencing changes, provides useful insights regarding the effect of peer review on manuscripts across different fields to the growing literature examining the effectiveness of peer review in performing its designated functions.

**Methods**

One of the main obstacles hindering studies on reference list changes is the lack of bibliometric databases indexing preprints as a publication type. Dimensions is one of the most recent databases that provides this type of metadata on a large scale. Thus, we matched preprints from the Dimensions database (Dimensions
Resources, 2019) to subsequent publications in journals. We adopted three methodological strategies here: 1) a broad descriptive and quantitative view of all publications and changes in reference lists, 2) a more fine-grained view of publications in PLOS journals with a further probe into references' location in the full-text, in addition to reference list changes and 3) a manual gold standard analysis of a subset of our data to assess the robustness of our conclusions.

As shown in Figure 1, we first identified all preprints indexed in Dimensions using the in-house database of 26th of April 2019 maintained by the German Competence Centre for Bibliometrics (KB). Dimensions includes preprints from popular servers such as arXiv, medRxiv, bioRxiv, SSRN and OSF, to name a few. There are a few notable limitations to Dimensions: Dimensions covers only a subset of all preprints that are deposited in preprint servers and its coverage of reference lists is not complete. In addition, Dimensions, like other bibliometric databases, has a biased coverage of different disciplines and lower coverage for social sciences and humanities has been observed. Bibliometric databases usually merge the preprint records (if they cover any) with the published version of the same record, which makes accessing and tracking changes in the preprint versus published version’s reference lists a difficult task. Further, if there are items that are not yet disambiguated in the Dimensions database, they are not included in the reference lists, which affects both sides of the comparison (i.e., both preprints’ and published items’ reference lists).

Our search of Dimensions returned 373,563 preprints deposited to preprint servers between 2000 and 2018, of which 25,032 had reference lists. We then matched these preprints to publications indexed in the KB’s in-house database of Clarivate’s Web of Science (WOS). We matched preprints to publications published in the same year or subsequent two years based on the Jaro Winkler distance between titles with a threshold of more than 80% similarity for acceptable matches. Matching was conducted using the stringdist package in R (Loo et al., 2020), and identified a total of 2,986 pairs. We used a window of two years after the preprint’s release year to reduce the likelihood of false matches, given that 90% of bioRxiv preprints are published within one year (Abdill & Blekhman, 2019), and to reduce the computational burden of the matching process. We considered titles a viable matching variable as prior studies have found titles to be very stable between preprint and publication versions (Klein et al., 2019).

To complement our data, we also included a set of 3,038 preprint and publication pairs identified and made publicly available by Fraser, Momeni, Mayr, & Peters (2019). They matched preprints submitted to bioRxiv between November 2013 and December 2017 to publications from Crossref, Scopus, and mentioned in bioRxiv publication notices by i) querying DOIs in Crossref’s “relationship” property via the API, ii) by scraping the bioRxiv website for publication notices, and iii) by fuzzy matching to Scopus publications based on author names, title, and the first 100 characters of the abstract, using the Jaro Winkler distance with a threshold of more than 80% similarity (Fraser et al., 2019). In addition, complementing our corpus this way extends our coverage from WOS to Scopus as another major source of bibliometric data.

After matching the preprints to the published versions and obtaining the published DOI, we extracted the reference lists of each published DOI from Dimensions. By using reference data for both preprints and publications from Dimensions, we were able to take advantage of Dimensions’ internal identifiers and match references between the preprint and publication references lists based on the Dimensions’ identifiers, rather than recreating this matching using metadata, which can be more error-prone. Once all reference data had been compiled, we merged all publication sets for both sources and de-duplicated the dataset. We further controlled for publication years (i.e., preprint year had to be equal to or smaller than publication year) and removed four problematic pairs.

We then confronted the preprint reference list against the published version. Following the methodology used by Strang & Siler (2015), we divided the references in each preprint-publication pair into three groups:

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1. Public Library of Science, https://plos.org/
2. Kompetenzzentrum Bibliometrie (KB), http://bibliometrie.info
3. https://app.dimensions.ai/discover/publication?or_facet_publication_type=preprint
4. https://arxiv.org/
5. https://www.medrxiv.org/
6. https://www.biorxiv.org/
7. https://www.ssrn.com/index.cfm/en/
8. https://osf.io/preprints/
9. https://en.wikipedia.org/wiki/Jaro%E2%80%93Winkler_distance
Start from Dimensions preprints

373,563 preprints

Has reference list? (25,032 preprints)

Yes

Matches with Fraser 2018?

Yes

3,038 pairs

No

Matches with WOS?

Yes

2,986 pairs

No

Is published in PLOS journals?

Yes

565 pairs

No

Extract full text citations from PLOS journals' XML

5,459 pairs

Total of 6,024 pairs

Analyze references (added/unchanged/removed)

Figure 1: Preprint and publication matching process
unchanged, added, and removed. “Unchanged” references were those that were included in both reference lists. References that were cited in the preprint but were not cited in the published version were “removed”, while the converse – references cited in the published version that were not cited in the preprint – were “added” references.

We assume the set of references used in preprint and/or publication as the main corpora of literature authors use. Thus, in calculating proportion of changes in reference lists, we take these corpora as the baseline and we do not use only the reference list of published version. For example, if a preprint had five references and two were removed, three were unchanged and one new reference was added, the proportions are calculated based on the total six references in both preprint and publication. See Figure 2 for an example.

| Preprint | Publication | Status |
|----------|-------------|--------|
| Ref. 1   | Ref. 1      | Unchanged |
| Ref. 2   | Ref. 2      | Unchanged |
| Ref. 3   | --          | Removed |
| Ref. 4   | Ref. 4      | Unchanged |
| Ref. 5   | --          | Removed |
|          | Ref. 6      | Added   |

| Status      | Count | Proportion |
|-------------|-------|------------|
| Unchanged   | 3     | 0.50       |
| Removed     | 2     | 0.33       |
| Added       | 1     | 0.17       |

Figure 2: Determining preprint and publication references’ change status

To analyse the sections of publications that were most affected by peer review, we used the full-texts of publications from PLOS journals. These full-texts are XML documents including hyperlinks to cited references within the documents which allowed us to track in which publication sections the references were cited. We downloaded a full corpus in November 2019 and extracted the full-text of publications that were matched to a preprint from WOS or Fraser et al. (2019) data using the published version’s DOI (a total of 565 pairs out of our 6,024 pairs). Although PLOS suggests authors use a unified set of titles for manuscript sections, in practice a diverse set of titles is used (e.g., methods, materials and methods, methods and materials, results, results and discussion, discussion, discussions, discussion and conclusions, conclusions). We first standardised the section names used to Introduction, Method, Results, Discussion and Conclusions, and Supplementary Material and then identified which sections underwent the highest (lowest) changes from preprint to published version based on the proportion of references added or unchanged. As we only had access to full-text of publications in PLOS journals and not their preprints, our full-text section analysis is limited to added and unchanged references’ changes. In-text citations that were not clearly assigned to a section were allocated to an “Unknown” section.

We investigated disciplinary differences on the basis of the OECD’s Fields of Science and Technology (FOS) classification (OECD, 2007). The FOS is a two-level classification comprised of 42 fields at the lower, more detailed level, which aggregate to six major fields: Agricultural Sciences (AS), Engineering Technology (ET), Natural Sciences (NS), Medical and Health Sciences (MHS), Humanities (H) and Social Sciences (SS). We present data on the FOS as a common classification from which we could map data from each of our sources, which use different discipline classifications. We used the native classification from WOS for the pairs’ published versions and then mapped each document to the FOS classification based on a correspondence.
provided by Clarivate Analytics. Please note that some publications are assigned to multiple fields. We present results using multiple counting of publications to each assigned discipline(s).

To control the academic impact of the references added, removed and unchanged, we obtained the cumulative citations received by each reference up to three years after its publication from WOS. We chose this 3-year threshold to allow sufficient time to elapse for accrued citations to be representative of the publication’s impact (Wang, 2013). Please note that citation counts are likely lower for more recent publications (e.g., after 2016) as they have had less than three years to accrue citations. Note also that for the DOIs without a match in WOS (due to difference in indexed records and coverage), the count of citations is considered 0. Finally, we standardised the names of journals of each preprint and publication references and matched them to the journal where the published version appeared to control for citations to the published journal.

Manual validation

To check the accuracy of our matching process and the Dimensions’ reference list data, one of the authors undertook a manual validation process for a sample of pairs, comparing our data against the documents’ versions in the preprint archives and journal websites. For this, we extracted a random sample of 10 pairs from 5 fields and 2 sources (WOS, Fraser’s set), and all 5 pairs from the humanities contained in our dataset. We also included an additional 20 pairs from those published in PLOS journals, 10 each from the medical and natural sciences, to validate our analysis of changes by section. Thus our final sample for manual checks consisted of 125 pairs.

We conducted several checks for accuracy using this sample. First, we compared the preprint and publication titles to assess the accuracy of matching the preprint-publication pairs. For correct matches, we then accessed the reference lists of the preprints and publications in their online versions, where these were available. We manually compared the online versions of the preprint and publication reference lists against the lists retrieved through Dimensions to confirm the presence of references and identify any missing references in the Dimensions data. We also extracted the document type and publication year for each reference, as recorded in the online versions. From these checks, we determined the accuracy of matching the pairs’ reference lists, and the completeness of the Dimensions reference lists. Then, based on the complete reference lists obtained online, we calculated the actual status of references as added, removed or unchanged between versions, and compared this with our results from the automated process to assess its validity. We also identified the section of the document – standardised as previously described – in which the added or removed references were cited to validate the analysis of references by section.

Finally, to supplement our quantitative analysis of referencing changes, we undertook a qualitative analysis of each preprint-publication pair to identify potential reasons for changes in references. To do this, for each reference we identified as added by comparing the reference lists, we identified the reference’s in-text citation in the publication and the corresponding paragraph in the preprint, which did not contain the reference, and examined the surrounding text for changes, assigning a reason for adding the reference based on the text changes and the type of reference added. For instance, if the sentence described software used in the study and the reference added was for the software website, we assigned the code “Added citation to software”. We conducted the same process for the removed references. Most changed references were cited in the text only once, but where they were added or removed multiple times, one reason was assigned for each change. Also in most cases, there was relatively little difference in the structure and text of the documents and we could easily identify the corresponding paragraphs in each version. In a small number of cases, authors had rewritten entire introductions or discussions. In these cases, the reason for change was assigned to the category “Change in background framing” or “Change in results interpretation” based on whether the introduction or discussion was rewritten. Once we had coded each individual change to a potential reason based on the context, we then analysed all the codes collectively to deduce overall themes for referencing changes. We then examined these themes by section and type of change – added or removed – to observe the patterns of referencing changes that occur during peer review.
Table 1: Preprints and publications by year

| Year | Number of preprints | Number of publications |
|------|---------------------|------------------------|
| 2002 | 1                   | 1                      |
| 2003 | 1                   | 1                      |
| 2007 | 3                   | 2                      |
| 2008 | 1                   | 1                      |
| 2009 | 1                   | 1                      |
| 2010 | 8                   | 6                      |
| 2011 | 4                   | 6                      |
| 2012 | 1                   | 1                      |
| 2013 | 14                  | 11                     |
| 2014 | 208                 | 142                    |
| 2015 | 22                  | 78                     |
| 2016 | 74                  | 13                     |
| 2017 | 3,501               | 823                    |
| 2018 | 2,187               | 4,930                  |
| 2019 |                     | 10                     |

Results

Table 1 shows the yearly distribution of our 6,024 preprints and publications pairs, which is skewed toward documents after 2013. The reason is twofold: the data prepared by Fraser et al. (2019) spanned 2013-2017, and also Dimensions’ coverage of preprints and availability of reference lists were mainly focused on recent years as preprint servers are relatively new (Dimensions Resources, 2019), which influenced our dataset and, as noted in Figure 1, we excluded preprints for which reference lists were unavailable in Dimensions. Approximately half (53%) of the preprints in our sample were published in the same year and 46% were published one year after the year they were released.

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Figure 3 compares the proportion of references added (green), removed (red) and unchanged (blue) by FOS disciplines. Natural sciences had the highest share of preprint-publication pairs in our sample, followed by medical and health sciences. In many disciplines, there were outlier publications with higher proportions of removed references (e.g., 75% in some cases). But, the general trend observed in this Figure is that most disciplines have less than 25% as median of the removed references (indicated with the dot inside violins). However, there were ten specific disciplines with median removed references close to or more than 25% or in some cases close to 50% (e.g., Agriculture, forestry, fisheries, Chemical sciences, Civil engineering, Electrical and electronic engineering, Materials engineering, Mechanical engineering, Nano-technology, Physical sciences and astronomy, Social and economic geography, and Veterinary science). See Table 4 in Appendix section for the exact frequency of pairs in each discipline and average number and proportion of reference list changes. It is important to note, as we will discuss in the manual gold standard results, Dimensions’ coverage of preprint references was much less reliable in contrast to publications’ references, thus the proportion of added references are substantially inflated here and part of these references would move to unchanged if Dimensions coverage was complete, thus, they should be interpreted with caution. Note also that some fields did not have any unchanged references which can further point out the problem of preprint reference list coverage in Dimensions.

Figure 4 presents the results of our probe into reference changes by manuscript section using full-texts from PLOS journals (top) and the ratio of added references to unchanged by full-text section (bottom). In the top panel, the colours each represent a section of the manuscript, while the dotted areas indicate the unchanged proportion, and the stripes are the added proportion. The proportions here are relative to all references in the single publication then aggregated over journals to allow comparison between sections and journals. PLOS journals on the Y axis are sorted based on the decreasing number of pairs in our sample from top to bottom. PLOS Genetics, Biology, Computational Biology, and One all have a primary focus in the natural sciences, while PLOS Pathogens is a mix of natural and medical sciences, and Neglected Tropical Diseases (NTD) is primarily a medical sciences journal. Taking an overall view, we see that in all sections and journals (except the results section in PLOS Biology) the share of added references is higher than unchanged
Figure 3: Distribution of proportion of references added, removed or unchanged by discipline in WOS
ones. But, this difference is the highest in NTD, i.e., the medical science journal. Then looking at sections, we see that in all 6 journals, the majority of bibliographic changes between versions occurred in the introductions and discussions of the manuscripts, more than in the methodology or results sections.

However, as the introduction and discussions are the sections used to frame the study in existing literature, it’s more likely that references would be added here than in the methodology or results (Bertin, Atanassova, Gingras, & Larivière, 2016). As such, the bottom panel of Figure 4 shows the ratio of added to unchanged references in each section to account for the uneven distribution of references across a manuscript. These ratios show a different picture of the changes within sections. In 3 of the 4 natural science journals (i.e., PLOS One, Computational Biology and Biology), the methods section underwent the most bibliographic change, with around 2 times as many references added as unchanged. In NTD and Pathogens i.e., the ones skewed more toward medical sciences, the results and discussion sections underwent the most changes. Genetics was somewhere in between having discussion section go through the most changes followed by the methods section. See Table 5 in Appendix section for the numbers behind this Figure.

We then checked whether added, removed and unchanged references have a different share of the journal where the published version of the pair has appeared. Figure 5 presents the results in terms of proportion of references based on change status to the published journal. Overall, the median references citing the publishing journal in all FOS fields is rather low (dots inside violins) and peer review reduces at least a share of references to the published journal (red violins). However, in engineering and technology, medical and health sciences, natural sciences and to a lesser extent agricultural sciences, most of the references to the published journal stayed unchanged (blue violins). In all fields there is still a share of added references (green violins) to the published journal. On the one hand, this shows a pre-emptive tendency among authors to cite the published journal before submission which then stays unchanged during the peer review. On the other hand, in case of fields with highly specialised research themes, this might signal a narrow area of research that authors must cite to build their arguments based on few prior studies. In addition, we checked the mean and median of the citations that added, removed or unchanged references have accrued in the first three years after publication. While the median of the cited references was close to 10, the mean was closer to 100, we could not identify significant trends of disproportionately adding highly cited references.

Manual validation

Of the 125 pairs selected for manual validation, comparison of the preprint and publication titles confirmed that 113 (90.4%) were correct matches. After removing the 12 (9.6%) false matches and an additional 15 pairs that were inaccessible due to paywalls or the removal of the preprint from its hosting repository, we analysed 98 pairs. Based on the manual checks of the preprint and publications’ online reference lists against the Dimensions lists, we identified that, on average, 30.8% of references were missing from the Dimensions reference lists of the 98 pairs. However, the reference lists were much more incomplete for preprints than they were for publications: 3,197 of the 5,669 (56.4%) references in the preprints were missing from the Dimensions data, or on average 51.6% of references per preprint, compared to 604 of the 5,938 (10.2%) references in the publications, or 10.0% missing per publication on average. References missing from the publication lists were more likely to be older publications, books, software, reports and non-English language documents, while missing references from preprints included these document types but also a large number of recent, English-language publications that were present in the publication reference list data. There was also a small number (65, 1.0% of all examined references) of false positives in the Dimensions reference lists that were not in the online reference lists. These usually consisted of dual entries for, for instance, a book chapter and also the book itself, when only the chapter was actually referenced.

Overall, for the 6,228 references considered across the 98 pairs, there were 495 (7.9%) added references, 225 (3.6%) removed references, and 5,443 (87.4%) were unchanged between the preprint and publication. The average per pair based on all relevant references was similar: on average, 7.7% of references were added, 3.3% were removed, and 89.0% were unchanged. In comparing these proportions to our main results, our validation process revealed that the large percentage of missing references in the preprint lists compared to publications inflated the number of “added” references in our main study. Table 2 shows the number and percentage of references in the 98 pairs by their initial status assigned in the main study and their actual status assigned in the validation process. We see here that, in our validation sample, 14.2% of references initially considered
Figure 4: Distribution of references change in full text sections by PLOS journals (top) and added to unchanged proportion by section (bottom, U = unchanged, A = added)
Figure 5: Proportion of references to the published journal
Table 2: Number and percentage of references in validation sample by initial status and actual status

| Initial status | Added (%) | Removed (%) | Unchanged (%) | Incorrect (%) | Total (%) |
|----------------|-----------|-------------|---------------|---------------|-----------|
| Added          | 430 (14.2)| 0 (0.0)     | 2,569 (84.6)  | 36 (1.2)      | 3,305 (100.0) |
| Removed        | 0 (0.0)   | 87 (56.1)   | 47 (30.3)     | 21 (13.5)     | 155 (100.0) |
| Unchanged      | 4 (0.2)   | 7 (0.3)     | 2,329 (99.2)  | 8 (0.3)       | 2,348 (100.0) |
| Missing        | 61 (8.8)  | 131 (19.0)  | 498 (72.2)    | 0 (0.0)       | 690 (100.0) |
| Total          | 495 (7.9) | 225 (3.6)   | 5,443 (87.4)  | 65 (1.0)      | 6,228 (100.0) |

added were confirmed to be so, however the majority (84.6%) were actually unchanged, which was driven by the missing preprint references. Of the references initially considered removed, validation confirmed 56.1% were accurate, while 30.6% were actually unchanged, and 13.6% were incorrect inclusions in the Dimensions lists. Unchanged references were most accurate, with 99.2% of references initially considered unchanged confirmed during validation. However, the overall number of unchanged references is under-reported in the initial status (2,348) compared to the actual status (5,443) due to the inaccurate inclusion of many unchanged references as added or removed. Finally, of the references initially missing from both reference lists and identified during validation, the majority were unchanged (72.2%), 8.8% were added, and 19.0% were removed.

Overall then, matching of preprint-publication pairs at the document level was 90% accurate. During validation, we detected no incorrect matches between references within a pair when matches were made, indicating the title-based matching process between reference lists was accurate. However, the extent of missing data in the preprint reference lists introduced a level of inaccuracy that means that results in the main study pertaining to added references should be interpreted cautiously as they are subject to inflation. Conversely, the main study under-reports unchanged references, however both unchanged and removed reference results are more reliable.

Figure 6 compares the proportion of references added, removed and unchanged by FOS field. At the top it shows the macro view based on our quantitative results and on the bottom are the results of our manual gold standard validation. The top panels show that the natural sciences and medical and health sciences both present a rather similar median of removed references, however there was a larger share of pairs with higher removed proportions in the medical and health sciences. Agricultural sciences in particular showed higher proportions of references being removed in the published version (median of 25%). In all fields, there are outlier publications with higher proportion of removed references (e.g., 75% in some cases). However, based on the validation sample in the bottom panel, we see that the proportions of unchanged references in all fields is generally higher, and the proportions of added references much lower, than is reported in the top panel. But in general, the distributions of unchanged and removed references in our macro study and gold standard are in agreement.

Figure 7 shows the distribution of added and removed references across document sections. Added references relate to the section of the publication and removed references relate to the preprint section. “Other section” includes non-standardised sections, such as acknowledgements. We included references in each section in which they were cited, as such references may be counted more than once and the denominator used for the percentage is the total number of references using multiple counting. Over one-third (35.5%, 82) of removed references and 1.7% (9) of added references could not be allocated to a section as, although they were in the reference list of the preprint or publication respectively, they were not actually cited in the text of the document. This issue occurred in 17 preprints, but was condensed primarily in 4 that had between 9 and 18 instances each.

These results validate the pattern seen in the main study that the majority of references were added to the introduction (30.0%) and discussion and conclusions sections (33.3%), with fewer changes in the methods (20.9%) and results sections (13.3%). The removed references here also follow this pattern, with the largest percentages removed from the introduction (29.4%) and discussion and conclusions (17.7%) over the methods (9.5%) and results (6.1%). Excluding the 82 references only removed as they were inaccurately included in the preprint reference list so that we may examine the distribution of “true” removals, nearly half of references were removed from the introduction (45.6%), 27.5% from discussion and conclusions, 14.8% from methods,
Figure 6: Distribution of references added, removed or unchanged in macro quantitative view (top) and validation sample (bottom) by field.
and 9.4% from results.

![Distribution of added and changed references in the validation sample by document section.](image)

Based on the qualitative analysis, we identified 10 themes describing the apparent motives for changing references during peer review, 6 of which were applicable for removing references. The number and percentage of references changed in accordance with each theme by field is shown in Table 3. Please note that, due to the assignment of the same publications to multiple fields in the native discipline classifications, references might be counted in more than one field and as such the sum of the fields is greater than the total.

The most common reason for removing references (35.5%) was the aforementioned referencing mistakes in the preprint. This was particularly a problem in the medical sciences and social sciences, where it accounted for half and over three-quarters of removed references, respectively. Eleven percent of added references also occurred through referencing mistakes, however the majority of these (82%) still stemmed from the preprint as references cited in the preprint full-text were missing from the reference list and so appeared to be added to the publication based on reference list information. The remaining 10 instances were due to referencing mistakes in the publication.

There was also a series of referencing changes that reflected small updates between the preprint and publication but did not result in notable changes in the content or structure of the manuscript. These include adding references for previously uncited software or other tools used in studies (4.6%), which was particularly pronounced in engineering manuscripts (18.3%) compared to the other fields (1.2-10.3%). References were also added to support knowledge claims that were made without supporting references in the preprint (5.1%). The social and medical sciences had substantially fewer additions for this reason than the other fields (1.2-1.8% compared to 5.2-10.3%). There was also a tendency for references to be added (8.6%) or removed (27.7%) without making substantial changes, or in many cases any change at all, to the surrounding text. In most of these cases (39, 60.9%), the reference was removed while other existing references were retained, or the removed reference was replaced (20, 31.3%), while in only 5 (7.8%) cases was the reference removed so that the text was unsupported. When references were added without changing the text, the reference was most often added to text already supported by references (82% of cases), or added to replace the existing references (18%). This theme was the most common circumstance under which references were removed in all fields, particularly agricultural sciences and engineering where it accounted for more than half of all removals. Also, a small percentage of references were removed (6.9%) and added (1.3%) as authors updated references from citing, for instance, a conference paper in the preprint to citing its published version in the publication, or
changed a standard citation to a URL or other format not requiring an entry in the reference list and thus being “removed”. This was notably more common in engineering and the natural sciences than other fields.

The remaining four themes were associated with notable changes to the manuscript’s structure or content between the preprint and published versions. The most common of these categories was providing additional information for interpreting results. Of these 133 references, 111 were added when authors included additional text with supporting references to better relate and interpret their results in regard to existing literature. The remaining 22 references in this category were added in sections addressing limitations or the significance of the study, which were missing from the preprint. This theme also accounted for the removal of 8.2% of references when authors reframed their studies’ results in comparison to existing literature. It was here that the social sciences had the largest percentage of references added (32.5%), and it was also a key area for the other fields. However, the small percentage of references removed compared to added in the social sciences (4.4%), and also the agricultural sciences and engineering fields, suggests these changes do not reflect a complete reframing of results but instead a more thorough contextualisation of the results within the existing literature. In comparison, there were nearly equal percentages of references added and removed in association with changes to interpreting results in the natural sciences, and an elevated percentage of removed references in the medical sciences also, suggesting there was a more extensive reframing of results within the literature in these fields.

In a related vein, the next most common theme was adding additional background information about the study subject (24.7%). Similar to changes for interpreting results, the majority of additions in this theme (82) were added to better place the study within the existing literature, however these additions typically sought to establish a theoretical or practical foundation for the study, rather than assist in interpreting the results. A smaller portion were added to address a change in scope (30, largely in one study), and revising knowledge claims. Authors also removed 16.5% of references in this revision process, often restructuring a section, most often the Introduction, and removing and adding references accordingly. This was the key theme for adding references for the natural, medical, and agricultural sciences, accounting for more than 28% of added references in each field. Once again the natural and medical sciences had higher levels of references removed for this purpose, alongside the added references, suggesting manuscripts in these fields undergo more transformation in the theoretical foundations of these studies than in other fields.

A third theme pertained to changes in the study’s methodology, which accounted for 15.4% of added references and 5.2% of removed references. Here, authors appeared to add references to provide missing or more extensive detail about data or processes (29 added references, 35.8%), to justify their selection of particular methods (17), such as demonstrating prior use for similar purposes, or to provide references for specific statistics or methods described but unreferenced in the preprint (9). These changes all pertained to the existing methodology, but another set of reference changes were triggered by changes in the study’s methodology. Twenty-six references were added in accordance with new analyses conducted between the preprint and publication, and 12 references were removed as authors changed aspects of the study’s method and removed details of the method and associated references (5 references), or tools or software no longer used (4 references), or moved a particular detail about the method to the supplementary information (3 references). Such methodological changes may have been requested through peer review or added of the authors’ own accord before submitting the manuscript to the journal. Engineering papers appeared to undergo the most methodological changes, with higher percentages of references added and, in particular, removed for this purpose than in other fields.

Authors added another small set of references (20, 3.8%) when discussing new suggestions for applications of the study’s findings and directions of future inquiry. Like additions made to address limitations or methodological issues, these sections regarding future directions often appeared to have been specifically requested by reviewers as they frequently appeared as wholly new paragraphs sandwiched between sections with no change. However, this is our impression based on the changes between preprints and manuscripts, as we did not have access to the reviewers’ reports to confirm the requests. The percentage of references added for this purpose was relatively equal across fields. Finally, the “other” category included one reference for which we did not have access to the publication’s full-text so could not identify a reason for change, and a second reference which was a reminder left in the preprint from the author to themselves to cite their in-review article, a task they completed in the publication. We have included in the Appendix the percentage

17
of references removed and added in these themes by manuscript section.

**Discussion**

In this paper, we sought to understand how the peer review process influences manuscripts in different disciplines, as measured by changes in reference lists and the document sections most altered between the submitted and published versions. To do this, we matched more than 6,000 preprint-publication pairs across multiple disciplines and quantified the changes in their reference lists. We also quantified the change in references per manuscript section for 565 pairs from PLOS journals. In addition, we conducted manual checks of a randomly chosen sample of 98 pairs to validate our results, and undertook a qualitative analysis based on the context of the reference to offer insight into the potential reasons for changing references.

Our study is a contribution to the field of studies of peer review identified by Batagelj et al. (2017). We used a mixed methods approach to provide a quantitative, macro exploration and complement the results with a qualitative in-depth analysis. Although, we lack information about the motivations behind citing behaviour of authors, nevertheless, our results offer insight into how peer review, or possible preemptive modifications authors might decide to apply, changes the reference lists of manuscripts.

In our macro and quantitative investigation, we found ten specific disciplines, mainly from the natural sciences, with a median of up to 25% or in some cases even 50% of references removed between the preprint and publication stages. Our more in-depth look at the full-text sections of publications in PLOS journals showed that, in the natural sciences, it is the methods section that undergoes the most changes while in the medical and health sciences, the results and discussion sections underwent the most changes. Furthermore, we found that publications pertaining to pure fields of science or disciplines, tend to undergo fewer changes while inter/multi-disciplinary publications (e.g., PLOS Genetics and Computational Biology) go through a mixture of changes similar to that of the fields they bridge. We found a rather stable trend of authors citing the journal in which the published version appeared that remained unchanged during peer review. This could signal preemptive behaviour of authors to cite prior works published in the journals they aim to publish in, or may reflect that the journal is a key source or perhaps one of only a few journals in a narrow, specialised research area. Some differences between disciplines in the extent of removed references might reflect discipline- or journal-specific hesitance to accept preprints as reliable sources as they have not undergone peer review and so are removed by the request of peer reviewers or editors, although we cannot confirm this without access to peer review comments sent to authors.

Using our gold standard validation sample, we determined that the preprint-publication matching at the document level was 90% accurate. However, when matching the reference lists between documents, we found that preprint reference lists in Dimensions were often incomplete, with 57% of references missing, compared to 10% missing from the publication reference lists. This means the proportion of added references in the quantitative results is inflated and, based on the validation sample, 85% of added references were
actually unchanged. Removed references were accurately identified in 56% of cases, while 30% were actually unchanged and 14% reflected inaccuracies in the Dimensions reference lists. Although, we accurately identified unchanged references 99% of the time, the results of the macro quantitative study under-represented the proportion of unchanged references as a number of unchanged references were inaccurately identified as added or removed.

Regarding the overall pattern of referencing changes, there was a notable stability in referencing between preprints and publications across all fields. Nearly 90% of references present in the preprint were unchanged between versions, 8% were newly added during peer review, and only 4% were removed. Indeed, the most common reason for removing references was because they were incorrectly included in the reference list in the preprint and this was corrected in publication, suggesting the publication process improves the accuracy of citation practices. We identified nine additional themes under which bibliographic changes occurred during peer review. Four of these pertained to changes that did not result in substantial or indeed any changes to the content or structure of the manuscript between versions, such as adding references for software, tools, or for claims that were unsupported in the preprint, updating references from conference papers or other early versions to publications, and changing references without changing the surrounding text. This latter practice was particularly common for removing references and may perhaps relate to reductions to conform to word count limitations, as noted by Teplitskiy (2016). Authors adding references for these purposes suggests reviewers have an important role in detecting unsupported claims and ensuring software, tools, and methods are appropriately cited in publications.

The bulk of referencing changes resulted from changes to the structure or content of the manuscript, including reframing the study’s placement or interpretation of its results within existing literature, addressing the future directions of research, or changes in the methods’ description or use. These changes align with the purposes of peer review to assess the methodological soundness of a study and improve the communication of its results to the academic community (De Vries et al., 2009). However, we observed differences between fields in the effect of peer review. Peer review in engineering appears to be more oriented toward methodological soundness, with most changes occurring in relation to methodological detail, citing software and tools, and the interpretation of results, likely to correspond with the methodological changes. In the other fields, the focus of peer review appeared to be on the theoretical framing of the study and its results. While the majority of reference additions in all of these fields occurred in relation to reframing the study’s theoretical background and results, we also observed higher levels of removing references for this purpose in the natural sciences and medical sciences than in the social sciences and agricultural sciences. This suggests that natural and medical science publications might undergo more extensive reframing of studies, with substitution of references as foundational and explanatory theories are exchanged, whereas studies in the social and agricultural sciences appear to become more embedded in the field, with references added but not removed. This reframing may reflect how, as described by Teplitskiy (2016), theoretical framing is a negotiation between authors and reviewers regarding how studies and their results are interpreted. However, in the social sciences there is perhaps larger overlap in the theories applicable to results than in the natural and medical sciences, where interpretation under one theory may necessarily preclude interpretation under another, thus requiring the removal of existing and addition of new references.

Arguably, the predominant focus of reviewers on theory over methodology in most fields may reflect the awareness reviewers, as academics themselves, have for the resource-intensive process of collecting and analysing data that goes into producing a publication. For many reasons, such as funding, time, and availability of data or equipment, a researcher usually cannot simply collect new data or run entirely new analyses to address reviewers’ concerns, particularly should these concerns not pertain to fatal flaws. As such, reviewers may focus on addressing the disconnection between the theoretical framing and methodological aspects of the study by suggesting reframing of the theory to align with the possible questions that can be answered by the available data in a data-driven approach, rather than the converse of retaining the question and adjusting the data in a question-driven approach (Teplitskiy, 2016). A future test of this hypothesis could be the focus of peer review in grant applications, where both theoretical and methodological aspects of a project are critiqued before any resources have been expended.

Finally, our findings regarding the social sciences align somewhat with those of Strang & Siler (2015) and Teplitskiy (2016) in their studies of sociology. As they did, we also find here that the key focus of peer
review in the social sciences appears to be the theoretical framing of the study and its results. However, changes in methodological details were also the second most common reason for references to be added in the social sciences and at levels generally in line with the other fields, suggesting methodological soundness is not a neglected aspect of peer review in the social sciences.

Limitations and future directions

There are limitations to our study that are important to consider.

While using references as a proxy for change in the section of a manuscript allows us to examine a large number of manuscripts (otherwise impossible with methods such as content analysis, e.g. Strang & Siler (2015)), the reliance on references might be flawed. For instance, methodologies, particularly when innovative, may not include references, providing unreliable results about the extent to which they are critiqued and addressed during peer review.

Reliance on completeness of reference lists in each of the databases (hence the use of two databases, to increase likelihood of completeness), which is particularly an issue for humanities and social sciences, means we could be missing references. However, our research question sought to examine whether a documented problem in the social sciences was also present in the hard sciences, and the hard sciences have a much more complete level of source references (Stephen, Stahlschmidt, & Hinze, 2020).

We match references from Dimensions to the reference lists in WOS. In these matching procedures, there is a probability to lose some references and this might affect the magnitude of observed trends and in reality they are more than presented here, so our results should be considered as the lower end of the continuum.

Detecting a match between preprint and published version of publications is also a difficult task. We have used multiple approaches, e.g., similarity between title of both sides while complementing it with currently existing pairs of DOIs (Fraser et al., 2019), but this still is prone to errors and could be improved.

Our study is only considering the impact of peer review on the eventually published articles and leaves the rejected ones out.

Finally, authors of academic publications may often improve their manuscript beyond the advice given by the reviewers. Thus the observed trends cannot be solely attributed to the peer review process and it can signal change and improvements made by authors of their own accord themselves, hence we may have overestimated the effect from peer review.

Noting these limitations, our study offers useful insight into the referencing changes manuscripts undergo during peer review and the differences in the effect of peer review on manuscripts in different fields. Future studies could attempt to bridge the advantage of sample size and specificity in detection of changes by using automated textual analysis, such as is used for plagiarism detection software, which could potentially facilitate the identification of specific changes in the text of a large sample of manuscripts (Strang & Dokshin, 2019), and preclude the reliance on reference lists and the issues we encountered here. There are some European level initiatives pursuing the goal of opening up peer review data (Squazzoni, Grimaldo, & Marušić, 2017; Squazzoni et al., 2020). We see that if those initiatives proceed, future research can benefit and do more fine-grained analysis of the changes that happen during the peer review from content changes and reference suggestions by reviewers (e.g., analysis of review notes similar to Casnici et al. (2017)). Whether those references that were removed were due to reducing the word count of the manuscript, could be an avenue for future studies by investigating journal guidelines for presence of strict word counts.

Conclusions

We conclude from our results that peer review does appear to function within its purposes of examining the methodological soundness of studies and improving manuscripts as tools to communicate academic findings. Despite a predominant focus on theoretical reframing in all fields but engineering, peer review also addresses methodological issues in each field. Further, this focus on theoretical framing, at least in the social and agricultural sciences, appears to serve to more thoroughly embed studies within their fields, emphasising the
focus of reviewers on improving communication of the studies results, which was also evident in reviewers’ apparent encouragement of authors to discuss the applications of their study’s findings and future research directions.

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Data Availability

Micro publication level data cannot be made publicly available due to the licensing and contract terms of the original data. However, contact authors for preprint-publication pair level data.

Declaration of competing interest

Authors declare that they do not have any conflict of interest.

Appendix

Table 4 presents the aggregated version of data behind the Figure 3 regarding number of preprint-publication pairs, average number and average proportion of added, removed and unchanged references in FOS disciplines.

Table 5 presents the data used in Figure 4. It presents number of preprint-publication pairs in each PLOS journal and proportion of changes in references used in full-text sections.

Figure 8 shows the percentage of references added and removed by theme and section of the manuscript. Percentages are of the total number of added or removed references per manuscript section.
Table 4: Preprint and publication pairs by WOS disciplines while multiple counting (N = number of references, P = proportion of references)

| FOS                                      | n_pairs | N_Unchanged | N_Removed | N_Added | P_Unchanged | P_Removed | P_Added |
|------------------------------------------|---------|-------------|-----------|---------|-------------|-----------|---------|
| Biological sciences                      | 2,514   | 27.15       | 6.09      | 31.22   | 0.47        | 0.09      | 0.51    |
| Other natural sciences                   | 1,555   | 27.31       | 5.04      | 26.96   | 0.50        | 0.08      | 0.48    |
| Basic medical research                   | 701     | 28.05       | 7.93      | 34.50   | 0.45        | 0.14      | 0.52    |
| Clinical medicine                        | 430     | 24.51       | 10.19     | 32.46   | 0.42        | 0.17      | 0.55    |
| Health sciences                          | 360     | 19.54       | 7.96      | 25.16   | 0.44        | 0.14      | 0.53    |
| Environmental biotechnology              | 341     | 21.46       | 5.08      | 22.76   | 0.49        | 0.10      | 0.48    |
| Psychology                               | 166     | 27.73       | 7.81      | 37.39   | 0.43        | 0.12      | 0.55    |
| Computer and information sciences         | 132     | 19.16       | 5.19      | 15.95   | 0.54        | 0.13      | 0.44    |
| Mathematics                              | 128     | 17.03       | 5.00      | 13.83   | 0.54        | 0.15      | 0.43    |
| Chemical sciences                        | 84      | 16.35       | 14.10     | 35.67   | 0.34        | 0.27      | 0.63    |
| Earth and related environmental sciences  | 56      | 25.58       | 9.07      | 30.18   | 0.44        | 0.13      | 0.58    |
| Physical sciences and astronomy           | 40      | 23.84       | 16.44     | 32.49   | 0.44        | 0.28      | 0.57    |
| Medical engineering                      | 30      | 21.23       | 10.50     | 35.14   | 0.39        | 0.17      | 0.59    |
| Agriculture, forestry, fisheries          | 31      | 18.75       | 17.12     | 40.23   | 0.37        | 0.28      | 0.58    |
| Materials engineering                    | 28      | 14.46       | 20.00     | 28.79   | 0.31        | 0.15      | 0.64    |
| Other engineering and technologies       | 26      | 14.47       | 12.12     | 30.81   | 0.39        | 0.24      | 0.60    |
| Other agricultural science               | 15      | 13.55       | 12.22     | 28.80   | 0.39        | 0.20      | 0.59    |
| Nano-technology                          | 14      | 6.20        | 21.80     | 33.21   | 0.21        | 0.34      | 0.60    |
| Environmental engineering                | 12      | 17.29       | 18.88     | 33.17   | 0.32        | 0.18      | 0.70    |
| Veterinary science                       | 11      | 15.00       | 28.17     | 35.91   | 0.39        | 0.37      | 0.61    |
| Social and economic geography            | 10      | 12.00       | 20.44     | 32.20   | 0.30        | 0.22      | 0.71    |
| Industrial biotechnology                 | 9       | 27.38       | 8.25      | 39.11   | 0.41        | 0.10      | 0.59    |
| Sociology                                | 9       | 19.43       | 9.17      | 36.78   | 0.34        | 0.17      | 0.62    |
| Economics and business                   | 7       | 8.00        | 33.71     | 0.21    | 0.79        |           |         |
| Animal and dairy science                 | 6       | 12.75       | 13.00     | 23.33   | 0.50        | 0.21      | 0.60    |
| Civil engineering                        | 6       | 24.00       | 24.61     | 0.46    | 0.54        |           |         |
| Mechanical engineering                   | 5       | 10.00       | 12.40     | 23.00   | 0.42        | 0.34      | 0.61    |
| Chemical engineering                     | 4       | 2.00        | 28.00     | 41.25   | 0.03        | 0.60      | 0.68    |
| Languages and literature                 | 4       | 32.75       | 2.67      | 31.25   | 0.48        | 0.04      | 0.48    |
| Educational sciences                     | 3       | 35.00       | 14.33     | 19.33   | 0.62        | 0.34      | 0.49    |
| Electrical eng, electronic eng            | 3       | 54.00       | 16.67     | 24.67   | 0.66        | 0.34      | 0.47    |
| Law                                      | 2       | 9.00        | 27.00     | 0.24    | 0.76        |           |         |
| Media and communication                  | 2       | 4.00        | 1.00      | 26.50   | 0.14        | 0.43      | 0.57    |
| Art                                      | 1       | 16.00       | 5.00      | 0.78    | 0.24        |           |         |
| History and archaeology                  | 1       | 18.00       | 5.00      | 0.76    | 0.24        |           |         |
| Other social sciences                    | 1       | 18.00       | 79.00     | 0.19    | 0.81        |           |         |
| Political science                        | 1       | 6.00        | 12.00     | 0.33    | 0.67        |           |         |

Table 5: References change in full text sections by PLOS journals (U = unchanged, A = added)

| PLOS journals               | n_pairs | introU | introA | methodU | methodA | resultU | resultA | discussionU | discussionA | supplementalU | supplementalA | unknownU | unknownA |
|-----------------------------|---------|--------|--------|---------|---------|---------|---------|-------------|-------------|----------------|----------------|----------|----------|
| One                         | 306     | 0.23   | 0.15   | 0.09    | 0.06    | 0.04    | 0.19    | 0.14         | 0.00         | 0.00           | 0.00           | 0.00     | 0.00     |
| Computational Biology       | 64      | 0.22   | 0.07   | 0.11    | 0.10    | 0.07    | 0.16    | 0.16         | 0.07         | 0.11           | 0.00           | 0.00     | 0.00     |
| Genomics                    | 33      | 0.18   | 0.15   | 0.12    | 0.09    | 0.11    | 0.24    | 0.24         | 0.22         | 0.13           | 0.00           | 0.00     | 0.00     |
| Pathogens                   | 31      | 0.19   | 0.14   | 0.10    | 0.09    | 0.11    | 0.20    | 0.20         | 0.20         | 0.08           | 0.00           | 0.00     | 0.00     |
| Biology                     | 30      | 0.18   | 0.10   | 0.09    | 0.09    | 0.11    | 0.21    | 0.21         | 0.21         | 0.09           | 0.00           | 0.00     | 0.00     |
| Neglected Tropical Diseases | 22      | 0.24   | 0.08   | 0.11    | 0.06    | 0.11    | 0.26    | 0.26         | 0.26         | 0.09           | 0.00           | 0.00     | 0.00     |

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Figure 8: The percentage of removed (top) or added (bottom) references per section by each thematic group.
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