Co-reviewing and ghostwriting by early career researchers in the peer review of manuscripts

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Abstract

The goal of this study is to shed light on the involvement of early career researchers (ECRs) during peer review of manuscripts for publication in journals. In particular, we sought to better understand how commonly ECRs contribute ideas and/or text to peer review reports when they are not the invited reviewer ("co-review"), and how commonly ECRs do not receive named credit to the journal editorial staff for these scholarly efforts ("ghostwrite"). First, we evaluated 1,952 publications in the peer-reviewed literature generated by exhaustive search terms that combined synonyms of "early career researcher" and "peer review" and found no previous studies about ECRs ghostwriting peer review reports. We then surveyed 498 researchers about their experiences with, and opinions about, co-reviewing and ghostwriting as ECRs. Three quarters of those surveyed have co-reviewed and most find it to be a beneficial (95% agree) and ethical (73% agree) form of training in peer review. Co-reviewing is the second most commonly reported form of training in peer review besides receiving reviews on one's own papers. Half of survey respondents have ghostwritten a peer review report, despite the 4/5ths majority opinion that ghostwriting is unethical. Survey respondents report that the three major barriers to including co-reviewer names on peer review reports are: a lack of communication between PIs and ECRs; a false belief that co-authorship is for manuscripts but not peer review reports; and prohibitive journal policies that are out of alignment with current practice and opinions about best practice. We therefore propose recommendations for changing this status quo, to discourage unethical ghostwriting of peer review reports and encourage quality co-reviewing experiences as normal training in peer review.

INTRODUCTION

Peer review of academic manuscripts is viewed as a fundamental scholarly activity to maintain the integrity of the scientific literature (Baldwin 2018; Tennant et al. 2017). Early career researchers (ECRs; Box 1: Definitions) often contribute to this peer review process. Indeed, in a recent survey shared on the INSIDE *eLife* blog that targeted ECRs in the life sciences, 92% of those surveyed reported undertaking reviewing activities (Inside eLIFE 2018). While it may be expected that ECRs review manuscripts jointly with or under the guidance of a principal investigator (PI; Box 1), more than half of survey respondents, including 37% of graduate students, reported reviewing a manuscript *without any assistance from their advisor*. Are these ECRs performing peer review independently as the invited reviewer? Or are they performing peer review on behalf of their advisor, the invited reviewer being named to the journal? In this case, is the journal editorial staff aware that someone other than the invited reviewer has contributed independently to the peer review report? If not, then these ECRs are participating in the practice of ghostwriting (Box 1). Combining the results of the INSIDE *eLife* survey with our own anecdotal observations of ECRs carrying out peer review without being identified to journal editorial staff, we came to the hypothesis that ghostwriting of peer review reports by ECRs is widespread.

BOX 1: DEFINITIONS USED IN THIS STUDY	
Early career researcher (ECR)	We consider this to be anyone engaged in research who is not recognized as an independent leader of a research group, including: undergraduate, graduate, and postdoctoral researchers; junior research assistants, associates, and staff scientists.
Principal Investigator (PI)	Anyone recognized as an independent leader of a research group, including: professors, group leaders. *Note*: We use this term to mean someone likely to be an invited reviewer due to their professional independence, including pre-tenure junior faculty (e.g. assistant professor in the US). We recognize that, in other contexts, pre-tenure faculty may also categorized as ECRs.
Co-reviewing	Contributing ideas and/or text to a peer review report when one is not the invited reviewer. Equivalent to a co-author on a manuscript when one is not the corresponding author. *Note*: We use this term to mean significant contributions to the peer review report, and so differentiate from casual or insignificant conversations about the manuscript under review that do not provide novel ideas and/or text to the peer review report.
Ghostwriting	Co-reviewing without named credit to the journal editorial staff. *Note*: We use this term to mean only the identification of a co-reviewer to the journal staff in an identical manner to the identification and naming of the invited reviewers. We are not referring to the *public* naming of peer reviewers, or reviewers *signing* reviews, or other forms of open peer review which is beyond the scope of this study (Ross-Hellauer 2017).

Indeed, co-reviewing and ghostwriting by ECRs appear to be understood as common practices in academia, summarized recently by Patterson and Schekman (2018):

"It is common practice for busy group leaders to ask their more senior PhD students and postdoctoral fellows to help with peer review, but in too many cases these contributions go unacknowledged."

This statement joins a growing discussion about co-reviewing and ghostwriting, which includes a workshop we led at the 2018 ASAPbio meeting on Transparency, Recognition, and Innovation in Peer Review in the Life Sciences (http://asapbio.org/peer-review/summary, (McDowell 2018)). However we wished to widen this conversation beyond those at attendance at a particular conference and facilitate an evidence-based dialogue about ghostwriting and, more broadly,

about the participation of ECRs in peer review. We therefore sought to collect data that answers: **How commonly do ECRs ghostwrite peer review reports, and what is their opinion of this practice? Do they find it valuable and ethical? Why do such practices take place? Are there any concerns that arise with this practice and could interventions be put in place to address these issues?**

We performed a systematic review of the extant literature to determine if these questions had been previously addressed. Among the ~2000 publications in peer reviewed journals on the topic of “early career researchers” and “peer review”, we found no research articles reporting data specifically on peer review reports ghostwritten by ECRs. Given the lack of data currently available about this practice, its frequency, and the rationales behind it, we conducted a survey of peer review experiences and opinions that primarily targeted ECR communities in the biomedical sciences. **We describe here our findings from 498 survey respondents that give the first specific evidence of the frequency of peer review ghostwriting and the motivations behind it.** Survey data reveal logistical barriers that prevent ECRs from receiving credit for reviewing activities, such as a lack of clarity in journal policies concerning the expectations and reporting mechanisms for the participation of ECRs in peer review. Our data also suggest that overcoming these policy barriers would not be sufficient to fully involve ECRs in peer review, since there are also incorrect assumptions and cultural practices out of line with the values held by researchers about the involvement of ECRs in peer review. We therefore propose a series of policy and cultural changes supported by our data that would have the potential to ensure the inclusion, training, and recognition of ECRs’ scholarship in manuscript peer review.

RESULTS: SYSTEMATIC LITERATURE REVIEW

We performed a systematic review of the peer-reviewed literature with the goal of identifying any previous studies on the role that ECRs play in the process of peer reviewing manuscripts. In particular, we wanted to know whether there was evidence in the literature of ECRs ghostwriting peer review reports. Since ghostwriting is, by definition, an outcome that results from a lack of documentation, transparency, and accountability, we hypothesized there would be little-to-no evidence-based literature on this topic. Investigating a null hypothesis is challenging and as a result we designed a comprehensive procedure based on evidence-based guidelines for systematic reviews using exhaustive search terms that combined any synonyms of “early career researcher” AND “peer review” (prisma-statement.org, (Moher et al. 2009), Methods: Systematic Literature Review).

Our search yielded 1,952 unique articles. Collected articles underwent two rounds of screening performed independently by 3 study authors using titles and abstracts to evaluate relevance to the topic of ECR co-reviewing and ghostwriting peer review reports (Methods: Relevance screening; Appendix: Results of relevance screening for literature review; Appendix Figure 1). 118 articles were considered relevant by at least one screener and 36 articles were considered relevant by two or more screeners. All 36 articles considered relevant by 2+ screeners then underwent a full text reading with specific attention being paid to: research question, motivation for article, method of study including details concerning study participants, relevant results and discussions, discussion of peer review and ECRs, and possible motivations for author bias. Of the articles uncovered by our search that were found not to be relevant to the topic of ECR involvement in the peer review of manuscripts, many discussed other forms of peer review

outside the scope of publishing manuscripts (e.g. students in a classroom setting engaging in peer review of each other's assignments as a pedagogical exercise).

Lack of literature on ECR ghostwriting of peer review reports

We found 0 research articles in the peer-reviewed literature on the practice of ghostwriting of peer review reports by ECRs[1]. There was one publication, not a research article, that mentioned ghostwriting of peer review reports by ECRs: the announcement of peer reviewer training policies from the journal *eLife* that was quoted above and was published after the ASAPbio meeting mentioned above (Patterson and Schekman 2018). This policy announcement acknowledged the phenomenon of ECR ghostwriting and stated a journal policy that ECRs are eligible to act as peer reviewers of manuscripts submitted to *eLife*.

Of the remaining 35 articles that were considered relevant to the topic of ECR involvement in the peer review of manuscripts but *did not* address ghostwriting, many instead investigated the value of co-reviewing as a training exercise. We summarize the major themes from these articles in the Appendix: Literature on ECR involvement in peer review as a training exercise. None of these articles discussed the issue of named credit for scholarly labor, nor did they include information on the frequency of, or ECRs' opinions about, ghostwriting in peer review.

[1] Our search did not recover the survey shared on the INSIDE eLife blog (2018), mentioned above, because it was not published in the peer-reviewed literature nor did it specifically address ghostwriting. Other grey literature would similarly not be included in this dataset.

RESULTS: SURVEY OF PEER REVIEW EXPERIENCES AND ATTITUDES

To address this gap in the literature on co-reviewing and ghostwriting, we designed a survey to evaluate the frequency of, and rationales for, ghostwriting and co-reviewing by ECRs. The IRB-approved, online survey garnered 498 responses over a month-long data collection period in September, 2018 (Methods: Survey of peer review experiences and attitudes; Appendix: Text of The Role of Early Career Researchers in Peer Review - Survey). Respondents hailed from 214 institutions that were geographically diverse both within and beyond the US. Most participants were from institutions in North America (n = 370), followed by Europe (n = 87) and Asia (n = 21). 74% of all respondents were based in the US, of which 64% were Citizens or Permanent Residents and 36% held temporary visitor status. Institutions from 40 US states or territories were represented, with the most respondents coming from Washington University in St. Louis, University of Kentucky, Rockefeller University, and the University of Chicago (Appendix: List of institutions with multiple survey respondents).

The majority of survey respondents (65%) were ECRs in the life sciences (Figure 1). The five largest groups of self-identified fields were: Neuroscience; Biomedical; Biology; Biochemistry; Cell and/or Developmental Biology (Appendix: List of topics assigned to fields of study). This was as expected given our efforts to primarily engage ECRs and our connections to biomedical postdoctoral populations (Methods: Survey distribution, limitations, and future directions). We surmise that postdocs (63% of all respondents) are over-represented in this survey (although it is difficult to determine the proportions of researchers by career stage in the U.S., particularly as the number of postdoctoral researchers in the US is currently unknown (Pickett et al. 2017)).

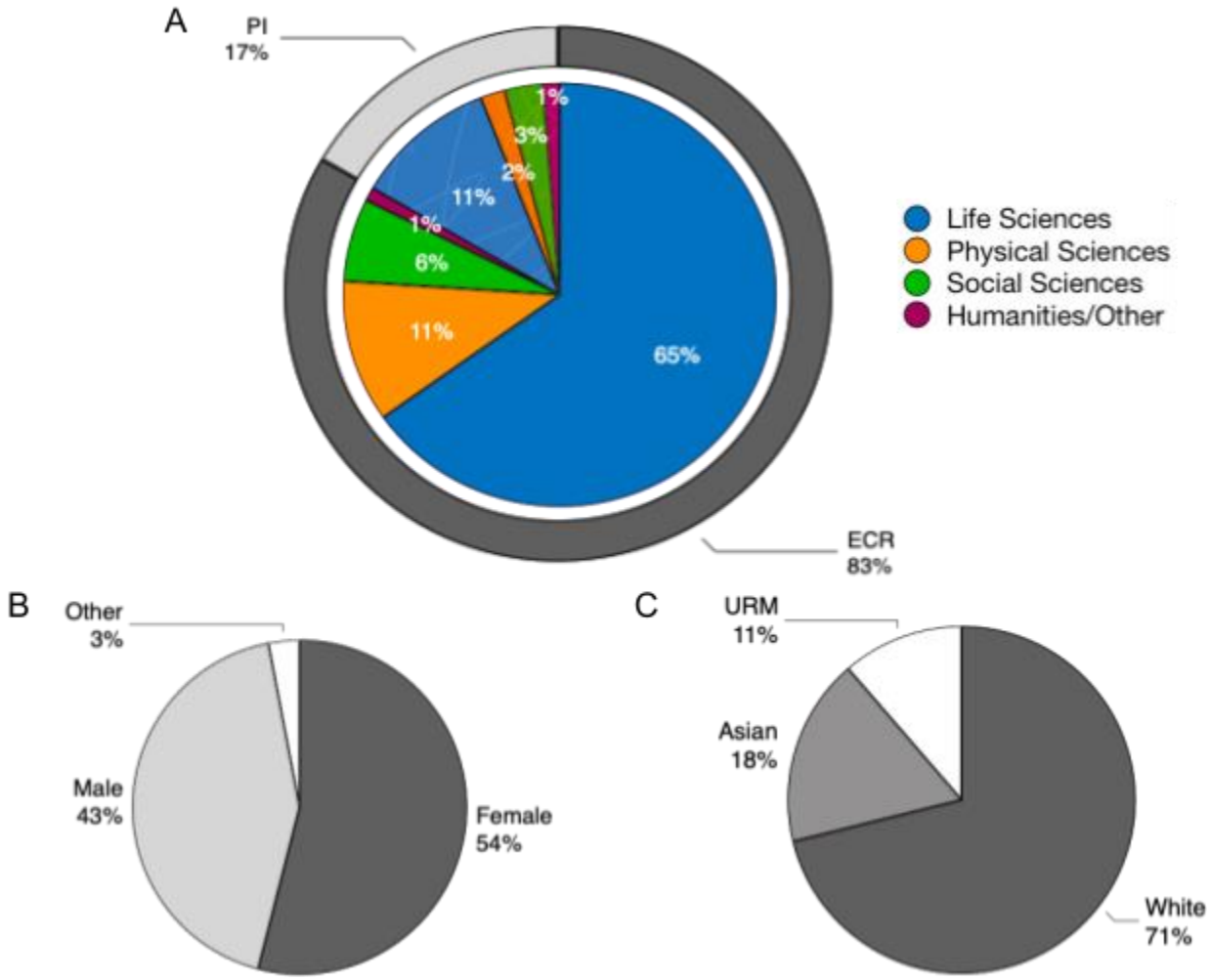

Figure 1: Demographics of survey respondents. (A) Distribution of responses by field of study and career stage. Respondents' write-in fields of study were categorized for analysis purposes (Appendix: List of topics assigned to fields of study). (B) Distribution of responses by gender. (C) Distribution of responses by race/ethnicity. URM, underrepresented minority in the sciences.

Ghostwriting happens frequently, despite a common belief that it is unethical

Frequency of co-reviewing

The results of our survey support the hypothesis that co-reviewing of manuscripts by ECRs is widespread and frequently goes unacknowledged to journal editorial staff. 73% of *all* survey respondents have acted as co-reviewers and often at numerous times (33% have co-reviewed on 6-20 occasions and 4% on more than 20 occasions, Figure 2A). Co-reviewing by ECRs is common, with 79% of postdocs and 57% of PhD students having “contributed ideas and/or text to peer review reports where [they are] not the invited reviewer (e.g. the invited reviewer is the PI for whom you work)” (Figure 2B). These data suggest that **collaboration on peer review reports, especially by ECRs who are not the invited reviewer, is an academic norm**. By contrast, when asked about independent reviewing experiences, 37% of *all* survey respondents stated that they had never had such an experience. 35% reported having had this experience on 1-5 occasions; 20% on 6-20 occasions; and 8% on more than 20 occasions. 55% of the ECR respondents have never carried out independent peer review as the invited reviewer (Figure 2C).

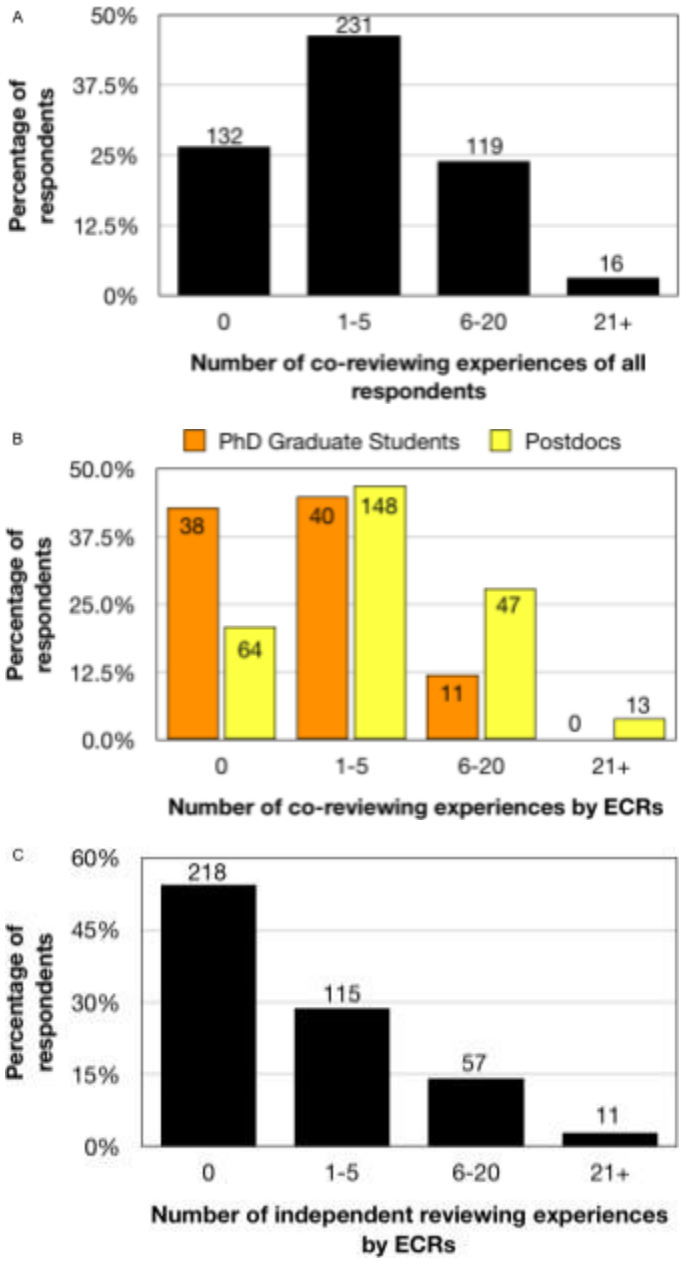

Figure 2: Responses to "How many times in your career have you contributed ideas and/or text to peer review reports where you are not the invited reviewer (e.g. the invited reviewer is the PI for whom you work)?" (A, B) and "How many times in your career have you reviewed an article for publication independently, i.e. carried out the full review and been identified to the editorial staff as the sole reviewer?" (C). (A) Number of co-reviewing experiences of all survey respondents (n = 498). 73% of respondents had participated in co-reviewing, of which 63% had carried out co-reviewing activities on 1-5 occasions; 33% on 6-20 occasions; and 4% on more than 20 occasions. (B) Number of co-reviewing experiences by ECR career stage. The distribution of postdocs (n=312) is skewed toward more co-reviewing experiences while the distribution of PhD students (n=89) is skewed toward fewer co-reviewing experiences. (C) Number of independent review experiences of ECRs. Breaking this down by career stage, we found that 218 respondents (55%) from our pool of 401 ECRs had never carried out independent peer review, and conversely 183 (46%) had carried out independent review as the invited reviewer. Of those who had carried out independent review, 63% (n=115) had done so 1-5 times; 31% (n=57) had done so 6-20 times, and 6% (n=11) had done so more than 20 times.

Motivations for co-reviewing

We hypothesized that a significant motivation for ECRs to engage in co-reviewing was to gain experience in peer review of manuscripts, a fundamental scholarly skill. We asked all survey respondents what training they received in peer review of manuscripts (Figure 3). Respondents report that their PIs provide the second most common source of training in peer review, bested only by the passive form of learning "from receiving reviews on my own papers." Training appears to be a major driver for why ECRs are involved in the peer review of manuscripts and indeed training through co-reviewing was the subject of many publications uncovered by our literature review (Appendix: Literature on ECR involvement in peer review as a training exercise).

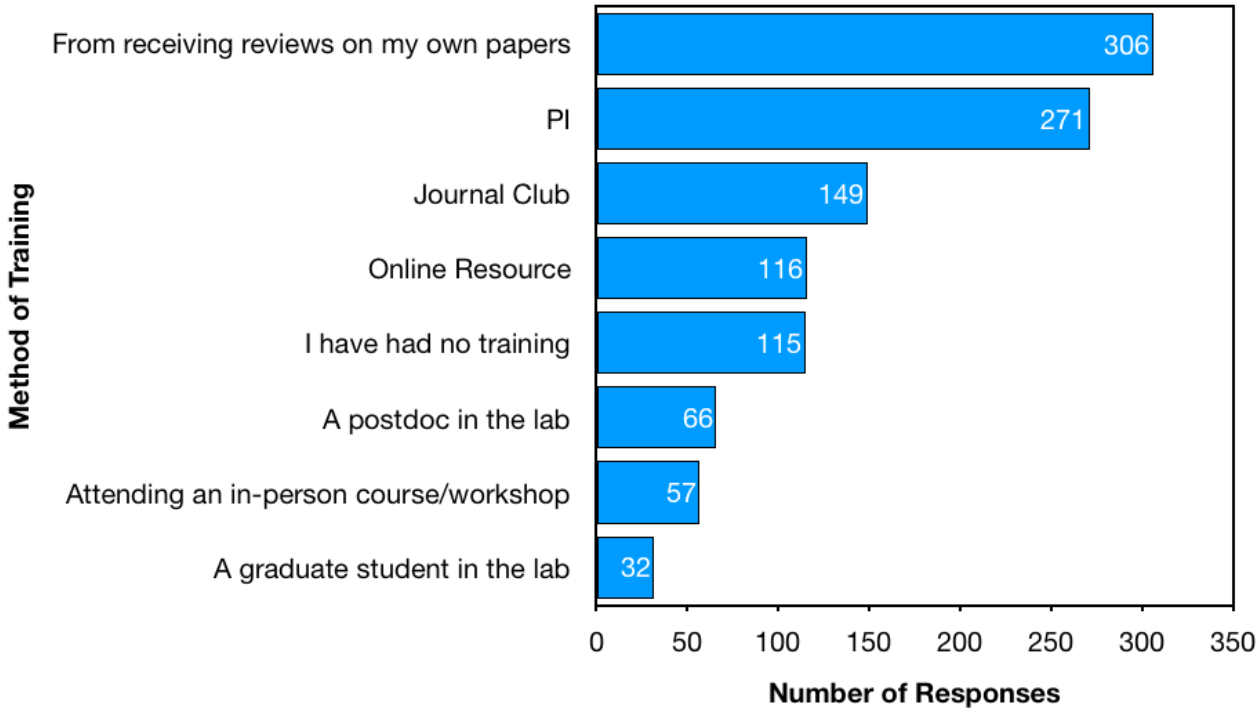

Figure 3: Responses to "How did you gain training in how to peer review a manuscript?" Respondents were able to select as many options as applied to them. These data include responses from all survey participants, including those without any independent or co-reviewing experience.

Frequency of ghostwriting

Are these co-reviewers being named to the journal? Or put another way, are journals being made aware that more than just the invited reviewer is contributing ideas and/or text to peer review reports? When we asked "To your knowledge, did your PI ever withhold your name from the editorial staff when you served as the reviewer or coreviewer?," 46% of respondents knew that their name had been withheld (Figure 4). These data align well with results from a separate question about co-reviewing and ghostwriting experiences: "When you were not the invited reviewer, what was the extent of your involvement in the peer review process?", to which 44% of respondents reported having had the experience of ghostwriting: "I read the manuscript, wrote the report, my PI edited the report and my PI submitted report with only their name provided to the editorial staff" (Table 1). Taken together, these data suggest that approximately **1 in 2 survey respondents has engaged in ghostwriting of a peer review report on behalf of their PI, the invited reviewer**.

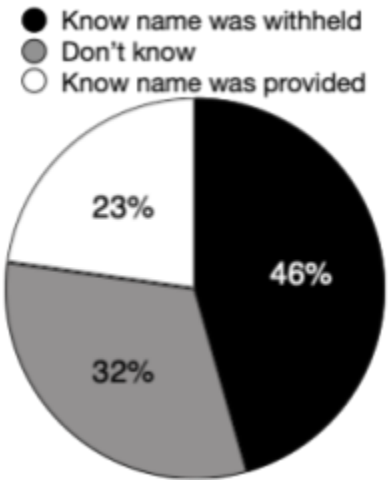

Figure 4: Responses to "To your knowledge, did your PI ever withhold your name from the editorial staff when you served as the reviewer or coreviewer?" 46% of respondents knew that their name had been withheld and 32% did not know. The remaining 23% responded that they knew for certain their name had been disclosed.

Table 1: Responses to "When you were not the invited reviewer, what was the extent of your involvement in the peer review process?" Survey participants were able to choose any and all applicable responses from a provided set of possible responses that can be broken down into three interpretation groups. Because respondents were able to select more than one answer, these data include all of the different co-reviewing experiences for each participant.

Possible survey responses	**Respondents that selected this as an answer (%)**	**Interpretation of response**	**Respondents that selected at least one of the answers in this group (n, %)**
"I read the manuscript, shared short comments with my PI, and was no longer involved"	**40**	No significant contribution	149 respondents (**40%**) selected this response
"I read the manuscript, wrote a full report for my PI, and was no longer involved"	**47**	Significant contribution, without known credit	258 respondents (**70%** of those with co-reviewing experience) selected at least one of the responses in this category
"I read the manuscript, wrote the report, my PI edited the report and my PI submitted report with only their name provided to the editorial staff"	**44**		
"I read the manuscript, wrote the report, my PI edited the report and we submitted the report together with both of our names provided to the editorial staff"	**20**	Significant contribution, with known credit	80 respondents (**22%** of those with co-reviewing experience) selected at least one of the responses in this category
"I read the manuscript, wrote the report, and submitted it independently without my PI's name provided to the editorial staff"	**3**		

Note: (Mis)representation of authorship on any scholarly work can be a subjective grey area. We sought to specifically avoid this in our survey questions by using the answers to the question "When you were not the invited reviewer, what was the extent of your involvement in the peer review process?" to disambiguate the grey areas of authorship. We consider any experience that began with "I read the manuscript, wrote a full report for my PI, and..." to be an unequivocally significant contribution deserving of authorship on the peer review report.

Furthermore, of respondents who co-reviewed, 70% report the experience of making significant contributions to a peer review report without knowingly receiving credit (Table 2). These data reveal a breakdown in communication between invited reviewers and co-reviewers. In a more specific follow up question that asked “To your knowledge, did your PI ever submit your reviews without editing your work?”, 52% of our survey respondents report that they were not involved in any editing process with their PI (Figure 5).

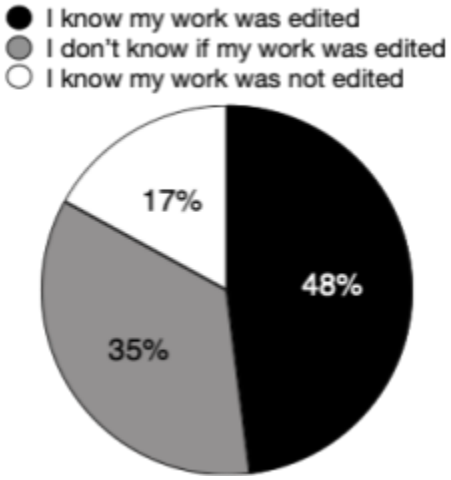

Figure 5: Responses to “To your knowledge, did your PI ever submit your reviews without editing your work?.” More than half of respondents are not involved in editing subsequent to submitting work to the invited reviewer. 17% of respondents answered “yes”, that they knew that their work had not been edited by the PI prior to submission to the journal. Another 35% of respondents were unaware of whether their work was edited by their PI prior to their PI submitting it to the journal. 48% of respondents indicated that “no”, indicating that they knew their work had been edited for sure.

As mentioned above, an INSIDE *eLife* survey found a slight majority of all respondents had performed peer review with no involvement from their supervisor (Inside eLIFE 2018). The *eLife* survey asked “Have you reviewed before?” and then “If so, to what extent was your supervisor involved?.” Of all respondents in the *eLife* survey (n = 264, 74% of which were postdocs or PhD students), slightly more than half replied “not at all” to the latter question, suggesting that they had done peer review without oversight. One interpretation of these data is that half of

respondents had engaged in independent peer review as the invited reviewer. Another interpretation of these data is that half of respondents had carried out peer review with no feedback from their supervisor, the invited reviewer. Our data expand upon that survey by disentangling these two possibilities, asking respondents to reflect on instances "When you were not the invited reviewer." Now with this added modifier, we still find that **slightly more than half of respondents have written peer review reports without feedback from their PI when the PI is the invited reviewer.**

Ethics of ghostwriting and co-reviewing

It seems incongruent and inefficient that half of co-reviewers are not involved in any editing process with their PIs, if a rationale for co-reviewing by ECRs is to receive training in the scholarly activity of peer review. At best, writing a peer review report without receiving feedback from one's PI prior to submission to a journal is a missed opportunity for the co-reviewer to receive training in this critical skill. At worst, a peer review report that is written by one person and submitted to the journal under the name of another person (the PI) might be considered a misrepresentation of authorship and so a breach of academic integrity. The Office of Research Integrity (ORI), which oversees Public Health Service-funded research in the biomedical sciences, defines plagiarism according to the American Association of University Professors wording as "taking over the ideas, methods, or written words of another, without acknowledgment and with the intention that they be taken as the work of the deceiver" (American Association of University Professors 1989). More specifically, the ORI states that "academic or professional ghost authorship in the sciences is ethically unacceptable"... "because the reader [in this case, the journal editorial staff] is misled as to the actual contributions made by the named author" (Citation: Guideline 27; https://ori.hhs.gov/plagiarism-34).

Our survey respondents strongly agree with the ORI, and specifically believe that ghostwriting of peer review reports is an unethical practice. 83% of respondents disagree with the statement that "The only person who should be named on a peer review report is the invited reviewer, regardless of who carried out the review"; 81% disagree with the statement that "Ghostwriting a peer-review report for your PI is an ethically sound scientific practice" and

77% disagree that “It is ethical for the invited reviewer (e.g. PI) to submit a peer review report to an editor without providing the names of all individuals who have contributed ideas and/or text to the report” (Figure 6). Put another way, 74% agree that “Anyone that contributes ideas and/or text to the review report should be included as a co-author on the review.” Sharing co-reviewer names with the journal staff is considered not only ethical, but also valuable, with 82% agreeing that “It would be valuable to have my name added to a peer review report (e.g. to be recognized as a co-reviewer by the editor; or to use a service such as Publons to be assigned credit).” Similarly, co-reviewing itself is considered ethical and valuable, with 73% agreeing that “It is ethical for the invited reviewer (e.g. PI) to involve others (e.g. their trainees) in reviewing manuscripts” and 95% agreeing that “Involving members of a research group in peer review is a beneficial training exercise.” The latter statement evoked the strongest positive sentiment of all 11 possible Agree/Disagree statements.

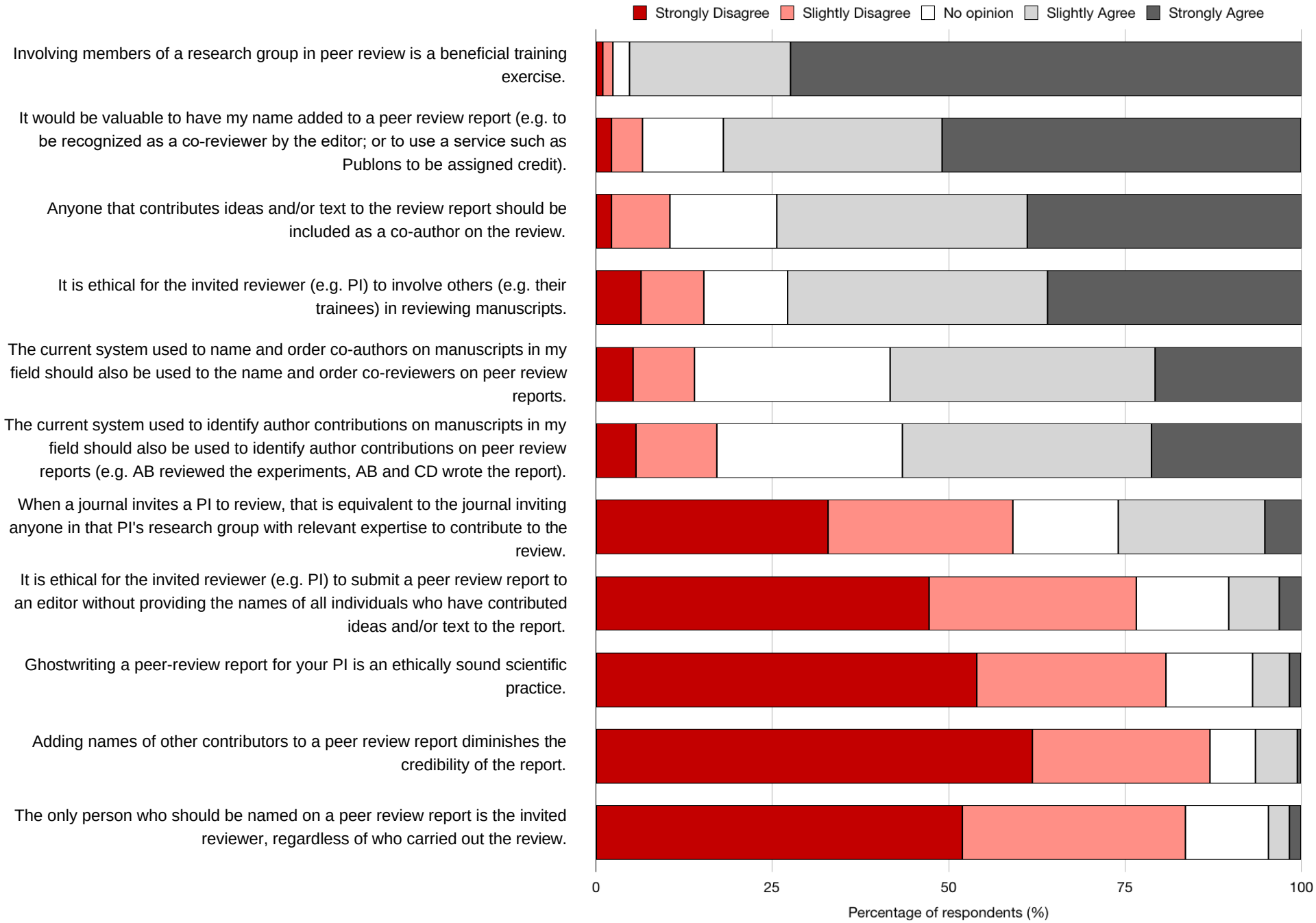

Figure 6: Responses to "Please indicate how strongly you agree with the following statements." Data represent the opinions (not experiences) of all respondents regardless of whether or not they had participated in peer review. Respondents were also provided with a textbox to submit comments to expand and/or clarify their opinions.

Since ECRs are the disadvantaged population when ghostwriting occurs, we hypothesized that ECRs might have more strongly held opinions about these practices than PIs. We calculated the degree to which ECRs and PIs agreed with each other by setting 1 as Strongly Agree through to 5 as Strongly Disagree, and 3 set as No Opinion, and then by calculating the mean degree of agreement as a score. Overall, there was a great degree of similarity between the responses of ECRs and PIs. We found only 3 of 11 statements where there was a significant difference in the extent of agreement between ECRs and PIs (Table 2). In all of these cases, ECRs felt significantly more strongly than PIs but still shared the same valance (e.g. both groups agreed or both groups disagreed with the statement, just to a differing strength). Since 21% of PIs vs. 10% of ECRs responded with “no opinion” to the statement about the value of credit for co-reviewing, we wondered whether the difference in means for this statement could be ascribed to more indifference on the part of the PI population. We recalculated the means removing the “no opinion” responses and found that the difference between the means was still significant but much less so ($p = 0.048$; ECRs: 1.57 ± 0.05 ($n = 365$) vs. PIs: 1.88 ± 0.15 ($n = 64$)).

Table 2: Statistically significant difference in agreement between ECR and PI populations on Agree/Disagree statements . The higher the mean value calculated for the group, the closer the group feels to disagreeing with statement. “No opinion” responses, coded as 3, are included in these means. A 2-tailed student’s t-test for equality of the means was used to calculate p values. *Indicates that p value was calculated assuming equal variance according to Levene’s test for Equality of Variances.

Statement	ECR Mean Score	PI Mean Score	*p* value	% ECRs with no opinion	% PIs with no opinion
Involving members of a research group in peer review is a beneficial training exercise.	1.32 ± 0.03 (n = 405)	1.54 ± 0.10 (n = 81)	$p = 0.033$	2.5	2.5
It is ethical for the invited reviewer (e.g. PI) to involve others (e.g. their trainees) in reviewing manuscripts.*	2.06 ± 0.06 (n = 406)	2.37 ± 0.14 (n=81)	$p = 0.029$	11	15
It would be valuable to have my name added to a peer review report (e.g. to be recognized as a co-reviewer by the editor; or to use a service such as Publons to be assigned credit).	1.71 ± 0.05 (n = 405)	2.11 ± 0.13 (n = 81)	$p = 0.003$	10	21

Motivations for ghostwriting

If 4 out of 5 survey respondents think ghostwriting is unethical, then why do half of all respondents participate? We measured the motivations for ghostwriting by: (1) asking all survey respondents, regardless of peer review experience, to surmise why someone might withhold the name of a co-reviewer (Figure 7), and (2) asking only survey respondents with ghostwriting experience to report specific reasons that the invited reviewer gave for withholding their name (Table 2). In this way, we compared cultural beliefs with actual practice.

The most commonly-believed barrier to naming co-reviewers was a lack of a physical mechanism to supply the name to the journal, with 73% of respondents selecting this as an option (Figure 7). Cultural expectations were the next most commonly-cited barriers, such as “A belief that reviews should only be done by the invited reviewer, and not by, or with assistance from, anyone else” and “A belief that including co-author information would demonstrate that the PI breached the confidentiality of the manuscript”, selected by 63% and 58% of respondents respectively. These latter responses allude to journal policies prohibiting invited reviewers from sharing unpublished manuscripts without prior permission. All three top responses relate to journal policies that are either absent or prohibitive. Write-in responses, summarized in Box 2, echo themes about how ghostwriting is simply the status quo in peer review. At the same time, respondents also wondered why this is the case, and why including co-reviewer names is not common practice.

BOX 2: THEMES FROM WRITE-IN REASONS FOR WHY GHOSTWRITING MAY OCCUR	
Theme	**Example write-in responses**
Cultural expectations	“A belief that ghostwriting does occur, but everyone accepts that it’s just the way it is.”
	“The belief it has always been like this so why doubt /change the process”
	“PIs simply don't think of it because they're used do doing things this way”
	“PIs think this practice is okay.”
Training	“A belief that this is 'how it is done,' and inviting trainees to contribute to reviews is important for their training, but it is not necessarily important for them to get credit for it.”
	“PI feels while the ECR is being trained in doing the review should not be listed as co-author of the review.”
“I don’t understand it”	“Either as a reviewer or as an editor, I would have no problem with a co-review. I'm not really sure why more people don't do it. They absolutely should.”
	“I have no idea why this is not common practice”

Box 2: **Themes and supporting examples of write-in responses to the question: “What do you think are the reasons why the names of co-authors on peer review reports may not be provided to the editorial staff?”**

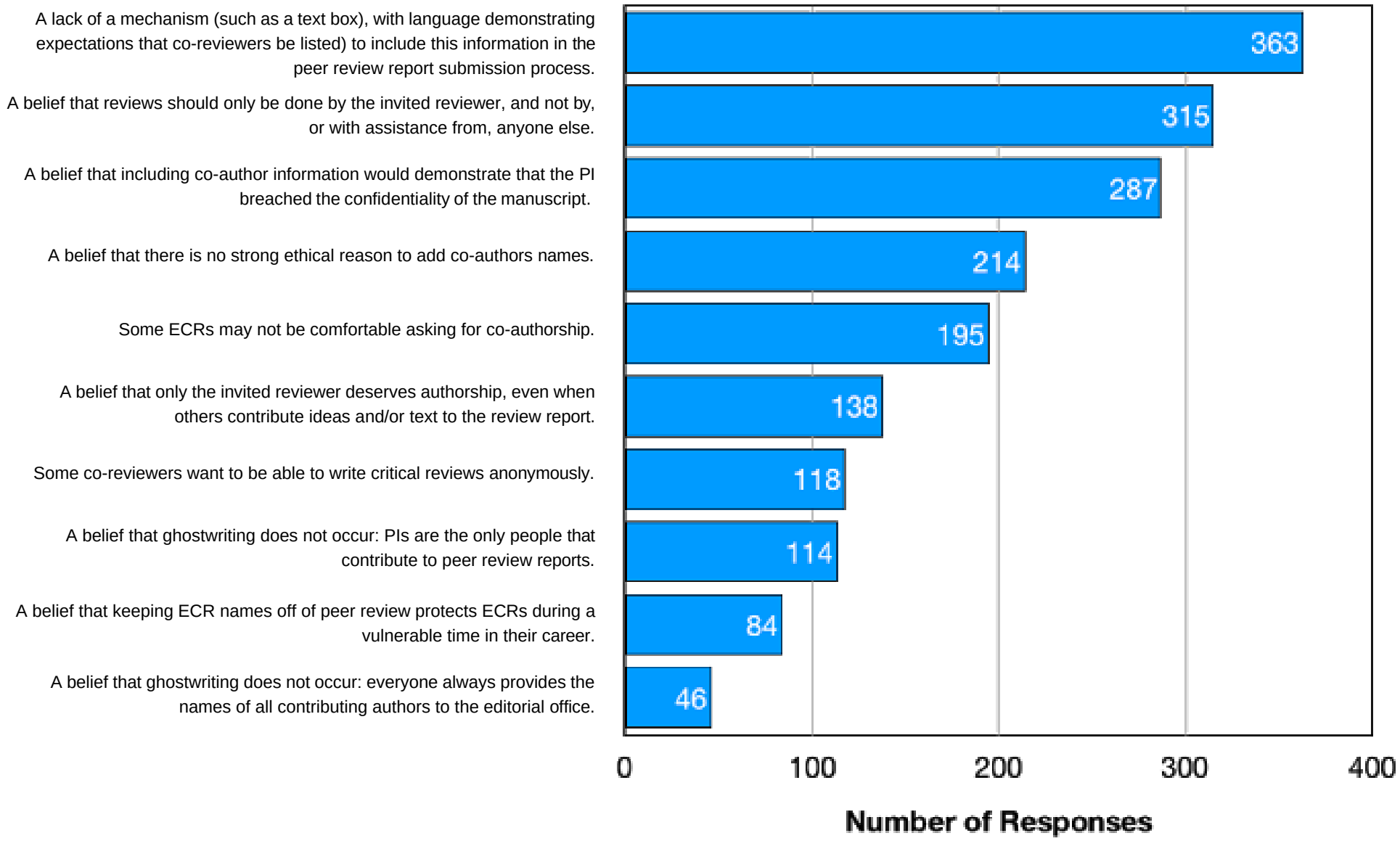

Figure 7: Responses to "What do you think are the reasons why the names of co-authors on peer review reports may not be provided to the editorial staff?." Here our intent was to ask the respondents *not for their personal opinions on whether co-reviewers should be named*, but rather for their perspective on what they thought the logistical or cultural barriers may be that would cause names to be withheld in general practice. Respondents were able to select as many answers as they felt applied. The frequencies do not allow us to assess how important the barriers are, and respondents were not asked to rank barriers, but simply to surmise which ones they felt were relevant to the current practice of ghostwriting.

In contrast, when we asked “Consider cases where you contributed to a peer review report and you know your name was NOT provided to the editorial staff. When discussing this with your PI, what reason did they give to exclude you as a co-reviewer?” 73% of respondents reported that they had not discussed this with their PI (Table 3). This is consistent with the lack of communication between invited reviewers and co-reviewers documented above (Table 1, Figure 5). Of the 27% of respondents who had ghostwritten and *did discuss* the matter with their PI, most were told that the reason their name was withheld was either a prohibitive journal policy and/or prevailing cultural expectations about co-authorship on peer review reports. Only 4% of those who had discussed the matter with their PI cited a practical barrier, such as the lack of a text box for co-reviewer names on the journal review submission form, as the reason given by their PI for withholding their name. Write-in responses to this question again refer to cultural expectations as the major drivers for ghostwriting (Box 3; Appendix: Written responses giving reasons PIs excluded survey respondents as co-reviewers). Many of these write-in reasons articulate that it is good practice for ECRs to participate in peer review; however, they simultaneously fail to explain why this necessitates withholding the names of co-reviewers. These data suggest that there is a common conflation of ghostwriting (withholding names) with co-reviewing (involving ECRs in peer review, often for the purposes of training).

Table 3: Responses to "Consider cases where you contributed to a peer review report and you know your name was NOT provided to the editorial staff. When discussing this with your PI, what reason did they give to exclude you as a co-reviewer?" In addition to the possible answers provided by the survey, respondents were also provided with a textbox to add write-in responses.

Reasons given by PIs for not naming co-reviewers	Number of Respondents
Did not discuss with my PI	210
Co-authorship is for papers, not for peer review reports; Intellectual contribution not deemed sufficient	33
Journal requires prior approval to share manuscript, which was not obtained; Journal does not allow ECRs to review	30
Write-in answers citing mechanistic barriers (e.g. lack of a text box to enter co-reviewer names)	3

BOX 3: THEMES FROM WRITE-IN REASONS GIVEN BY PI FOR WITHHOLDING ECR NAME	
Theme	**Example write-in response**
Sin of omission	"They forgot"
	"Didn't think of including me; didn't know how to do so"
	"He was in a hurry and he couldn't figure out the journal's website"
Cultural expectations	"This was not explicitly discussed, but the PI implied this is "common practice" and normal for ECRs to gain experience"
	"[PI] said only [they] would be invited to review for such a prestigious journal and "we" need this for future submissions"
	"Apparently this duty is part of my job description"
	"I was told this is how one gets to train to review papers and grants"
A good way to train	"Reviewing papers as [an] ECR is part of the ECR training"
	"It's good experience for me."
	"It was good for my career to practice"

Box 3: Themes and supporting examples of write-in responses to the question "Consider cases where you contributed to a peer review report and you know your name was NOT provided to the editorial staff. When discussing this with your PI, what reason did they give to exclude you as a co-reviewer?"

DISCUSSION

Journal peer review is an important part of scholarly work and, as such, scholars should be well-trained in this activity to ensure quality peer review into the future. Our dataset demonstrates that involving ECRs in peer review is an academic norm, with ¾ of our survey population having contributed significantly to a peer review report when they were not the invited reviewer (co-reviewed) and ½ having done so without being named to the journal editorial staff (ghostwritten). These high frequencies starkly contrast with journal policies and widely-held cultural expectations that only the invited reviewer engages in the peer review of a manuscript for publication. They also fly in the face of our values as a community, when ⅘ of those surveyed agree that ghostwriting is unethical. What drives these differences between community values and experience, and what can be done to reconcile them?

Explanations for ghostwriting are conflated with explanations for co-reviewing

Co-reviewing as a training exercise and ghostwriting are separable processes: training through co-review can and does happen *whether or not* named credit is given to the co-reviewer, and excluding co-reviewer names from peer review reports can and does happen *whether or not* the co-reviewer has experienced quality training in the process. Even as we sought to collect data that would disentangle these two processes, we found that the rationales for ghostwriting were all too often conflated with the rationales for co-reviewing. For example, when we asked respondents specifically for the reason(s) their PI gave them for excluding their names on a peer review report they co-authored, many wrote-in responses such as "I was told this is how one gets to train to review papers..." (Box 3). This explanation for why ghostwriting occurs - that it is a beneficial and common practice for ECRs to participate in peer review as a training exercise - does not actually answer why co-reviewers are not named to the journal editor. **An important first step in reducing unethical ghostwriting practices will be to decouple it in the zeitgeist from the beneficial training of ECRs through the process of co-review.** We therefore separate our discussion of the motivations for co-reviewing and ghostwriting in an effort to find solutions to ghostwriting that simultaneously support ECR co-reviewing as training in peer review.

Why does co-reviewing happen so frequently?

Co-reviewing by ECRs as a common and valuable training exercise

Perhaps the most intuitive and optimistic answer to the question stated in the heading is that, when the issue of named credit on peer review reports is set aside, **co-reviewing by ECRs is considered a valuable, ethical, and common form of training in the peer review of manuscripts.** 95% of survey respondents find co-reviewing to be "a beneficial training exercise" and 73% agree that "it is ethical for the invited reviewer (e.g. PI) to involve others (e.g. their trainees) in reviewing manuscripts." Co-reviewing is also the second most commonly reported source of training in peer review, bested only by "receiving reviews on my own papers," a method of passive learning. These data should be weighed heavily when considering journal policies regarding co-reviewing broadly, and ECRs as co-reviewers specifically, since **any policy that prevents co-reviewing by ECRs would remove a common and valuable training exercise in peer review**.

Survey respondents clearly find that co-reviewing by ECRs has significant benefits and is not inherently problematic. Yet problems with using "ECR training" as a rationale for co-reviewing arise when training doesn't actually take place and instead co-reviewing devolves into an exploitative delegation of scholarly labor, when this mode of training is ineffective at improving ECR's ability to peer review, and/or when co-reviewing perpetuates unethical conditions like ghostwriting or breaches of manuscript confidentiality.

Co-reviewing by ECRs as a delegation of scholarly labor

A major limitation with using "ECR training" as a rationale for co-reviewing arises when half of survey respondents report writing a peer review report without any training interaction with their PIs. The hidden delegation of scholarly labor to ECRs benefits the invited reviewer, often an overburdened PI in a hypercompetitive research environment (Alberts et al. 2014). As the number of ECRs has grown steadily in biomedicine since the mid-20th Century, academic positions to employ them have not (Heggeness et al. 2016; Heggeness et al. 2017). The resulting hypercompetitive environment incentivizes the use of ECRs as cheap labor to fulfil productivity requirements. This can include scholarly labor that PIs lack the time or even expertise to perform, such as manuscript peer review.

These market forces provide a second explanation, beyond ECR training, for why co-reviewing is commonplace: that the selective pressures of a hypercompetitive research environment have caused co-reviewing and ghostwriting by ECRs to become the status quo. Our survey respondents agree, with many providing write-in responses such as: "apparently this duty is part of my job description" (Box 3). The delegation of scholarly labor to ECRs is not necessarily, nor intentionally, exploitative, although it can easily become so given the power dynamics and documented lack of communication between mentors and mentees (Van Noorden 2018). Any successful intervention to address concerns about the ethics of co-reviewing by ECRs should take into account this status quo - that **it is commonly an unstated expectation that ECRs carry out peer review on behalf of their PI, and that ECRs may not feel they have the freedom to decline even if they feel it is unethical to participate**. We encourage the scientific community to recognize this dynamic and recommend that journals adopt policies that specifically address this common yet unethical practice.

Limitations to depending on co-reviewing as training

A lack of evidence-based training structures and community oversight

The top three forms of peer review training reported by our survey are notable in that they do not necessarily involve any formal training structure, quality control, or community oversight (Figure 3). “Receiving reviews on my own papers” is only able to give a limited number of examples of how others review. Since it is a common complaint that reviews are overly critical and fail to give constructive feedback (Schneiderhan 2013), it seems counter-intuitive to have this be the main example by which ECRs learn how to conduct peer review. This is also a passive form of learning that lacks individualized or iterative feedback from a mentor. By contrast, training received “from PI” may benefit from a personalized teaching relationship; however, the quality of this teaching is again dependent on the training the PI may have received, which may be from their own reviews and previous mentors. Journal clubs too may be self-organized groups comprised of e.g. only graduate students, that may lack a desired level of peer review expertise and/or a rigorous training component.

These data suggest that **one’s training in peer review is largely determined by a small number of individual experiences outside of evidence-based training structures.** Such training experiences are likely to be self-reinforcing, their quality dependent on the quality of the reviews received or the quality of training received by PIs themselves. The small sample size of these experiences may also reinforce a number of biases, including selection bias where one’s few experiences may not be representative of the population, memory biases where negative experiences (e.g. from receiving highly critical reviews) are more readily remembered and so taught (Kensinger 2007), and gender or other demographic biases currently being studied in the

peer review process (Murray et al. 2018). The quality and consistency of training that is drawn from a small number of different personal experiences, in turn, is likely to be highly variable.

These results highlight an area of opportunity to improve and standardize training in peer review of manuscripts as a critical scholarly skill. One intervention to be considered is the establishment of more standardized, evidenced-based training for peer review of manuscripts. This might be accomplished by graduate programs, scientific societies, or even journals themselves, and some already provide training materials (Appendix: Examples of formalized training in peer review). Given the central place that peer review has in maintaining trust in our ability to scrutinize each other's work (Patel et al. 2017) and the public's trust in our enterprise, we are concerned that insufficient attention is given to rigorous peer review training from the very beginning of graduate programs. That "Peer Review 101" does not appear to be a compulsory and ubiquitous course at graduate schools should give the community pause for thought, and future efforts should tie mentoring efforts with evidence-based training in the peer review process to ensure that all PhD-holders are competent and capable of engaging in a constructive peer review process.

A lack of training the trainers

Since the top two reported forms of training involve PIs (either as manuscript reviewers or ECR mentors), interventions that attempt to ensure PIs have received training in peer review *and in communicating this skill to ECRs* may also be appropriate. We have encountered the perspective that a postdoc should not undertake peer review while a PI is assumed to be expert at it, and **this is illogical, given that there are no systematic steps to ensure proficiency at**

peer review during the postdoc-to-PI transition. Indeed, a lack of "training the trainers" was cited as a main reason for why pairing experts with new peer reviewers failed to improve review quality in one of the few randomized controlled trials of this practice (Houry et al. 2012). In this study, the expert reviewers were not given any training themselves in an effort to minimize their burden, which the authors conclude resulted in an ineffective training program. They suggest that effective mentoring of new reviewers should include training in providing feedback from expert to trainee. Others echo this recommendation, finding that iterative feedback from the mentor leads to positive outcomes as measured by reviewers' beliefs and by objective evaluations of improved review quality (Castelló et al. 2017; Doran et al. 2014). One mechanism that proved efficacious was directing the PI to report on the same manuscripts as the trainees, thereby providing trainees with an example/comparison peer review report (Castelló et al. 2017). An emerging theme, therefore, is be **a need for improved communication between mentors and mentees during the co-review training experience**.

Why does ghostwriting happen so frequently?

A lack of communication about authorship of peer review reports

Even in the best case scenario for co-reviewing as a training exercise, when training *is* taking place and *is* effective, its benefits can still be confounded by ethical lapses such as ghostwriting. The most common explanation for ghostwriting was that providing co-reviewer names to the editor was simply not discussed (Table 3, 73% of responses from those who knew their names had been withheld). Of those who had contributed significantly to peer review reports with or without known credit, 39% of their experiences fall into the category of "I read the manuscript, wrote a full report for my PI, and was no longer involved" (n = 107 of 274 total responses that begin with "*I read the manuscript, wrote the full report…*", Table 1). These **data reveal a significant breakdown in communication between invited reviewers and those actually writing the peer review report**, that is concerning on many levels - e.g. with regards to plagiarism, mentor-mentee relationships, and the exploitation of ECR labor.

Why is authorship on peer review reports not a topic of conversation between collaborating invited reviewers and co-reviewers, as it might be between senior and junior authors on a manuscript? One simple reason may be that not naming co-reviewers is the expected status quo. This theme is echoed even when discussions between PIs and ECRs do occur: 25% of respondents who discussed the issue with their PI were told that the reason their name was excluded was "co-authorship is for papers not for peer review reports" (Table 3). Many write-in responses support this idea that ghostwriting may come about as a "sin of omission:" [PI] "didn't think of including me" and "they forgot" (Box 3). ECRs express similar opinions, with one postdoc writing: "I'd never really thought about this before. I just assumed it was part of the

process. But it is very time consuming and I do believe that all reviewers should receive credit for the review." Therefore, if ghostwriting arises from PIs and ECRs simply not thinking to include co-reviewer names on peer review reports vs. intentional withholding of names, then building awareness about this issue should encourage more conversation within the community and between mentors and their trainees. Mentors should discuss with mentees how they approach peer review and how credit is given for peer review work to impart proper review ethics to trainees.

We recognize that a naive "sin of omission" may not be the only roadblock that prevents open conversation about authorship between PIs and ECRs. Certainly, power imbalances might prevent an ECR from feeling able or willing to initiate this conversation with their PI. Given that the prevailing cultural norm is to not provide co-reviewer names, ECRs may not feel equipped with evidence to support their self-advocacy, regardless of how strongly they feel about the topic. Indeed, 39% of respondents think that ghostwriting occurs because "some ECRs may not be comfortable asking for co-authorship" (Figure 7). As one write-in states: "you don't want to piss off the boss." Ghostwriting, therefore, may be a symptom of the larger problem in academia that ECRs are extremely dependent on their PI's goodwill for retention in the hypercompetitive research environment (eg. for letters of recommendation throughout their career, or immigration status).

A lack of perceived value in naming co-reviewers?

Do co-reviewers see a benefit to having their name disclosed to the journal editor?

82% of survey respondents agree that “It would be valuable to have my name added to a peer review report.” Co-reviewers, especially ECRs, may value having their name provided to the journal for many reasons, including the ability to be “known” in the field to scientific editors and potential colleagues; the ability to have their scholarly work acknowledged by a verified third party service (e.g. Publons) for career advancement; and/or the ability to demonstrate eligibility for visas and residency. While not all co-reviewers will find equal benefit in receiving credit for every co-reviewing experience, **each individual should have the ability to choose to be named as a co-reviewer**. A lack of universal benefit in being named as a co-reviewer is not a suitable reason to withhold co-reviewer names.

It is the co-reviewer and not the invited reviewer who perceives most benefit from having recognized co-authorship of a peer review report. We see in our data that, while PIs and ECRs both agree that there is value in this practice, ECRs agree more strongly than PIs that there is value in receiving credit or being known to the journal editorial staff as a co-reviewer (Table 2). This was one of only 3 (of 11) statements in which there was a significant difference between the mean agreement score of ECRs and PIs. More PIs also had no opinion on this statement than ECRs (21% of PIs vs. 10 % of ECRs having no opinion). This may suggest that the difference in strength of agreement is not due to opposition, per se, but rather due to greater indifference on the part of the PI population, who may not see value in it, perhaps because they are already known to editors. In the words of one write-in response: “PI surprised I would be interested in being acknowledged, and seemed like too much trouble to acknowledge my contribution.” This ambivalence for due credit for co-reviewers likely derives from a position of

social privilege. Ironically, it is the individuals in the scientific community with positions of relative privilege who may be less likely to recognize the benefit of credit for co-reviewing - e.g. tenured PIs, US citizens - and yet who may have the greatest power to change the status quo. When people of privilege are the only community members that participate in decision-making, they may (inadvertently) create policies or reinforce cultural standards that fail to consider the differing values of less privileged members of the community members, like ECRs. We support the growing effort to include more diverse voices in leadership roles in science, including Future of Research's "Who's on board" initiative to seat more ECRs on the advisory boards of scientific organizations and journals, citing examples such as the Early Career Advisory Group at *eLife* (https://elifesciences.org/about/early-career).

A perceived value in withholding co-reviewer names?

Survey respondents clearly see a benefit to having co-reviewer names disclosed to the journal editor. At the same time, do survey respondents think that there is any counterbalancing value *to not naming* co-reviewers to the editor? We wondered whether ghostwriting might occur because of the perception that adding co-reviewer names diminishes the peer review report itself (e.g. by providing evidence that someone other than the invited reviewer contributed to the review)? Survey respondents overwhelmingly do not find this to be the case, with 87% of respondents regardless of career stage disagreeing with the statement that "Adding names of other contributors to a peer review report diminishes the credibility of the report." This statement evoked the strongest negative sentiment of all 11 possible Agree/Disagree statements. We would be curious to know the opinion of journal editorial boards on this subject, since there are journals with policies that prevent ECRs from serving as co-reviewers (or invited reviewers). **If**

journal policies derive from a concern that ECR contributions to peer review diminish the credibility of the report, then they would be significantly out of line with the scientific community's opinion represented in this dataset. They also go against the results of an ongoing experiment in co-reviewing at 3 Elsevier journals, in which editors did not rate the co-reviewed reports as poor or low quality, and more than half were considering co-reviewers to serve as invited reviewers on future manuscripts (Mehmani 2019). Indeed, that there should be no diminution of quality in co-reviewed peer review reports supports research suggesting that reviewers who are earlier in their careers may be perceived by editors as better reviewers (Black et al. 1998; Evans et al. 1993; Callaham and Tercier 2007). Being closer to bench research, rather than having more experience in reviewing itself, may be a key determinant of this trait (Stossel 1985).

Another reason for why there might be perceived value in withholding co-reviewers names to the editor is to protect ECRs during a vulnerable time in their careers. Occasional write-in responses support this hypothesis, such as "It [being named on a peer review report] may give certain ECRs a bad reputation if they review things really harshly." However, on the whole, survey respondents largely do not see this protectionism argument as a driver of ghostwriting, with only 17% of respondents choosing "a belief that keeping ECR names off of peer review reports protects ECRs during a vulnerable time in their career" as a potential reason for why ghostwriting occurs. This finding might be because we specially asked about traditional peer review, where reviewer names are known only to the journal editor and excluded cases of open peer review, where the names of reviewer(s) might be made more widely available. Moreover, the choice of a contributing author to withhold their name on occasion - as would be the case if a collaborator chose to recuse their name from a manuscript - does not justify the use of

protectionism as an explanation for ghostwriting in general. In summary, **survey respondents find added value in naming co-reviewers, and also see no loss of value to peer review reports when co-reviewer names are added**.

A lack of a practical mechanism for reporting co-reviewers?

Could it be that a main driver of ghostwriting boils down to a practical roadblock such as a lack of clear reporting mechanism? An obvious, unavoidable mechanism (e.g. a mandatory checkbox and/or textbox) for reporting co-reviewer names on the submission page for peer review reports might be necessary and sufficient to prompt an invited reviewer to discuss co-reviewer authorship and/or to name co-reviewers to the journal editors. We hypothesized that a lack of such a mechanism was a major reason why co-reviewer names are often excluded. Indeed, respondents seemed to agree with our hypothesis, with 73% surmising that ghostwriting occurs because of "A lack of a mechanism (such as a text box, with language demonstrating expectations that co-reviewers be listed) to include this information in the peer review report submission process."

However, we noticed a striking difference between these beliefs and the actual experiences reported in our survey. When we asked unnamed co-reviewers to reflect on their own experiences with **ghostwriting**, **only 3 responses cited a lack of a practical mechanism such as a checkbox**. This represents only 4% of those who were given a reason by their PI for withholding named credit (n = 77). These data reveal a major difference between a culturally perceived barrier and an actual barrier to naming co-reviewers. A policy shift that fixes this

practical mechanism - e.g. adding a checkbox - may still help and may feel like the right thing to do but may not be as impactful as hoped if it fails to address the actual barriers that are faced.

Our data reveal two specific barriers to naming co-reviewers on peer review reports, in addition to the more general problem of a lack of communication about authorship. Both of these barriers arise because **common practice is out of alignment with consensus opinion about best practices**, according to survey respondents.

A belief that co-reviewers don't deserve credit regardless of how much they contribute

The first of these rationales for ghostwriting is a cultural expectation that co-reviewers don't deserve named credit to the editor regardless of how much they contribute. 43% of ghostwriting experiences were explained by "co-authorship is for papers, not for peer review reports" or "intellectual contribution not deemed sufficient" even though the question stipulated to only consider cases where the co-reviewer contributed ideas and/or text to a peer review report. These experiences are substantiated by community perceptions, with 28% of respondents surmising that ghostwriting occurs due to "A belief that only the invited reviewer deserves authorship, even when others contribute ideas and/or text to the review report." These given rationales for ghostwriting contradict community opinion about whether this *should be* the case, with 83% disagreeing that "the only person who should be named on a peer review report is the invited reviewer, regardless of who carried out the review" and 74% agreeing that "anyone that contributes ideas and/or text to the review report should be included as a co-author on the review."

Prohibitive journal policy that is out of alignment with current practice

The other most commonly reported reason given by invited reviewers to justify ghostwriting experiences to co-reviewers is prohibitive journal policies. 39% of co-reviewers who discussed with the invited reviewer the possibility of including their name on the peer review report cite "journal requires prior approval to share manuscript, which was not obtained" or "journal does not allow ECRs to review" as the reason why PIs chose to withhold their names. These experiences are substantiated by community perceptions, with 58% of respondents surmising that ghostwriting occurs because of "a belief that including co-author information would demonstrate that the PI breached the confidentiality of the manuscript" and 63% surmising that ghostwriting occurs because of "a belief that reviews should only be done by the invited reviewer, and not by, or with assistance from, anyone else." These are the second and third most commonly selected responses out of 11 provided responses. We interpret this to mean that the community understands that many journals have policies that prevent invited reviewers from sharing manuscripts with anyone else and/or policies that prevent ECRs from serving as reviewers or co-reviewers without prior permission from the editor[2]. Yet it seems that, in practice, invited reviewers may not seek prior permissions or may not wish to risk doing so and so choose instead to not reveal the presence of co-reviewers upon submission. In these cases, adding co-reviewer names to a peer review report is equivalent to admitting that journal policies were disobeyed. Given how frequently ghostwriting occurs based on survey data, and how commonly journal policies are cited as the reason for ghostwriting, it seems that **current policies that require invited reviewers to gain permission of the editor prior to involving ECRs in peer review are not effective deterrents for ghostwriting**. Instead, these policies

[2] Many journals adhere to The Committee on Publication Ethics (COPE) Ethical Guidelines for Peer Reviewers (https://publicationethics.org/files/Ethical_Guidelines_For_Peer_Reviewers_2.pdf) which state that, "Supervisors who wish to involve their students or junior researchers in peer review must request permission from the editor and abide by the editor's decision."

may have the opposite, if unintended, consequence of preventing invited reviewers from feeling free to disclose co-reviewer names upon submission and so promoting unethical ghostwriting practices.

A call for harm reduction interventions

Our data suggest that **one unethical practice - ghostwriting - is being justified by another unethical practice that is a pervasive status quo - sharing a manuscript without editorial permission with a co-reviewer, who may not be allowed to review due to ECR status**. These two wrongs do not make a right. How can we remedy this situation? Any policy that requires individuals to simply stop participating in a pervasive practice - and the subsequent policing required to ensure this is resolved - as a way to prevent its undesirable downstream consequences may be ineffective.

We see an analogy to the public health concept of harm reduction, which aims to minimize harm to vulnerable populations while the more challenging work of changing the status quo is tackled, rather than continuing to perpetuate short-term harmful practices because of ideological absolutism (Box 4). Harm reduction interventions as applied to ghostwriting should be "grounded in the recognition that many people are unable or unwilling to stop" (hri.global/what-is-harm-reduction) co-reviewing without due credit - because they see it as a required feature of beneficial peer review training, because they see it as a obligatory status quo and/or necessary delegation of labor in a hypercompetitive environment, because they don't think to discuss or feel able to discuss authorship, etc. - even when this activity comes at the cost of engaging in widely-accepted unethical behaviors such as not gaining prior permission, breaching manuscript confidentiality policies, or plagiarism.

BOX 4: APPLYING PRINCIPLES OF HARM REDUCTION TO GHOSTWRITING

Harm reduction:

- Accepts, for better and or worse, that CO-REVIEWING is part of our world and chooses to work to minimize its harmful effects rather than simply ignore or condemn them.
- Understands GHOSTWRITING as a complex, multi-faceted phenomenon that encompasses a continuum of behaviors from severe abuse to total abstinence, and acknowledges that some ways of CO-REVIEWING are clearly MORE ETHICAL AND/OR BENEFICIAL than others.
- Recognizes that the realities of social inequalities affect both people's vulnerability to and capacity for effectively dealing with GHOSTWRITING.
- Ensures that INVITED REVIEWERS/PIS AND COREVIEWERS/ECRS routinely have a real voice in the creation of programs and policies designed to serve them.

Box 4: Text in CAPS is original to this manuscript, all other text is quoted verbatim from: harmreduction.org/about-us/principles-of-harm-reduction/

In summary, we suggest that the best way to reduce the harms of ghostwriting is to 1) make immediate changes to policies that facilitate giving credit where credit is due and ensure that co-review is an effective training exercise and not exploitation of cheap labor while 2) simultaneously working towards promoting long term cultural changes that recognize the role and value gained from involving ECRs in peer review.

RECOMMENDATIONS

Based on the experiences and opinions of survey respondents presented above, we recommend efforts that encourage ethical practices in quality co-reviewing in peer review. We propose a series of cultural changes for the research community at large (Box A) and practical changes for key stakeholders (Boxes B-D) to improve transparency and the recognition of ECRs in the peer review of manuscripts.

Cultural changes for the research community at large

BOX A: CULTURAL CHANGES FOR THE RESEARCH COMMUNITY AT LARGE

Recognize that:

1. involving ECRs in peer review is already a common activity and one of the most frequent ways that new reviewers are trained.

2. involving ECRs in peer review is considered a valuable opportunity for interactive training in this scholarly activity.

3. soliciting intellectual contributions (ideas and/or text) from any co-reviewer, including ECRs, and then withholding their names from the peer review report to the editor is unethical.

4. peer review of manuscripts is a genuine scholarly endeavor akin to manuscript writing that deserves similar considerations when determining authorship of the peer review report.

5. adding co-reviewer names does not diminish the quality of the peer review report nor does it diminish the important role of the invited reviewer, akin to a senior author on a manuscript.

6. there is value in disclosing the names of all co-reviewers to journal editor, in order to:
    a. act with academic integrity and provide due credit to those who contribute ideas and/or text to the peer review report;
    b. improve transparency for journal editors, who may benefit from including ECRs to broaden their reviewer pools;
    c. allow ECRs to be recognized for this scholarly labor not only to journal editors, but also more broadly, through sites such as Publons, should they wish it for career development and immigration status purposes.

BOX B: FOR JOURNAL EDITORIAL BOARDS AND COPE

1. Create unequivocal policy statements on i) sharing manuscripts with ECRs, ii) ECRs as co-reviewers, and iii) ghostwriting of peer review reports (see example statements[3]).

2. To best reflect current practices and opinions, adopt policies that:
    a. allow invited reviewers to share manuscripts with ECRs for co-reviewing and/or training purposes,
    b. remove barriers to naming co-reviewers on peer review reports, such as prior permissions requirements that are ineffective deterrents of ghostwriting,
    c. require invited reviewers to disclose the names of all individuals who have contributed ideas and/or text to the report at the time of submission of the peer review report, regardless of whether prior permissions have been requested or granted.

3. Put policy statements not only in Reviewer Guidelines, which veteran invited reviewers may not read regularly, but also throughout the review process so that they cannot be missed, e.g. when the invited reviewer is asked to accept invitation to review and when the invited reviewer uploads the peer review report.

4. Couple policy statements on report submission forms with required checkboxes for the invited reviewer to complete. For example:
    a. "Did anyone else participate in the review process of this manuscript, for example: your graduate students or postdocs? [Yes / No]. If Yes, please provide all name(s) to the editor to avoid plagiarism of ideas and/or text in the peer review report. [textbox]"

Note: Journal editors may want to look into the TRANsparency in Scholarly Publishing for Open Scholarship Evolution project (TRANSPOSE, transpose-publishing.github.io/), gathering journal policies including those for co-review, for further information on developing policies. The project aims to provide information for journals, and develop suggested template policies.

[3]Example journal policy statements:

a. "We recognize that invited reviewers may wish to involve their trainees who are early career researchers ("ECRs" such as graduate students, postdocs) in the peer review process. It is the policy of this journal that manuscripts may be shared with trainees of the invited reviewer for co-reviewing and/or training purposes and that these ECRs may contribute text and/or ideas to the peer review report. If this occurs, it is the responsibility of the invited reviewer to disclose these names to the editorial staff at the time of submission in order to recognize the contributions of all parties that were involved in the peer review process. It is the policy of this journal that submission of a peer review report without disclosing the names of all individuals who have contributed ideas and/or text to the report is breach of academic integrity. All parties, including the invited reviewer and their designated trainees, must uphold the confidentiality of the manuscript and its authors."
b. "We recognize that invited reviewers may wish to involve their trainees who are early career researchers ("ECRs" such as graduate students, postdocs) in the peer review process. It is the policy of this journal that manuscripts may be shared with trainees of the invited reviewer for training purposes but that these ECRs may not contribute text and/or ideas to the peer review report. No one except the invited reviewer may contribute text and/or ideas to the peer review report. The invited reviewer will be asked to confirm that they are the sole author of the peer review report at the time of submission. It is the policy of this journal that submission of a peer review report without disclosing the names of all individuals who have contributed ideas and/or text to the report is breach of academic integrity. All parties, including the invited reviewer and their designated trainees, must uphold the confidentiality of the manuscript and its authors."
c. "We recognize that invited reviewers may wish to involve their trainees who are early career researchers ("ECRs" such as graduate students, postdocs) in the peer review process. It is the policy of this journal that manuscripts may not be shared with anyone, including trainees of the invited reviewer even for training purposes. No one except the invited reviewer may contribute text and/or ideas to the peer review report. The invited reviewer will be asked to confirm that they are the sole author of the peer review report at the time of submission. It is the policy of this journal that submission of a peer review report without disclosing the names of all individuals who have contributed ideas and/or text to the report is breach of academic integrity. The invited reviewer must uphold the confidentiality of the manuscript and its authors."

BOX C: FOR GRADUATE PROGRAMS, SCIENTIFIC SOCIETIES, ETC.

1. Create and implement evidence-based training programs for mentored peer review.
2. Advocate for cultural and practical changes to benefit your constituents.

Note: It is in the interests of graduate programs and scientific societies to ensure that their students and membership are adequately and effectively trained in peer review, not least to cultivate trust with wider society that scientists are capable of objectively critiquing peer-reviewed publications in order to establish knowledge.

BOX D: FOR INVITED REVIEWERS AND CO-REVIEWERS

Both	Inform yourself of each journal's policies on sharing manuscripts with ECRs, ECR contributions to peer review reports, and ghostwriting. Participate in peer review training, especially evidence-based trainings that involve iterative feedback between mentors and mentees.
Invited reviewers	Inform your trainees of journal policies prior to involving them in peer review. Even if journal policies are not clearly stated, initiate a conversation with your trainees about the ethics of co-reviewing, expectations for an ethical division of labor in co-reviewing, and your intentions as to whether you will share ECRs' names to the editor. Provide constructive feedback to your trainees on the ideas and/or text that they have contributed to the peer review report, as a training exercise. Even if no opportunity is provided to you (e.g. on peer review report submission form), add names of everyone who contributed ideas and/or text to the peer review report on the report itself for the editor to see at the time of submission.
Co-reviewers	Inform yourself of journal policies prior to agreeing to join an invited reviewer in peer review. If comfortable doing so, initiate a conversation with your PI about an ethical division of labor in co-reviewing and your expectations to be/not be named to the journal editor. If comfortable doing so, request constructive feedback from your PI on the ideas and/or text that you have contributed to the peer review report, as a training exercise. If comfortable doing so, educate others about any value you perceive in being named to the journal editor.

Note: Responsibility for ethical and effective peer-review training should be a central part of any mentee-mentor relationship, and appropriate training, including feedback from mentors, should be developed in accordance with career stage.

Differing ability of key stakeholders to affect change

It is important to recognize that the key stakeholders in this process - journals, invited reviewers/PIs, and co-reviewers/ECRs - have differing abilities to affect change based on existing power dynamics in the research and publishing enterprise. While ECRs have an important role to play in asking their mentors for named credit on peer review reports, their vulnerable and relatively disenfranchised role in this hypercompetitive research environment may make them least able and/or willing to advocate for change to the status quo, especially when this can be further affected by concerns arising due to factors such as immigration status. At the next level, invited reviewers in isolated conversations with journal editors may not feel able and/or willing to critique journal policy, especially for journals in which they hope to publish themselves. Journals, therefore, may have the greatest ability to lead on this issue by creating policies that recognize the role that ECRs play in the peer review process, and the value of that role to ECRs themselves, invited reviewers, editors, and the research community at large.

Benefits of implementing recommendations

All key stakeholders and especially journals stand to benefit significantly from making these common sense changes that recognize ECRs as frequent and valuable contributors to the peer review system. Box E summarizes what we see as the advantages of discouraging ghostwriting and encouraging co-reviewing as training in peer review. We are optimistic that, together, we can change the cultural expectations and policies regarding ECR participation in peer review to reduce harm to vulnerable members of the community and to support the implementation of transparent and ethical practices that align with community experiences and values.

BOX E: BENEFITS OF ENCOURAGING CO-REVIEW AS TRAINING AND DISCOURAGING GHOSTWRITING

For journals	Increase in pool of potential reviewers*
	Increase in the likelihood that PI/invited reviewer will accept invitation to review when they can do so with co-reviewer help*
	Naming co-reviewers improves transparency, allowing editors to know exactly who contributed to the review
	Co-review as training results in higher quality peer review reports
For ECRs, co-reviewers	Named recognition of scholarly labor, with the added potential benefits of: ● Being known to the scientific editors ● Invitations to review independently ● Recognition of peer review experience for career advancement or immigration status
	Become a better peer reviewer through co-review as training
For PIs, invited reviewers	Become a better peer reviewer (and mentor) through training co-reviewer
	Involving ECR as co-reviewer decreases workload for overburdened PIs
For the peer review system, and so scientific enterprise, on the whole	Ethically better system that recognizes all participants fairly
	Objectively better system with higher quality, less biased peer review
	Improved clarity of expectations for all participants
	Improved integrity of system improves public trust in science

* indicates ideas supported by a Reviewer Experience Lead at Elsevier (Mehmani 2019).

METHODS

Systematic Literature Review

Search procedures

The following procedures were used to perform a systematic review of the peer-reviewed literature for any research on the topic of ECR participation in manuscript peer review. These procedures were developed under the guidance of a professional librarian (author SO) and were based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria ((Moher et al. 2009); see Appendix Figure 1). The databases that were searched cover peer-reviewed literature across the life sciences, public policy and social sciences and were comprised of: PubMed, PsychInfo, Web of Science, and PAIS International. These databases were then searched using the following keyword search strategy: ("early career researcher" OR "graduate student" OR "postdoc" OR "fellow" OR "contingent faculty" OR "adjunct" OR "lecturer" OR "instructor" OR "technician" OR "junior scientist" OR "trainee" OR "lab member" OR "research scientist" OR "postdoctoral fellow" OR "research fellow" OR "teaching fellow" OR "junior researcher" OR "mentee") AND ("peer review" OR "refereeing" OR "invited reviewer" OR "referee" OR "reviewer" OR "co-reviewer" OR "first time reviewers" OR "reviewer training" OR "review partners" OR "contributing author" OR "co-reviewing" OR "reviewing" OR "journal reviewer policy" OR "reviewer guidelines" OR "instructions for reviewers"). These search terms were designed to be broadly inclusive so as to capture any research article with possible relevance to the topic of ECR involvement in manuscript peer review. The resulting collection of 2103 records were imported into the RefWorks 3 bibliographic management database, and

duplicate articles were identified and removed using the “Legacy close match” de-duplication filter, resulting in a de-duplicated set of 1952 articles.

Relevance screening

Collected articles underwent two rounds of relevance screening. In the initial round, article titles and abstracts were screened independently by two study authors (JG and GM). Both authors used the same inclusion criteria to sort search results into “relevant,” “maybe relevant,” and “not relevant” categories. The criteria for article inclusion were: written in English, published in a peer-reviewed journal, mention of ECRs, and mention of peer reviews of manuscripts. Any article that did not meet the inclusion criteria above was excluded as well as database hits for conference proceedings and dissertations.

118 unique articles remained in the “relevant” and/or “maybe relevant” categories at this stage of screening (see Appendix: Results of relevance screening for literature review). Articles categorized as “relevant” by both initial screeners were selected for full text review (n = 3). Articles categorized as “maybe relevant” by both initial screeners and articles that were differentially categorized as “relevant” vs. “maybe relevant” or “not relevant” by the initial screeners (n = 51) underwent a second round of evaluation by a third, independent screener (author RL) to either confirm categorization as “relevant” or recategorize as “not relevant” to the topic of ECR participation in the peer review of manuscripts. A resulting list of 36 “relevant” articles underwent a full text reading with specific attention being paid to: research question, motivation for article, method of study including details concerning study participants, relevant results and discussions, discussion of peer review and ECRs, and possible motivations for author bias. Of the articles that were found to be “not relevant” to the topic of ECR participation

in the peer review of manuscripts for publication in a journal, most discussed other forms of peer review outside the scope of publishing manuscripts (e.g. students engaging in peer review of each other's written work in a classroom setting as a pedagogical exercise).

Survey design

We designed a survey to evaluate the peer review experiences of researchers with a specific focus on ghostwriting of peer review reports. The survey was verified by the Mount Holyoke Institutional Review Board as Exempt from human subjects research according to 45CFR46.101(b)(2): Anonymous Surveys - No Risk on 08/21/2018. All survey respondents provided their informed consent prior to participating in the survey. The survey comprised 16 questions presented to participants in the following fixed order:

- 6 **demographic** questions that collected data on their professional status (current institution, field of research, and career stage) and personal information (gender identity, race/ethnicity, and citizenship status in the United States);
- 7 questions that collected data about their **experience** participating in the peer review of manuscripts for publication in a journal:
    - 2 questions about their experience with independent reviewing vs. co-reviewing
    - 4 questions about receiving credit for reviewing activities, and
    - 1 question about whether and how respondents' received training in peer review;
- 3 questions that collected data about their **opinions** about co-reviewing and ghostwriting as practices, regardless of whether they had personal experience with these practices:
    - 1 question about their degree of agreement on a 5-point Likert scale (*Strongly Disagree; Slightly Disagree; No Opinion; Slightly Agree; Strongly Agree*) with 11 statements about the ethics and value of co-reviewing and ghostwriting,
    - 1 question asking their opinion about why ghostwriting as a practice may occur, and

- 1 exploratory future direction question asking if their opinions would change if the names of peer-reviewers were made publically available ("open peer review").

Throughout the survey, there were many opportunities to provide write-in responses in addition to the multiple choice answers. The full text of the survey can be found in the Appendix: Text of The Role of Early Career Researchers in Peer Review - Survey.

Survey distribution, limitations, and future directions

The survey was distributed online through channels available to the nonprofit organization Future of Research including via blog posts (McDowell and Lijek 2018), email lists, social media, and word-of-mouth through colleagues. The main survey data collection effort was from August 23 to September 23, 2018. The survey had gathered 498 responses at the time of data analysis.

We recognize that conclusions drawn from any survey data are limited by the size and sample of the population that is captured by the survey. We sought to address this limitation first by collecting as large and geographically and institutionally diverse of a population of ECRs as possible within the month-long timeframe we set for data collection. Secondly, we wished to preemptively address the concern that our survey distribution efforts were inherently biased towards those with strong opinions on the subject and/or those who self-select to receive communication from Future of Research (e.g. listservs, Twitter followers). We therefore attempted to create a "negative control" comparison group of participants who received our survey from channels independent of Future of Research. We created a separate survey form asking identical questions and personally asked 25+ PIs known to the authors, as well as organizational collectives of PIs, to distribute this survey link to their own networks (e.g. lab members, departments). Both surveys were live during the same month-long time period;

however, the PI-distributed survey gathered only 12 responses and so was not sufficient to be used in the analyses presented here. Since the goal of the second, PI-distributed survey was to be independently distributed outside of our efforts, we are not able to determine whether it garnered so few responses because of a lack of genuine distribution or because the populations it reached were not motivated to participate in the survey. Therefore any conclusions drawn from this study reflect the 498 experiences and perspectives of those individuals so moved to participate in the survey distributed by Future of Research and our results should be considered in this context. One possible future direction for this study is to reopen the survey in conjunction with publication of this manuscript in an effort to broaden and diversify the sampled population, to compare subsequent rounds of responses to our initial 498 responses, and to improve clarity on survey questions (see Appendix: Future directions for survey questions).

Survey data analysis

Survey data were analyzed using Microsoft Excel, Version 16 and IBM SPSS Statistics for Macintosh, Version 25 (SPSS® Inc., Chicago, IL, USA). Whenever statistical analyses were used, the exact tests and p values are reported in the appropriate figure legend and/or results text. A p value of less than 0.05 was considered significant. Where a number of demographics are combined in the reporting throughout this study, any analysis group with less than 20 respondents is reported as “<20” instead of the raw n value in an effort to protect the identity of participants.

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Authors GM and RSL designed the study, wrote and carried out the survey, supervised survey data analysis, supervised the literature review, and wrote the manuscript. JDK performed the data analysis and contributed to the survey design and manuscript. JG and SO performed the systematic literature review and contributed to the manuscript.

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APPENDICES

Results of relevance screening for literature review

List of all search records categorized by initial screeners as "relevant" and/or "maybe relevant" to the topic of ECR involvement in the peer review of manuscripts based on title and abstract (n = 118). Y = yes, relevant; M = maybe relevant; N = not relevant; - = not evaluated.

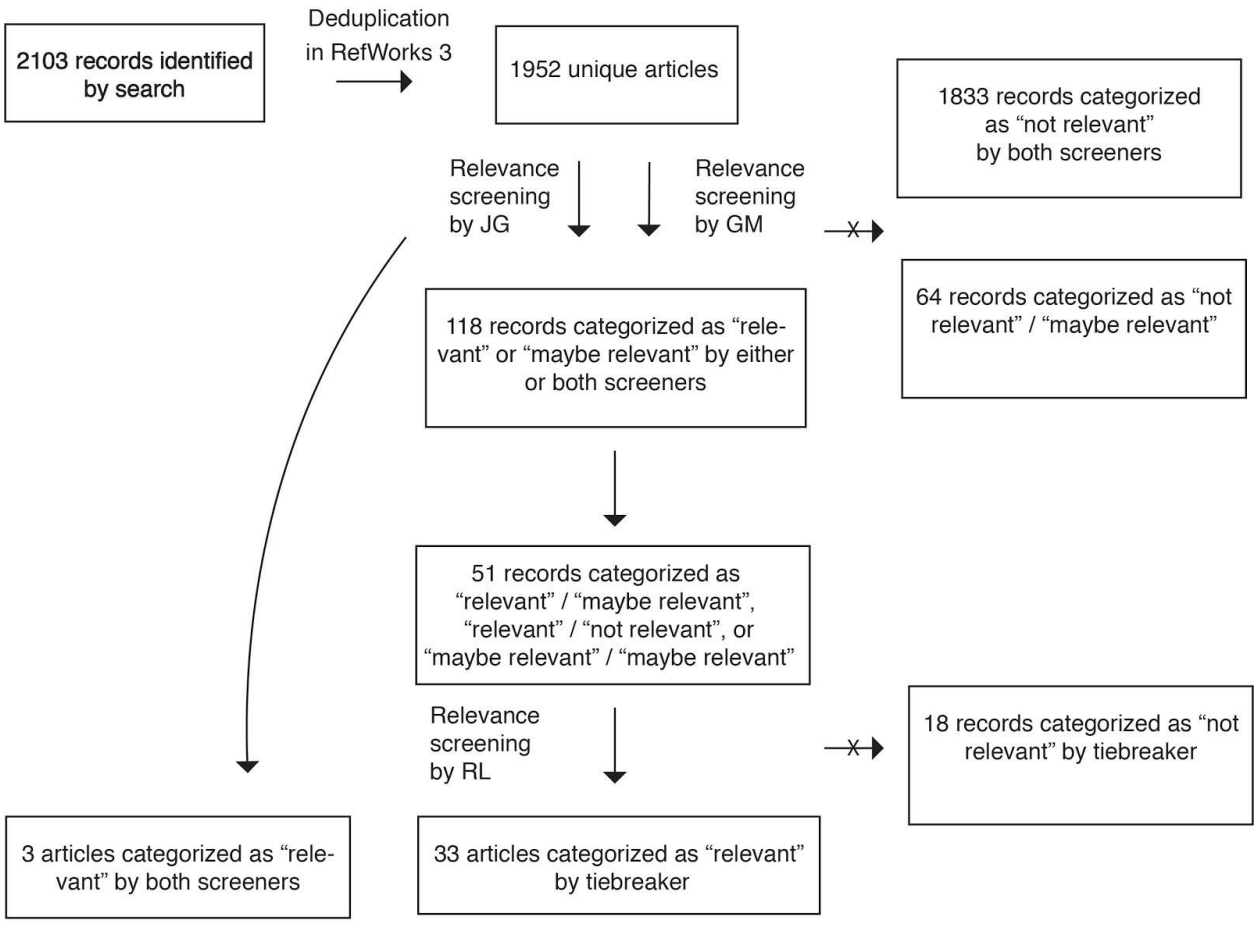
Article title (alphabetical order)	**Initial Screeners**		**Tie-breaker**	**Full Text Reading**
	#1	**#2**	**#3**	
A Fine Balance: How Authors Strategize Around Journal Submission	N	M	-	
A guide to critiquing a research paper. Methodological appraisal of a paper on nurses in abortion care	M	N	-	
A Mentoring Opportunity: A Joint Effort in Writing Letters of Recommendation	N	Y	N	
A model for scholarship in nursing: The case of a private liberal arts college	N	M	-	
A Pragmatic Approach to Getting Published: 35 Tips for Early Career Researchers	M	Y	Y	Y
A Survey of Methods for Improving Review Quality	N	M	-	
A web-based synchronous collaborative review tool: A case study of an on-line graduate course	N	M	-	
Advise to research trainees in biomedical sciences - A very personal tribute to the late Dr. Susumu Ohno	N	Y	N	
An ounce of prevention: An associate editor's view	N	M	-	
Assessing postgraduate student perceptions and measures of learning in a peer review feedback process	M	M	N	
Assessment for Learning Research and Writing Skills through Scaffolded Online Peer Review	N	M	-	
Becoming a peer reviewer: engaging in sharing and gaining knowledge	M	Y	Y	Y
Being a researcher is not only a matter of publishing: Learning to review scientific articles	Y	Y	Y	Y
Biosecurity and the review and publication of dual-use research of concern	N	M	-	
Building Scholarly Writers: Student Perspectives on Peer Review in a Doctoral Writing Seminar	M	M	N	
Calibrated Peer Review: Enabling Technology for a Large - Scale Writing Intensive Neuroscience Course.	M	M	N	
Calibrated Peer Review: Implementation of a computer-based writing-to-learn tool in a large lecture-based introductory biology class	M	M	N	
Calibrated peer review: The application of statistical concepts to a biological research question	N	M	-	

Can Online Peer Review Assignments Replace Essays in Third Year University Courses? And if so, What are the Challenges?	N	M	-	
CAREERS eLife and early career researchers	N	Y	Y	Y
Celebrating Peer Review Week	M	M	Y	Y
Chinese Early-Career Researchers' Scholarly Communication Attitudes and Behaviours: Changes Observed in Year Two of a Longitudinal Study	M	Y	Y	Y
Conducting mental health research: Key steps, practicalities, and issues for the early career researcher	M	N	-	
Developing Knowledge Generation, Communication and Management In Teacher Education: A Successful Attempt of Teaching Novice Computer Users	N	M	-	
Developing laboratory skills by incorporating peer-review and digital badges	N	M	-	
Do peer review models affect clinicians' trust in journals? A survey of junior doctors	M	Y	Y	Y
Does mentoring new peer reviewers improve review quality? A randomized trial	Y	Y	Y	Y
Does peer review predict the performance of research projects in health sciences?	N	M	-	
Doing peer review and receiving feedback: impact on scientific literacy and writing skills	M	M	Y	Y
Doing Peer Review: Reflections From an International Group of Postdoctoral Fellows	M	Y	Y	Y
Editorial training models for early-career psychiatrists	N	Y	Y	Y
Emergent areas to visualize by the journal strategy holders	M	N	-	
Enhancement of Resident Competencies Via Participation in the Peer Review/Quality Improvement Processes and Morbidity and Mortality Presentations	M	N	-	
Evaluation of multi- and interdisciplinary research - the no-peer problem	N	M	-	
Examining the Effects of Trained Peer Feedback on EFL Students' Writing	N	M	-	
Expanding Group Peer Review: A Proposal for Medical Education Scholarship	M	Y	Y	Y
Facilitating improvements in laboratory report writing skills with less grading: a laboratory report peer-review process	N	M	-	
Feedback on Peer Feedback in EFL Composing: Four Stories	N	Y	N	
Graduate student-run course framework for comprehensive professional development	N	M	-	
Guidelines for assessment of publications for contribution to scholarship: a view point.	N	Y	Y	Y
Heroes of peer review: Robert Lowe	N	M	-	
How early-career researchers are shaping eLife	N	Y	Y	Y

How to achieve accurate peer assessment for high value written assignments in a senior undergraduate course	N	M	-	
Improving peer reviewing in scientific conferences	M	M	Y	Y
Increasing the Quality of Peer Feedback in a Professional Writing Course	N	M	-	
Instructors' uses, experiences, thoughts and suggestions regarding Calibrated Peer Review	M	M	N	
Integrating critical analysis, peer review, and independent research in the laboratory phase of a microbiology course	M	M	N	
Investigating peer review as a systemic pedagogy for developing the design knowledge, skills, and dispositions of novice instructional design students	M	N	-	
Judging plagiarism: a problem of morality and convention	N	Y	Y	Y
Korean University Students,Äô Attitudes towards Peer Review in EFL Writing	N	M	-	
Learning by reviewing	N	Y	Y	Y
Literature search in medical publications	N	M	-	
Manuscript peer review: A helpful checklist for students and novice referees.	M	M	Y	Y
Mentor/mentee relationship with the focus on meeting promotion/tenure guidelines	N	M	-	
Misrepresentation and responsibility in medical research	M	M	N	
Mixed Method Study Examines Undergraduate Student Researchers' Knowledge and Perceptions About Scholarly Communication Practices	M	Y	Y	Y
Moving from trainee to junior: faculty: a brief guide	M	M	Y	Y
Nature neuroscience	N	M	-	
New Reviewer Mentoring Program	N	Y	Y	Y
Observations: The Introduction of "Junior Editor" Posts Within Journals	N	M	-	
Open Access Open Grad Students	N	Y	Y	Y
Open peer review: a randomised controlled trial	M	M	Y	Y
Peer Assessments Using the Moodle Workshop Tool	N	M	-	
Peer review as an educational strategy to improve academic work: An interdisciplinary collaboration between communication disorders and nursing	N	M	-	
Peer Review in Radiology: A Resident and Fellow Perspective	M	N	-	
Peer review process: Guidelines for clinical and forensic psychological reviews	N	M	-	
Peer review: why we need nurse leaders to serve as reviewers for nursing publications	M	M	-	
Peer-Review - using a Paired-Comparison Technique	N	M	-	
Perception of Academic Writing: A Case Study of an ESL Writer during Peer Review	N	M	-	

Perspectives from early career researchers on the publication process in ecology - a response to Statzner & Resh (2010)	M	Y	Y	Y
Pit-bull reviewing, the pursuit of perfection and the victims of success	N	M	-	
Plagiarism: an egregious form of misconduct	M	Y	Y	Y
Plagiarism. A fools' errand	M	Y	Y	Y
Potential of information technology in dental education	N	M	-	
Power of peer review: An online collaborative learning assignment in social psychology	N	M	-	
Preparing the senior or graduating student for graduate research	M	Y	Y	Y
PRO myths vs. facts	N	M	-	
Professional Skills Courses Increase Trainee Skills in Writing, Reviewing, Networking, and Poster Presentations	M	M	N	
Professionalism and Communication Education in Pediatric Critical Care Medicine: The Learner Perspective	M	N	-	
Promoting operational research through fellowships: a case study from the South-East Asia Union Office	M	N	-	
Publish or Perish: A Mandate With Negative Collateral Consequences	M	N	-	
Pursuing the journal mission	M	Y	Y	Y
Religion, Rebel Scientists, and Peer-Review - 3 Hot Topics	N	M	-	
Replacing the Traditional Graduate Chemistry Literature Seminar with a Chemical Research Literacy Course	M	N	-	
Republished paper: Assuring validity of multisource feedback in a national programme	M	N	-	
Research as a subject--for research	N	M	-	
Research Ethics II: Mentoring, Collaboration, Peer Review, and Data Management and Ownership	N	Y	Y	Y
Responsible Conduct of Research in Communication Sciences and Disorders: Faculty and Student Perceptions	M	M	Y	Y
Review, revise, and resubmit: The effects of self-critique, peer review, and instructor feedback on student writing	N	M	-	
Reviewing a Manuscript: Disparity Amongst Peer Reviewers' Priorities from Basic Health Sciences and Clinicians	M	Y	Y	Y
Student peer review decisions on submitted manuscripts are as stringent as faculty peer reviewers	Y	Y	Y	Y
Supersizing e-learning: What a CoI survey reveals about teaching presence in a large online class	N	M	-	
Survey of publication outlets in early childhood education: Descriptive data, review processes, and advice to authors	M	N	-	
The "Peer" in "Peer Review"	N	M	-	
The 5th Annual AABT Postdoctoral Panel and Overview: November 2004	N	M	-	

The Acta Psychiatrica Scandinavica Trainee Advisory Board: Education, mentoring, and experience with the editorial process	M	Y	Y	Y
The association between four citation metrics and peer rankings of research influence of Australian researchers in six fields of public health	M	M	N	
The ethics of peer review: What to know before saying "yes"	M	Y	Y	Y
The Fox and the Crow' or 'the Foolishness of Vanity Publishing in Fake Academic Journals': A Story from the Arabian Gulf	N	M	-	
The impact of E-learning in medical education	N	M	-	
The invited review ? or, my field, from my standpoint, written by me using only my data and my ideas, and citing only my publications	M	N	-	
The lecturer should know what they are talking about: Student union officers perceptions of teaching-related CPD and implications for their practice	N	M	-	
The More You Know: The Impact of Publication and Peer-Review Experience on Psychology Graduate Students	M	Y	Y	Y
The peer review gap: A longitudinal case study of gendered publishing and occupational patterns in a female-rich discipline, Western North America (1974-2016)	M	Y	N	
THE PIPELINE Scientific Teaching in Practice	N	M	-	
The planning and implementation of a faculty peer review teaching project	N	M	-	
The Use of Mock NSF-type Grant Proposals and Blind Peer Review as the Capstone Assignment in Upper-Level Neurobiology and Cell Biology Courses.	M	M	N	
The value of peer feedback opportunities for students in writing intensive classes	N	Y	N	
Three tough acts to follow	N	M	-	
Two Modes of Peer Review among Adult Writers: Which Is Better?	N	M	-	
Use of Peer-Review System for Enhancing Learning of Programming	N	M	-	
Using an Undergraduate Immunology Laboratory Course to Integrate Scholarship and Teaching	N	M	-	
Using Calibrated Peer Review to Teach Basic Research Skills	M	M	N	
Validity and reliability of scaffolded peer assessment of writing from instructor and student perspectives	N	M	-	
Variability in students' evaluating processes in peer assessment with calibrated peer review	M	Y	N	
Where does all the research go? Reflections on supporting trainee-applied psychologists to publish their research	M	Y	N	
Why not assess another trainer and his/her trainee?	N	M	-	
Writing to learn: an evaluation of the calibrated peer review program in two neuroscience courses	M	Y	Y	Y



Appendix Figure 1: Search strategy for literature review with number of records remaining at each stage.

Literature on ECR involvement in peer review as a training exercise

Many of the articles uncovered by our systematic literature review on the topic of ECR involvement in peer review of manuscripts that *did not* address our desired topic of ghostwriting instead discussed ECR involvement in peer review of manuscripts as a training exercise for the ECR. Here, we summarize their findings.

Peer review training programs with positive outcomes

Trends from the literature indicate several components of a successful peer review training program and where such programs are currently in process. Authors studying the peer review training process for new reviewers tend to conclude that students of peer review learn best by participating themselves in the review process while receiving feedback from more senior reviewers. Successful training programs, in which the reviewers expressed that they had benefited from the training or were evaluated and determined to have benefited from the training, tended to include participation in several rounds of review followed by feedback and revising. Additionally, successful programs often expanded feedback by directing the expert reviewers to report on the same manuscripts as the trainees. This method provided trainees with specific written feedback as well as a pertinent example report to reference. Authors of successful program studies and authors with general policy recommendations for peer review training strategies conclude that a hands-on, iterative process of peer review training with regular and specific feedback are components which positively benefit the peer review trainee (Castelló et al. 2017; Doran et al. 2014).

Peer review training programs without positive outcomes

However, one reviewer training study in the pool generated negative results. In their paper, Houry, Green and Callaham found that after a period of training involving mentorship from an expert reviewer to a new reviewer, no differences in mean reviewer quality scores between the mentored and unmentored groups was found. The study goes on to conclude that this similarity in group quality scores is dependent on the mentoring relationship: the expert reviewer mentors were not given any training on how to offer feedback to the trainees. This aspect of the program was deliberately constructed in an attempt to model a training program in which there would be minimal stress on the expert mentors. However, it appears that this ultimately led to an inconsequential training program. Accounting for this information, the authors conclude that a mentorship program should include training and guidelines for mentor-mentee communications which allow for regular feedback from expert to trainee (Houry et al. 2012).

Institutions where peer review training takes place

Sources mentioned two primary institutions where training in peer review may take place. Training institutions were identified, with undergraduate education as the first opportunity for training, followed by graduate programs. Journals were the other institutions identified.

The majority of training programs represented in the sources take place within a journal setting. Journal programs tend to include ECRs, such as undergraduate or graduate students, joining the editorial board for a set time period or acting as a reviewer (Castelló et al. 2017; Doran et al. 2014; Houry et al. 2012; Navalta and Lyons 2010; Patterson and Schekman 2018; Picciotto 2018; Harrison 2009).

Training may also take place within undergraduate or graduate institutions. One peer review training study in the found literature took place in an undergraduate setting. Despite the lack of associated literature, Riehle and Hensley determined that undergraduate students are interested in learning about the peer review process (Riehle 2017). In a training study, the Calibrated Peer Review™ system was employed in two undergraduate classes to facilitate students to peer review the work of their classmates while minimizing the extra workload such an exercise might otherwise entail for the professor (Prichard 2005). The participating students were in two separate courses, an introductory neuroscience course and a more advanced neuroscience course. Students in the advanced class did not perform better on peer review exercises than the introductory students, suggesting that until that point, advanced students had not been exposed productively to peer review practice. Authors deemed this to be a successful method for exposing undergraduate students to the peer review process while requiring a realistic time commitment from the course instructor.

While no papers were found detailing the effectiveness of peer review training within graduate institutions, several sources did indicate graduate student perceptions about their program peer review training. In a study including psychology masters and PhD students, a large proportion of participants indicated that their education had lacked in providing information on the peer review and revision process as well as information about how to practice review (Doran et al. 2014). These students indicate that this was a negative aspect of their programs, saying more opportunities for peer review practice should be made available. Authors of this article do indicate that this information may not be generalizable to graduate students as a group because the participating students were found when they pursued a journal review program, something students with adequate peer review education may not be likely to do.

Self-facilitated training

Merry et al. provides a list of recommendations for ECRs to facilitate their own training of peer review (Merry et al. 2017). Authors advise working with the mentoring faculty as well as contacting journals directly to seek out peer review opportunities. If mentors are able to give consistent feedback regarding the trainees peer review, it seems that this could be a positive environment in which to learn the skill.

Roadblocks to positive outcomes in training programs

Papers discussing journal training programs cite feasibility as the largest roadblock to success (Castelló et al. 2017; Houry et al. 2012). As discussed, it is recommended that peer review training programs for ECRs feature a system which provides regular, specific feedback from expert reviewers. Such programs require high levels of labor, involving organization and time commitment from program leaders and expert reviewers. This is a significant investment for a business which may be in conflict with the desire to maximize journal profit. One possible solution presented involves student-run journals hiring increased numbers of student reviewers and editors so experience may be gained in the field (Doran et al. 2014; Patterson and Schekman 2018). However, this solution does not address the recommendation for expert reviewers to provide feedback.

Text of The Role of Early Career Researchers in Peer Review - Survey

Background

Peer review of academic manuscripts is essential to maintain integrity in science and is integral to the journal publication process. Early Career Researchers (ECRs) often contribute to this peer review process. While ECRs may review manuscripts jointly with or under the direction of a senior academic, such as a Principal Investigator (PI), Group Leader, or Professor, a large number of ECRs claimed in a recent survey to have acted as peer review “ghostwriters”; that is, the peer review report (i.e. the final review submitted to the journal editor) had only the senior academic’s name attributed to the report. For the rest of this survey, we refer to the senior academic as the “PI” and any junior academics under their supervision as “ECRs.”

This survey is designed to collect more data about the phenomenon of ghostwriting by ECRs. The goal of this survey is to assess the experiences and opinions of the community, and to recommend best practices for recognizing co-reviewing activities.

This survey contains 16 questions and is estimated to take 15 minutes.

Statements of Disclosure, Ethics and Informed Consent

This survey was created by researchers affiliated with the Future of Research, a non-profit organization in the United States that is promoting an effort to increase transparency about co-reviewing activities by ECRs. You can find out more about our work on ECRs in peer review at our website here: http://futureofresearch.org/ecrpeerreview/

The researchers respect the confidentiality and anonymity of all respondents. No identifiable private information will be collected by this survey. Your participation is voluntary and you can choose to stop at any time. Please complete this survey only once. By choosing to submit answers to this survey, you thereby provide your informed consent to voluntarily share your experiences and opinions with the researchers, who intend to publish a summary of the results of the survey but not the raw data with participants' individual demographic information.

You may contact Gary McDowell, Executive Director of the Future of Research, at futureofresearch@gmail.com at any time during the study if you have questions or concerns about your participation.

This survey has been verified by the Mount Holyoke Institutional Review Board as Exempt according to 45CFR46.101(b)(2): Anonymous Surveys - No Risk on 08/21/2018.

I provide my informed consent to participate in this survey.

- Yes

Professional Information

Q1.

1. What is your current institution? Fill in blank box (e.g. Harvard School of Medicine).

Q2.

What is your current field of research? Fill in blank box (e.g. biomedicine; physics; philosophy; economics;
etc.).

Q3.

What is your current career stage?

- Undergraduate Student
- Graduate Student - Masters
- Graduate Student - PhD
- Postdoctoral Researcher
- Staff Scientist
- Adjunct Professor
- Principal Investigator (PI)
- Other (please describe)

Demographic Information

Please feel free to skip any of the following questions if you feel they would be sufficient to uniquely identify you.

Q4.

What is your gender identity?

- Female
- Male
- Prefer not to say
- Other (please describe)

Q5.

What is your race/ethnicity? Select all that apply.

- Asian
- Black or African American
- Hispanic or Latinx
- Native American or Alaska Native
- Native Hawaiian or Pacific Islander
- White
- Prefer not to say
- Other (please describe)

Q6.

If you are based in the U.S., are you a U.S. Citizen/Permanent Resident?

- Yes
- No
- Not based in the U.S

Your peer review experience

Q7.

How many times in your career have you reviewed an article for publication independently, i.e. carried out the full review and been identified to the editorial staff as the sole reviewer?

- 0
- 1-5
- 6-20
- 21+

Q8.

How many times in your career have you contributed ideas and/or text to peer review reports where you are not the invited reviewer (e.g. the invited reviewer is the PI for whom you work)?

- 0 - skip to question 13
- 1-5 - go to question 9
- 6-20 - go to question 9
- 21+ - go to question 9

Q9.

When you were not the invited reviewer, what was the extent of your involvement in the peer review process? Please select all that apply to your entire peer review experience (e.g. across multiple manuscripts).

- I read the manuscript, shared short comments with my PI, and was no longer involved
- I read the manuscript, wrote a full report for my PI, and was no longer involved
- I read the manuscript, wrote the report, my PI edited the report and we submitted the report together with both of our names provided to the editorial staff
- I read the manuscript, wrote the report, my PI edited the report and my PI submitted report with only their name provided to the editorial staff
- I read the manuscript, wrote the report, and submitted it independently without my PI's name provided to the editorial staff

Q10.

To your knowledge, did your PI ever submit your reviews without editing your work?

- Yes
- No
- Don't know

Q11.

To your knowledge, did your PI ever withhold your name from the editorial staff when you served as the reviewer or coreviewer?

- Yes - proceed to question 12
- No - skip to question 13
- Don't know - proceed to question 12

Q12.
Consider cases where you contributed to a peer review report and you know your name was NOT provided to the editorial staff. When discussing this with your PI, what reason did they give to exclude you as a co-reviewer?

- Did not discuss with my PI
- Journal does not allow ECRs to review
- Journal requires prior approval to share manuscript, which was not obtained
- Intellectual contribution not deemed sufficient
- Co-authorship is for papers, not for peer review reports
- Other (please describe)

Q13.
How did you gain training in how to peer review a manuscript? Select all that apply.

- Online resource
- Your PI
- A postdoc in the lab
- A graduate student in the lab
- Journal Club
- Attending an in-person course/workshop
- From receiving reviews on my own papers
- I have had no training
- Other (please describe)

Your opinions on peer review
The following questions are about your opinions, not necessarily your experiences. Please answer the following questions regardless of whether or not you have participated in peer review.

A ghostwriter is defined as a person that writes text or other scholarly works without receiving authorship.

These questions are about submitting names of co-authors to the editorial office, not making the identities of reviewers publicly available.

Q14.
Please indicate how strongly you agree with the following statements. You may also submit comments to expand and/or clarify your opinions in the textbox below.
Options: Strongly Disagree; Slightly Disagree; No Opinion; Slightly Agree; Strongly Agree

- Involving members of a research group in peer review is a beneficial training exercise.
- It is ethical for the invited reviewer (e.g. PI) to involve others (e.g. their trainees) in reviewing manuscripts.
- It is ethical for the invited reviewer (e.g. PI) to submit a peer review report to an editor without providing the names of all individuals who have contributed ideas and/or text to the report.
- Ghostwriting a peer-review report for your PI is an ethically sound scientific practice.
- When a journal invites a PI to review, that is equivalent to the journal inviting anyone in that PI's research group with relevant expertise to contribute to the review.
- It would be valuable to have my name added to a peer review report (e.g. to be recognized as a co-reviewer by the editor; or to use a service such as Publons to be assigned credit).
- Anyone that contributes ideas and/or text to the review report should be included as a co-author on the review.
- The only person who should be named on a peer review report is the invited reviewer, regardless of who carried out the review.
- Adding names of other contributors to a peer review report diminishes the credibility of the report.
- The current system used to name and order co-authors on manuscripts in my field should also be used to the name and order co-reviewers on peer review reports.
- The current system used to identify author contributions on manuscripts in my field (e.g. AB did the experiments, AB and CD analyzed the data and wrote the paper), or the CRediT taxonomy (https://casrai.org/credit/), should also be used to identify author contributions on peer review reports (e.g. AB reviewed the experiments, AB and CD wrote the report).

Please submit any extra thoughts or comments regarding question 14 here:

Q15.
What do you think are the reasons why the names of co-authors on peer review reports may not be provided to the editorial staff? Please select all that you think apply.

- A lack of a mechanism (such as a textbox, with language demonstrating expectations that co-reviewers be listed) to include this information in the peer review report submission process.
- A belief that reviews should only be done by the invited reviewer, and not by, or with assistance from, anyone else.
- A belief that only the invited reviewer deserves authorship, even when others contribute ideas and/or text to the review report.
- A belief that there is no strong ethical reason to add co-authors names.
- A belief that including co-author information would demonstrate that the PI breached the confidentiality of the manuscript.
- Some ECRs may not be comfortable asking for co-authorship.
- A belief that keeping ECR names off of peer review protects ECRs during a vulnerable time in their career.
- Some co-reviewers want to be able to write critical reviews anonymously.
- A belief that ghostwriting does not occur: everyone always provides the names of all contributing authors to the editorial office.
- A belief that ghostwriting does not occur: PIs are the only people that contribute to peer review reports.
- Other (please describe)

Q16.
16. Would any of the opinions you have just expressed change if the content of peer review reports (i.e. the text of reviews) were published openly alongside the papers? And should such published reports include or exclude the reviewer's name(s)? Please explain.

Thank you!

You have completed the survey. Many thanks for your responses! Please check http://futureofresearch.org/ecrpeerreview/ or subscribe to our blog to keep updated on the results. Please share the link to the survey with your colleagues: https://tinyurl.com/ECRs-in-peer-review

List of institutions with multiple survey respondents

In alphabetical order:

Albert Einstein College of Medicine
Baylor College of Medicine
Boston Children's hospital
Boston University
Broad Institute
California Institute of Technology
Carnegie Mellon University
Cold Spring Harbor Laboratory
Columbia University
City University of New York
Dana-Farber Cancer Institute
Dartmouth College
European Molecular Biology Laboratory
Fred Hutchinson Cancer Research Center
Harvard Medical School
Harvard University
Icahn School of Medicine at Mount Sinai
Imperial College London
Indian Institute of Technology Madras
Lawrence Berkeley National Laboratory
Ludwig Maximilian University of Munich
Max Planck Institute
Mayo Clinic
Memorial Sloan Kettering
New York University
Not Disclosed
Ohio State University
Okinawa Institute for Science and Technology
Princeton University
Rockefeller University
South Dakota State University
St Jude Children's Research Hospital
Stanford
Tufts University
University of California Berkeley
University of California Los Angeles
University of California San Francisco
Université de Montréal/University of Montreal
University of Alabama at Birmingham
University of British Columbia
University of Cambridge
University of Chicago
University of Georgia
University of Illinois at Chicago
University of Kentucky
University of Massachusetts
University of Michigan
University of Minnesota
University of North Carolina at Chapel Hill
University of Oxford
University of Pennsylvania
University of Pittsburgh
University of Puerto Rico
University of Technology of Vienna
University of Toronto
University of Vermont
University of Washington
University of Wisconsin
University of Würzburg
Vienna University of Technology
Washington University in St. Louis
Yale University

List of topics assigned to fields of study

Life Sciences:

Aging
Agriculture
Alzheimer diseases
Animal Behaviour
Bacterial genomics
Biochemistry
Biochemistry and molecular biology
Biochemistry, Microbiology
Bioelectrochemical systems
Bioinformatics
Bioinformatics, Molecular Biology
Bioinformatics, Computational biology
Biological Anthropology
Biological/life sciences
Biology
Biology, Environment, Ecotoxicology
Biology, Hematology, Oncology
Biology/Ecology
Biomaterials
Biomedical
Biomedical engineering
Biomedical optics
Biomedical Research
Biomedical Science
Biomedicine
Biomedicine / evolutionary biology
Biophysics
Biophysics, Cell Biology and Immunology
Bioscience
Body MRI
Cancer
Cancer Biology
Cancer imaging
Cancer immunology
Cancer mechanobiology
Cancer Research
Cardiac Biology/Pharmacology
Cardiology
Cardiovascular Biology
Cardiovascular pathology
Cell and Developmental Biology
Cell Biology
Cell Biology and Genetics
Cellular and Molecular Biochemistry
Chemical Biology
Clinical and Translational Science
Cognitive neuroscience
Computational Biology
Computational biology/genomics
Computational human Genetics
Developmental and Stem Cell Biology
Developmental biology
Developmental Blood
Developmental neurobiology
Developmental Neuroscience
Disease ecology
Drug Delivery
Ecology
Ecology & Evolution
Entomology
Environmental Science
Evolutionary Biology
Experimental Design
Food Systems
Gastroenterology
Gene therapy
Genetics
Genetics/prematurity
Genomics
Genomics; Neuroscience
Health
Hematology
Human Genetics
Human/integrative physiology
Immunology
Immunology and Virology
Inflammation research
Life sciences
Math biology
Medical Imaging

Medicine
Medicine, Epidemiology and public health
Microbiology
Microbiology and Infectious Diseases
Midwifery
Molecular Biology
Molecular engineering
Molecular Medicine
Molecular Microbiology
Molecular Neurobiology
Neurobiology
Neuroimaging
Neuroimmunology
Neuropathology
Neuropsychiatry
Neuroscience
Neuroscience, cell biology
Occupational Therapy
Oceanography
Oligonucleotide therapeutics
Oncology
Orthopaedic Surgery
Parasitology
Pharmaceutical Sciences
Pharmacology
Pharmacy
Physical Therapy
Physiology
Plant biology
Plant science
Protein therapeutics
Proteomics
Psychiatry
Psychiatry and Behavioral Neuroscience
Radiology
Reproductive biology/toxicology
Reproductive Physiology
Stem cell and tissue engineering
Structural Biology
Structure vaccinology
Systems biology
Toxicity research
Toxicology and Cancer Biology
Translational cellular biology
Translational Medicine
Vascular Physiology and Pharmacology
Virology
Wildlife Diseases

Physical Sciences:

Applied Engineering
Applied mathematics
Applied physics
Astronomy
Chemical Engineering
Chemistry
Civil Engineering
Computational chemistry
Computer Science
Earth Sciences
Electrical & Systems Engineering
Electrical Engineering
Engineering
Environmental engineering
Geology
Geosciences
Health informatics
Informatics
Material Science
Mathematics
Mechanical engineering
Mechanism in Broadband Wireless Network
Microfluidics
Physics
Planetary Science
Polymer chemistry
Radiochemistry
Robotics
Surface Science

Social Sciences:

Anthropology
Business & Management
Cognitive psychology
Communication sciences
Computational social science
Economics, Marine Science
Education & Religious Studies
Education and educational leadership
Education Policy
Education, professional development
Educational psychology/qualitative research
Environmental psychology
Epidemiology
Health economics
Health services administration
Integration & risk assessment
Linguistics
Management
Mathematical Economics
Medical sociology
Political Science
Psychology
Psychology; neuroscience
Psychometrics
Public health
Social and Behavioral Sciences
Social Sciences
Social work
Sociology

Humanities OR Other:

Archaeology
Art Conservation
ATMP Development and policy
English and Humanities
Graduate Career Development
History and philosophy of science
Information theory
Landscape Architecture
MS and HS Teacher Development
N/A
No longer researching
Palaeontology
Postdoc Affairs
Water Policy

Written responses giving reasons PIs excluded survey respondents as co-reviewers

In response to Question 12. Responses are not edited unless noted *[in this fashion]*:

- Apparently this duty is part of my job description
- At my request; wished to remain "anonymous" to manuscript authors
- Didn't think about including me, didn't know how to do so
- Good training/practice and could put journal reviewer on my CV *[subsequent personal information about respondent's career stage removed]*
- He said only he would be invited to review for such a prestigious journal and "we" need this for future submissions.
- He wanted me to learn under his supervision first. I did this twice, then the third time I reminded him to suggest my name to the editorial staff so that I could get the invite for review myself, which I did receive.
- He was in a hurry and he couldn't figure out the journal's website.
- I did not ever submit paper
- I did volunteer to review manuscripts knowing my name was not gonna be listed as a reviewer
- I was told this is how one gets to train to review papers and grants
- In my case I assisted other ECRs with their reviews, and there was no mechanism to indicate multiple reviewers collaborated on the review
- In my opinion my intellectual contribution was not sufficient. It was a training exercise and no one really gets career benefit for reviews anyway. Frankly this is a leading serries of questions.
- It was good for my career to practice.
- Its good experience for me
- Journal doesn't have co-reviewers.
- no clear answer given
- no reason given other than to help me learn to write reviews
- PI is not fit to sit in editor or reviewers position so only he requests me to review the manuscripts.
- PI signs review and review was v contentious
- Pi surprised I would be interested in being acknowledged, and seemed like too much trouble to acknowledge my contribution . There was no box in the online form to declare it.
- reviewing papers as ECR is part of the ECR training
- The interaction was teh form of a discussion over elements of the review, neither of us considered my contribution as "co-reviewing"
- There wasn't a field to add my name/ it wasn't clear if co-reviewers were allowed (I.e. he didn't know whether it was allowed or not)
- Theres not an option in most cases to list multiple people as reviewers from the same lab, you can still list on CV.
- They forgot
- this is standard practice in *[place name redacted]* - it's never questioned
- This was not explicitly discussed, but the PI implied this is "common practice" and normal for ECRs to gain experience
- tried to discussed but it was ignored by my PI.
- We discussed it but they did not give me a reason
- When I reviewed papers with my PI it was more so an exercise for me, not a situation where my PI did not actually review the work in question and only took my review. It was reviewed jointly as part of a learning/training process for me. I do not know whether or not my comments ended up being incorporated into his final review of the manuscripts.

Examples of formalized training in peer review

Some graduate programs, scientific societies, and journals already provide materials for training in peer review. For example, the American Chemical Society's Publications branch provides the free ACS Peer Review Lab™ course, designed by editors, researchers and publication staff (acsreviewerlab.org). GENETICS, a journal of the Genetics Society of America, provides a peer review training program with virtual training sessions for ECR members (genetics-gsa.org/careers/training_program.shtml). Nature provides an online course on peer review (https://masterclasses.nature.com/courses/205). The Journal of Young Investigators (jyi.org) provides training at the undergraduate level. Publons (which provides a mechanism for recording and crediting peer review activity) has a peer review academy online (https://publons.com/community/academy/).

In terms of graduate training, some examples exist at the level of the graduate program. For example, Dr. Needhi Bhalla, at the University of California Santa Cruz, has shared their system (see below for Template from Dr. Needhi Bhalla (UCSC) for peer review training using preprints, adapted from (Halbisen and Ralston 2017)) whereby students review pre-prints in the graduate cell biology class, using a template, and then send reviews to the preprint authors, thereby combining peer review training in journal clubs with the ability to actually make comments on preprints that authors can then use in preparation of a final manuscript for publication at a peer-review journal, should they wish (Avasthi et al. 2018). Examples of other classes that we have so far found or received information on include Class 230 in the PhD Program in Biological and Biomedical Sciences at Harvard; a class on critiquing papers at University of California San Diego; a class in the graduate program in Systems Biology at Harvard Medical School; a

requirement to review a paper as a final exam recently introduced at the Graduate Field of Biochemistry, Molecular, and Cell Biology at Cornell University and the University of Texas Southwestern is experimenting with an advanced course combining peer review, literature review, debate and commentary communication and lay-audience oriented writing.

Template from Dr. Needhi Bhalla (UCSC) for peer review training using preprints

Assignment description

"Your assignment is to pick a cell biology preprint from biorxiv (http://biorxiv.org/collection/cell-biology) and review it. This assignment is due [DATE] [TIME]. Please submit your review as a word document so that I can edit it.

I'll assess, edit and grade your review. Afterwards, you will email your edited review to the corresponding author(s), cc'ing me on this email. Your grade is contingent upon submission of your review to the authors.

I'd like you to organize your review as follows:

Part 1. Summary (less than 500 words):
Write a brief overview of the author's findings and provide a general assessment on the quality of the work: strengths and weaknesses.

Part 2. Detailed comments:
Address each of the questions below, providing specific examples to justify your comments.
1. Significance
Does the author provide justification for why the study is novel and how their results will influence the field?

2. Observation
Are the author's descriptions of the data accurate and are all key experiments and hypotheses covered? Are the author's arguments logically and coherently made? Are counterbalancing viewpoints acknowledged and discussed? Are they sufficiently detailed for a non-expert to follow? Do they include superfluous detail?

3. Interpretation
Are the inferences supported by the observations? Do you agree? If not, what experiments would you need to see to be convinced? Please limit any requests for new work, such as

experiments, analyses, or data collection, to situations where the new data are essential to support the major conclusions. Any requests for new work must fall within the scope of the current submission and the technical expertise of the authors.

4. Clarity
Is the manuscript easy to read and free of jargon, typos, and grammatical or conceptual errors? Is the information provided in figures, figure legends, boxes and tables clear and accurate? Is the article accessible to the non-specialist?

Tips:
It is important to provide a helpful review that you would want to receive. Critical thinking does not need to be negative to be convincing!

Let me know if you'd like to consult with me about your choice of papers or have any questions."

Future directions for survey questions

Opinions on open peer review reports and public naming of reviewers

The final (16th) question of the survey provided respondents with an open comment box in which to reflect on whether any of their opinions would change if either the *contents* of peer review reports or the *names of reviewers* were openly published to journal readership. This question is a stark contrast to the the rest of the survey questions, all of which instead only ask about naming co-reviewers to the journal staff and editors but not openly to the public readership. We included this question as a test balloon for future surveys that might focus on open peer review vs. traditional models of closed peer review. Due to its tangential relationship to the goals of the current study on ghostwriting and due to the question's open-ended, write-in nature, we did not perform a systematic analysis of responses as with the other questions. A qualitative summary of responses is below.

61% of respondents chose to write a response to this question, and of these approximately one third reported that no, their opinions would not change if the peer review reports nor names of reviewers were openly shared with the public readership (it should be noted that these comments mostly, but not necessarily, endorsed the specific open peer review features suggested in the question). The remaining respondents expressed a variety of concerns, mostly surrounding the loss of anonymity of reviewers rather than what appeared to be the less controversial concept of publishing the contents of peer review reports. Respondents' hesitations about anonymity often centered on the effect that naming ECRs and URMs might have on these vulnerable populations. These responses reflect other conversations about open peer review (Polka et al. 2018; Tennant et al. 2017; Ross-Hellauer 2017; Ross-Hellauer et al.

2017) and in the context of recent data about referee behavior in open peer review (Bravo et al. 2019) warrant further analysis beyond the scope of this manuscript.

Improving clarity in survey questions

One survey question that would benefit from disambiguation in future iterations of the survey is: "Agree/Disagree: When a journal invites a PI to review, that is equivalent to the journal inviting anyone in that PI's research group with relevant expertise to contribute to the review." It was brought to our attention by respondents' emails and write-in comments during the survey response period that there was confusion about this statement. We had hypothesized that we might find agreement with the statement; however, we found a substantial amount of disagreement which may be due in part to the various ways the question may have been interpreted. Our intention was to determine if respondents agreed that, in practice, it could be reasonable for all engaged in journal publication and peer review to expect that an invited reviewer would have various motivations to share a manuscript with the relevant expertise in their research group, particularly in cases where a postdoc is likely more familiar with the literature or experimental techniques than a Principal Investigator overseeing a number of projects. However it became apparent that this question was quite open to various interpretations as described in write-in comments received on the question, including:

- Does the respondent believe this *should* be the case?
- Does the respondent believe this is what is *actually happening*?
- Does the respondent consider that journals have this intent when they invite reviewers?

This therefore renders interpretation of responses to this question difficult, and so we chose not to draw conclusions from this particular result. We aim to clarify this question should there be future iterations of this survey.

Another survey question that would benefit from future disambiguation draws from respondents' ability to select multiple responses for the question "When you were not the invited reviewer, what was the extent of your involvement in the peer review process? Please select all that apply to your entire peer review experience (e.g. across multiple manuscripts)." and indeed the inability to discern whether respondents supplying only one answer were selecting that response because that comprised the totality of their experiences, or because they selected the most common experience. In comparing responses to this question with other questions, it may be that there are analyses that are affected by the assumption that it is possible to apply one response of many to a response to another question. We attempted to preemptively disambiguate responses by asking whether respondents had "ever" experienced certain things in subsequent questions.

We are also keen to solicit suggestions on possible questions to include or expand upon in a revised study, and possibly removing certain questions. Of course, we also recognize that sharing the results of the first 498 respondents could itself bias subsequent data collections efforts, and we are currently considering which direction to take, particularly as to which questions could potentially be prejudiced by awareness of prior data.

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FEATURE ARTICLE

RESEARCH CULTURE

Co-reviewing and ghostwriting by early-career researchers in the peer review of manuscripts

Abstract Many early-career researchers are involved in the peer review of manuscripts for scientific journals, typically under the guidance of or jointly with their advisor, but most of the evidence about this activity is anecdotal. Here we report the results of a literature review and a survey of researchers, with an emphasis on co-reviewing and 'ghostwriting'. The literature review identified 36 articles that addressed the involvement of early-career researchers in peer review, most of them about early-career researchers and their advisors co-reviewing manuscripts for the purposes of training: none of them addressed the topic of ghostwriting in detail. About three quarters of the respondents to the survey had co-reviewed a manuscript. Most respondents believe co-reviewing to be a beneficial (95%) and ethical (73%) form of training in peer review. About half of the respondents have ghostwritten a peer review report, despite 81% responding that ghostwriting is unethical and 82% agreeing that identifying co-reviewers to the journal is valuable. Peer review would benefit from changes in both journal policies and lab practices that encourage mentored co-review and discourage ghostwriting.
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Introduction

The peer review of manuscripts submitted to scientific journals is widely viewed as fundamental to efforts to maintain the integrity of the scientific literature (*Baldwin, 2018*; *Tennant, 2017*). Early-career researchers (ECRs) often contribute to the peer review process. Indeed, in a recent survey that targeted ECRs in the life sciences, 92% of respondents reported that they had been involved in the peer review of at least one manuscript (*Inside eLife, 2018*). More than half of survey respondents, including 37% of graduate students, reported reviewing a manuscript without any assistance from their advisor. Journals may not be fully aware of the extent to which ECRs are involved in peer review (*McDowell, 2018*). Indeed, a recent editorial in this journal contained the following sentence: "It is common practice for busy group leaders to ask their more senior PhD students and postdoctoral fellows to help with peer review, but in too many cases these contributions go unacknowledged" (*Patterson and Schekman, 2018*).

We conducted a literature search and a survey to explore the involvement of ECRs in peer review more thoroughly and, in particular, to determine the prevalence of both co-reviewing (i.e., when the journal knows that the ECR contributed to the review) and 'ghostwriting' (i.e., when the journal does not know that the ECR contributed to the review). Please see *Table 1* for a definition of terms used in this article.

Results

Lack of literature on ECR ghostwriting of peer review reports

We performed a comprehensive review of the peer-reviewed literature to identify any previous studies on the role that ECRs play in peer review, particularly with respect to ghostwriting. Exhaustive search terms that combined any

synonyms of "early-career researcher" and “peer review” were used per evidenced-based guidelines for systematic reviews (prisma-statement.org; *PRISMA Group et al., 2009*; see Methods: Systematic literature review for details). Our search yielded 1952 unique articles. Collected articles underwent two rounds of screening performed independently by three of the present authors using titles and abstracts to evaluate relevance to the topic of ECR co-reviewing and ghostwriting peer review reports (see Methods: Relevance screening for details; *Supplementary file 1*; *Figure 1—figure supplement 1*).

We did not find any research articles on ghostwriting peer review reports by ECRs. One article (the eLife editorial mentioned previously; *Patterson and Schekman, 2018*) acknowledged the phenomenon of ECR ghostwriting, and stated that ECRs are eligible to act as peer reviewers for manuscripts submitted to eLife. 35 other articles addressed ECR involvement in manuscript peer review but did not address ghostwriting. Many of these instead investigated the value of co-reviewing as a training exercise (see Appendix 1). None discussed the issue of named credit for scholarly labor, nor did they include information on the frequency of ghostwriting in peer review or the opinions of ECRs on ghostwriting.

Surveying the rates and rationales for co-reviewing and ghostwriting

To address this gap in the literature, we designed a survey to evaluate the frequency of, and motivations for, ghostwriting and co-reviewing by ECRs. The IRB-approved, online survey garnered 498 responses over a month-long data collection period in September, 2018 (see Methods: Survey of peer review experiences and attitudes for details; the survey itself is available in *Supplementary file 2*). Respondents came from 214 institutions that were geographically diverse both within and beyond the United States. Most participants were from institutions in North America (n = 370), Europe (n = 87) and Asia (n = 21). 74% of all respondents were based in the US, of which 64% were citizens or permanent residents, and 36% held temporary visitor status. Institutions from 40 US states or territories were represented: the four universities with the most respondents were Washington University in St. Louis, the University of Kentucky, Rockefeller University, and the University of Chicago. The majority of survey respondents (65%) were ECRs in the life sciences (*Figure 1*). This was as expected given our efforts to primarily engage ECRs and our connections to biomedical postdoctoral populations (see Methods: Survey distribution, limitations, and future directions). We surmise that postdocs (63% of all respondents) are over-represented in this survey, although the

Table 1. Definitions used in this study.

Term	Definition
Early-career researcher (ECR)	We consider this to be anyone engaged in research who is not recognized as an independent leader of a research group, including: undergraduate, graduate, and postdoctoral researchers; junior research assistants.
Principal Investigator (PI)	Anyone recognized as an independent leader of a research group, including: professors, group leaders. *Note*: We use this term to mean someone likely to be an invited reviewer due to their professional independence, including pre-tenure junior faculty (e.g. assistant professor in the US). We recognize that, in other contexts, pre-tenure faculty may also categorized as ECRs.
Co-reviewing	Contributing ideas and/or text to a peer review report when one is not the invited reviewer. Equivalent to a co-author on a manuscript when one is not the corresponding author. *Note*: We use this term to mean significant contributions to the peer review report, and so differentiate from casual or insignificant conversations about the manuscript under review that do not provide novel ideas and/or text to the peer review report.
Ghostwriting	Co-reviewing without named credit to the journal editorial staff. *Note*: We use this term to mean only the identification of a co-reviewer to the journal staff in an identical manner to the identification and naming of the invited reviewers. We are not referring to the *public* naming of peer reviewers, or reviewers *signing* reviews, or other forms of open peer review which is beyond the scope of this study (*Ross-Hellauer, 2017*).

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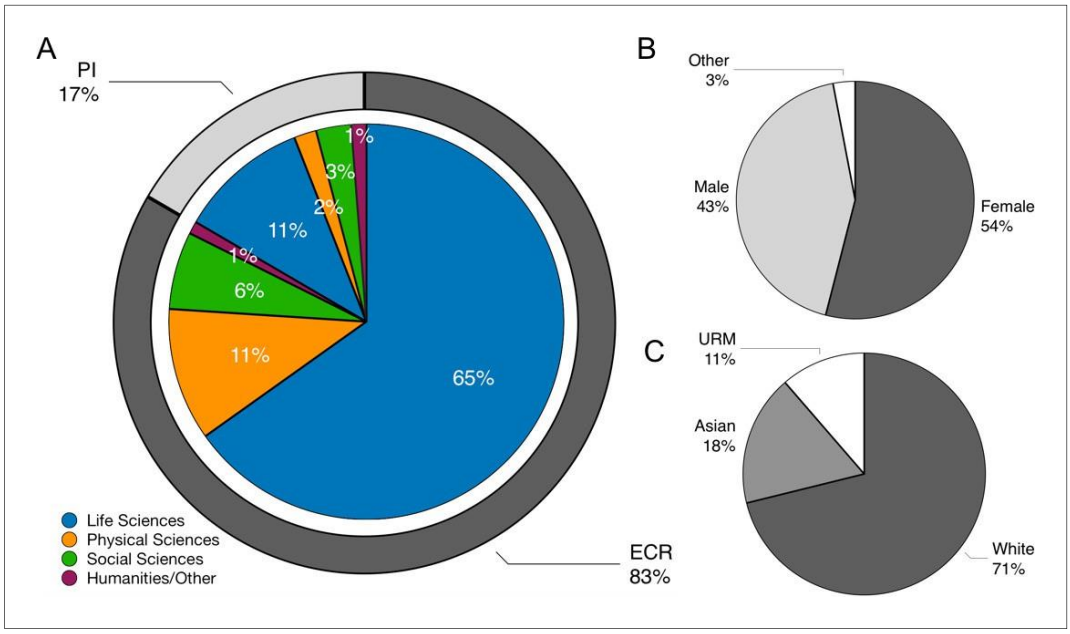

Figure 1. Demographics of survey respondents. (A) Distribution of responses by field of study and career stage. Of a total of 498 respondents, 488 were categorized as an early career researcher (ECRs; n = 407/488; 83%) or principal investigator (PIs; n = 81/488; 17%). Of these, 76% were in the life sciences (318 ECRs; 52 PIs), 13% were in the physical sciences (53 ECRs; 9 PIs), 9% were in the social sciences (31 ECRs; 14 PIs), and 2% were in the humanities/other (5 ECRs; 6 PIs). 10 respondents were neither ECR nor PI (e.g., "unemployed"; data not shown). (B) Distribution of responses by gender: 54% (271/498) of respondents were female, 43% (216/498) were male, and 3% (11/498) provided another or no response. (C) Distribution of responses by race/ethnicity: Of the 481 respondents who provided an answer to this question, 71% (342/481) were coded as white, 18% (84/481) Asian, and 11% (55/481) URM (underrepresented minority in the sciences).

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The following source data and figure supplement are available for figure 1:

Source data 1. De-identified demographic data for survey respondents.

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Figure supplement 1. Search strategy for literature review with number of records remaining at each stage.

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number of postdoctoral researchers in the US is currently unknown (*Pickett et al., 2017*).

Co reviewing by ECRs is the norm and motivated by training

It is a widespread practice to contribute ideas and/or text to a peer review report when one is not the invited reviewer. 73% of all respondents have co-reviewed and often at numerous times (33% on 6–20 occasions, and 4% on more than 20 occasions; *Figure 2A*). Co-reviewing by ECRs specifically is common, with 79% of postdocs and 57% of PhD students having co-reviewed when "the invited reviewer is the PI for whom you work" (*Figure 2B*). These data suggest that collaboration on peer review reports is an academic norm, especially by ECRs who are not the invited reviewer. By contrast, 55% of ECR respondents have never carried out independent peer review as the invited reviewer (*Figure 2C*).

A major motivation for ECRs to co-review is to gain training in peer review of manuscripts, a fundamental scholarly skill. All survey respondents were asked what training they received in peer review of manuscripts (*Figure 3*). Respondents report that PIs are the second most common source of peer review training, bested only by the passive form of learning "from receiving reviews on my own papers." Training through co-review was the subject of many publications uncovered by our literature review (Appendix 1).

Ghostwriting is common despite a belief it is unethical

The frequency of ghostwriting was measured in two survey questions which revealed comparable rates. When we asked "To your knowledge,

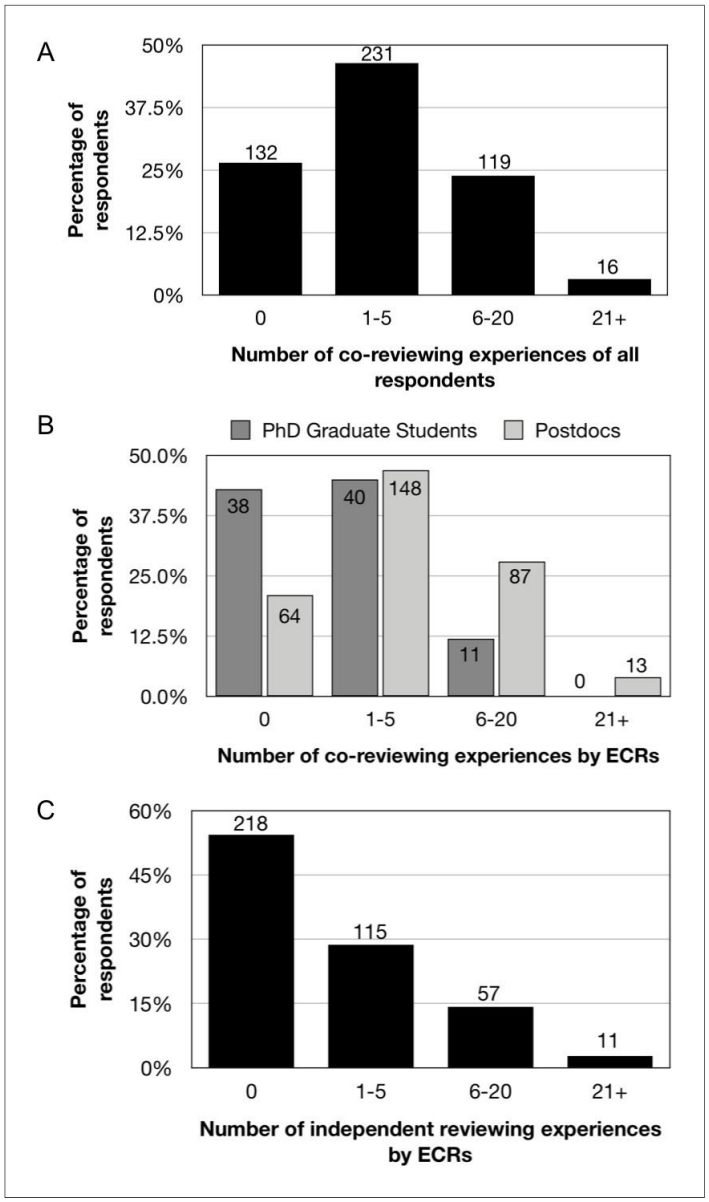

Figure 2. Experiences of co-reviewing and being invited to review. (A,B) Responses to question: "How many times in your career have you contributed ideas and/or text to peer review reports where you are not the invited reviewer (e.g. the invited reviewer is the PI for whom you work)?" 73% of all respondents (366/498) had participated in co-reviewing: 63% of this subsample had carried out co-reviewing activities on 1–5 occasions; 33% on 6–20 occasions; and 4% on more than 20 occasions. (B) Number of co-reviewing experiences by career stage for 401 ECRs: the distribution of postdocs (n = 312) is skewed toward more co-reviewing experiences, whereas the distribution of PhD students (n = 89) is skewed toward fewer co-reviewing experiences. (C) Responses to question for ECRs: "How many times in your career have you reviewed an article for publication independently, i.e. carried out the full review and been identified to the editorial staff as the sole reviewer?" 55% of the ECR respondents (218/401) had never carried out independent peer review, and 46% (183/401) had carried out independent review as the invited reviewer: 115 had done so 1–5 times, 57 had done so 6–20 times, and 11 had done so more than 20 times.

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did your PI ever withhold your name from the editorial staff when you served as the reviewer or co-reviewer?," 46% of respondents knew that their name had been withheld (*Figure 4A*). These data are consistent with results from a separate question: "When you were not the invited reviewer, what was the extent of your involvement in the peer review process?". For this question, 44% of respondents reported having had the experience of ghostwriting: "I read the manuscript, wrote the report, my PI edited the report and my PI submitted report with only their name provided to the editorial staff" (*Table 2*). Taken together, these data suggest that approximately 1 in 2 survey respondents has engaged in ghostwriting of a peer review report on behalf of their PI, the invited reviewer. Furthermore, 70% of co-reviewers report the experience of making significant contributions to a peer review report without knowingly receiving credit (*Table 2*). This experience is much more common than the 22% of co-reviewers who experienced making significant contributions with known credit (*Table 2*). These data reveal a breakdown in communication between invited reviewers and co-reviewers.

In a more specific follow up question that asked "To your knowledge, did your PI ever submit your reviews without editing your work?", 52% of respondents report that they were not involved in any editing process with their PI (*Figure 4B*). This proportion is similar to that reported in *Inside eLife (2018)*. That survey asked "Have you reviewed before?" and then "If so, to what extent was your supervisor involved?" to which slightly more than half of the 264 respondents replied "not at all." One interpretation of these data is that half of respondents had engaged in independent peer review as the invited reviewer. Another interpretation of these data is that half of respondents had engaged in co-review with no feedback from their supervisor, the invited reviewer. Our data support the latter interpretation that slightly more than half of respondents have written peer review reports without feedback from their PI when the PI is the invited reviewer.

The Office of Research Integrity (ORI), which oversees research funded by the US Public Health Service, states that "academic or professional ghost authorship in the sciences is ethically unacceptable" (https://ori.hhs.gov/plagiarism-34). Respondents are also of the view that ghostwriting peer review reports is unethical: 83% disagree with the statement that "The only person who should be named on a peer

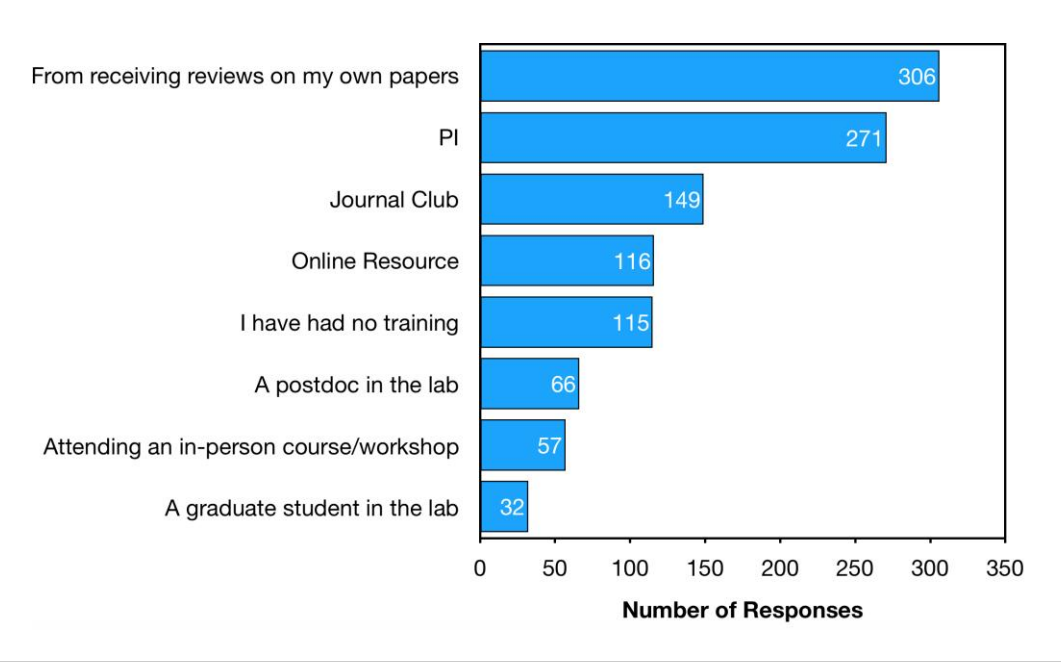

Figure 3. Training in how to peer review a manuscript. Responses to the question: "How did you gain training in how to peer review a manuscript?" Respondents were able to select as many options as applied to them. These data include responses from all survey participants, including those without any independent or co-reviewing experience.

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review report is the invited reviewer, regardless of who carried out the review"; 81% disagree with the statement that "Ghostwriting a peer-review report for your PI is an ethically sound scientific practice"; and 77% disagree with the statement that "It is ethical for the invited reviewer (e.g. PI) to submit a peer review report to an editor without providing the names of all individuals who have contributed ideas and/or text to the report" (*Figure 5*). Respondents were also supportive of co-reviewing providing their contributions are known about: 74% agree that "Anyone that contributes ideas and/or text to the review report should be included as a co-author on the review"; 82% agree that "It would be valuable to have my name added to a peer review report (e.g. to be recognized as a co-reviewer by the editor; or to use a service such as Publons to be assigned credit)"; 73% agree that "It is ethical for the invited reviewer (e.g. PI) to involve others (e.g. their trainees) in reviewing manuscripts"; and 95% agree that "Involving members of a research group in peer review is a beneficial training exercise." The latter statement evoked the strongest positive sentiment of all 11 Agree/Disagree statements.

There was a significant difference in the extent of agreement between ECRs and PIs for certain aspects of co-reviewing and ghostwriting (*Table 3*). In 3 of 11 statements, ECRs felt significantly more strongly than PIs but still shared the same valance (e.g. both groups agreed or both groups disagreed with the statement, just to a differing strength). For the remaining 8 statements, ECRs and PIs did not significantly differ in their opinions.

Motivations for ghostwriting

If 4 out of 5 survey respondents think ghostwriting is unethical, then why do half of all respondents participate? We measured the motivations for ghostwriting by: i) asking all respondents, regardless of peer review experience, to surmise why someone might withhold the name of a co-reviewer (*Figure 6*); ii) asking only respondents with ghostwriting experience to report the specific reasons that the invited reviewer gave for withholding their name (*Table 4*). In this way, we compared cultural beliefs with actual practice.

The main perceived barrier to naming co-reviewers was a lack of a physical mechanism to supply the name to the journal (e.g. a textbox for co-review names), with 73% of respondents

Table 2. Experiences with co-review and ghostwriting.

Responses to the question: "When you were not the invited reviewer, what was the extent of your involvement in the peer review process?" Survey participants were able to choose any and all applicable responses from a provided set of possible responses that can be broken down into three interpretation groups. Because respondents were able to select more than one answer, these data include all of the different co-reviewing experiences for each participant.

Possible survey responses	Respondents that selected this as an answer (%)	Interpretation of response	Respondents that selected at least one of the answers in this group (n, %)
"I read the manuscript, shared short comments with my PI, and was no longer involved"	40	No significant contribution	149 respondents (40%) selected this response
"I read the manuscript, wrote a full report for my PI, and was no longer involved"	47	Significant contribution, without known credit	258 respondents (70% of those with co-reviewing experience) selected at least one of the responses in this category
"I read the manuscript, wrote the report, my PI edited the report and my PI submitted report with only their name provided to the editorial staff"	44		
"I read the manuscript, wrote the report, my PI edited the report and we submitted the report together with both of our names provided to the editorial staff"	20	Significant contribution, with known credit	80 respondents (22% of those with co-reviewing experience) selected at least one of the responses in this category
"I read the manuscript, wrote the report, and submitted it independently without my PI's name provided to the editorial staff"	3		

Note: (Mis)representation of authorship on any scholarly work can be a subjective grey area. We sought to specifically avoid this in our survey questions by using the answers to the question "When you were not the invited reviewer, what was the extent of your involvement in the peer review process?" to disambiguate the grey areas of authorship. We consider any experience that began with "I read the manuscript, wrote a full report for my PI, and..." to be an unequivocally significant contribution deserving of authorship on the peer review report.

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selecting this as an option (*Figure 6*). Cultural expectations were the next most commonly-cited barriers, such as "A belief that reviews should only be done by the invited reviewer, and not by, or with assistance from, anyone else" (selected by 63% of respondents) and "A belief that including co-author information would demonstrate that the PI breached the confidentiality of the manuscript" (58%). These latter responses allude to journal policies prohibiting invited reviewers from sharing unpublished manuscripts without prior permission. Write-in responses echo themes about how ghostwriting is the status quo in peer review (*Table 5*). At the same time, respondents also wondered why including co-reviewer names is not common practice.

In contrast, when we asked "Consider cases where you contributed to a peer review report and you know your name was NOT provided to the editorial staff. When discussing this with your PI, what reason did they give to exclude you as a co-reviewer?" 73% of respondents reported that they had not discussed this with their PI (*Table 4*). This is consistent with the lack of communication between invited reviewers and co-reviewers documented above (*Table 2*; *Figure 4B*). Of the 27% of respondents who had ghostwritten and did discuss the matter with their PI, most were told that the reason their name was withheld was either a prohibitive journal policy and/or prevailing cultural expectations about co-authorship on peer review reports. Only 4% of those who had discussed the matter with their PI cited a practical barrier, such as the lack of a text box for co-reviewer names on the journal review submission form. Write-in responses to this question again refer to cultural expectations as the major drivers for ghostwriting (*Table 6*). Many of these write-in reasons articulate that it is good practice for ECRs to participate in peer review; however, they simultaneously fail to explain why this necessitates withholding the names of co-reviewers. These data suggest that there is a common conflation of ghostwriting (withholding names) with co-reviewing (involving ECRs in peer review, often for the purposes of training).

Other demographic analyses

We also performed preliminary analyses by gender, field, citizenship and race/ethnicity, but any differences we observed were small or not statistically significant, and some demographic subsets were too small for analysis. We are considering how to share these data more completely.

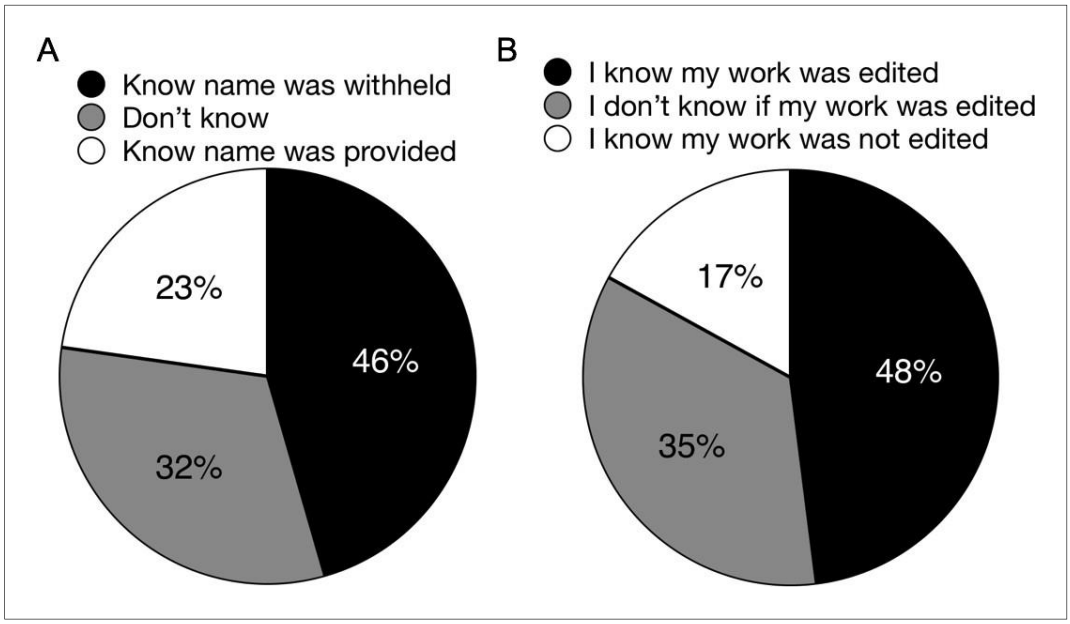

Figure 4. The actions of PIs during co-review. (A) Responses to the question: "To your knowledge, did your PI ever withhold your name from the editorial staff when you served as the reviewer or co-reviewer?" 46% of respondents (171/374) knew that their name had been withheld, and 32% (118/374) did not know. The remaining 23% (85/374) responded that they knew for certain their name had been disclosed. (B) Responses to the question: "To your knowledge, did your PI ever submit your reviews without editing your work?" 17% of respondents (66/375) answered "yes", that they knew that their work had not been edited by the PI prior to submission to the journal. Another 35% of respondents (132/375) were unaware of whether their work was edited by their PI prior to their PI submitting it to the journal. Taken together, these 52% of respondents were not involved in editing, regardless of whether it took place. 48% of respondents (177/375) answered "no", indicating that they knew their work had been edited for sure.

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Discussion

Journal peer review is an important part of scholarship. As such, ECR training and authorship on peer review reports deserves thoughtful consideration to ensure the integrity of the peer review process. Our data reveal that involving ECRs in peer review is an academic norm, with about three-quarters of our survey population having contributed significantly to a peer review report when they were not the invited reviewer (co-reviewed), and about half having done so without being named to the journal editorial staff (ghostwritten). These high frequencies contrast with journal policies and cultural expectations that only the invited reviewer engages in the peer review of a manuscript. They also fly in the face of community values when about four-fifths of those surveyed agree that ghostwriting is unethical. What drives these differences between community values and experience?

Explanations for ghostwriting are conflated with explanations for co-reviewing

Co-reviewing as a training exercise and ghostwriting are separable processes: training through co-review can and does happen *whether or not* named credit is given to the co-reviewer, and excluding co-reviewer names from peer review reports can and does happen *whether or not* the co-reviewer has experienced quality training in the process. Even as we sought to collect data that would disentangle these two processes, the rationales for ghostwriting were often conflated with the rationales for co-reviewing. For example, when we asked respondents specifically for the reason(s) their PI gave them for excluding their names on a peer review report, many wrote responses such as "I was told this is how one gets to train to review papers..." (*Table 6*). This response – that it is a beneficial and common practice for ECRs to participate in peer review as a training exercise – does not actually explain why *ghostwriting*

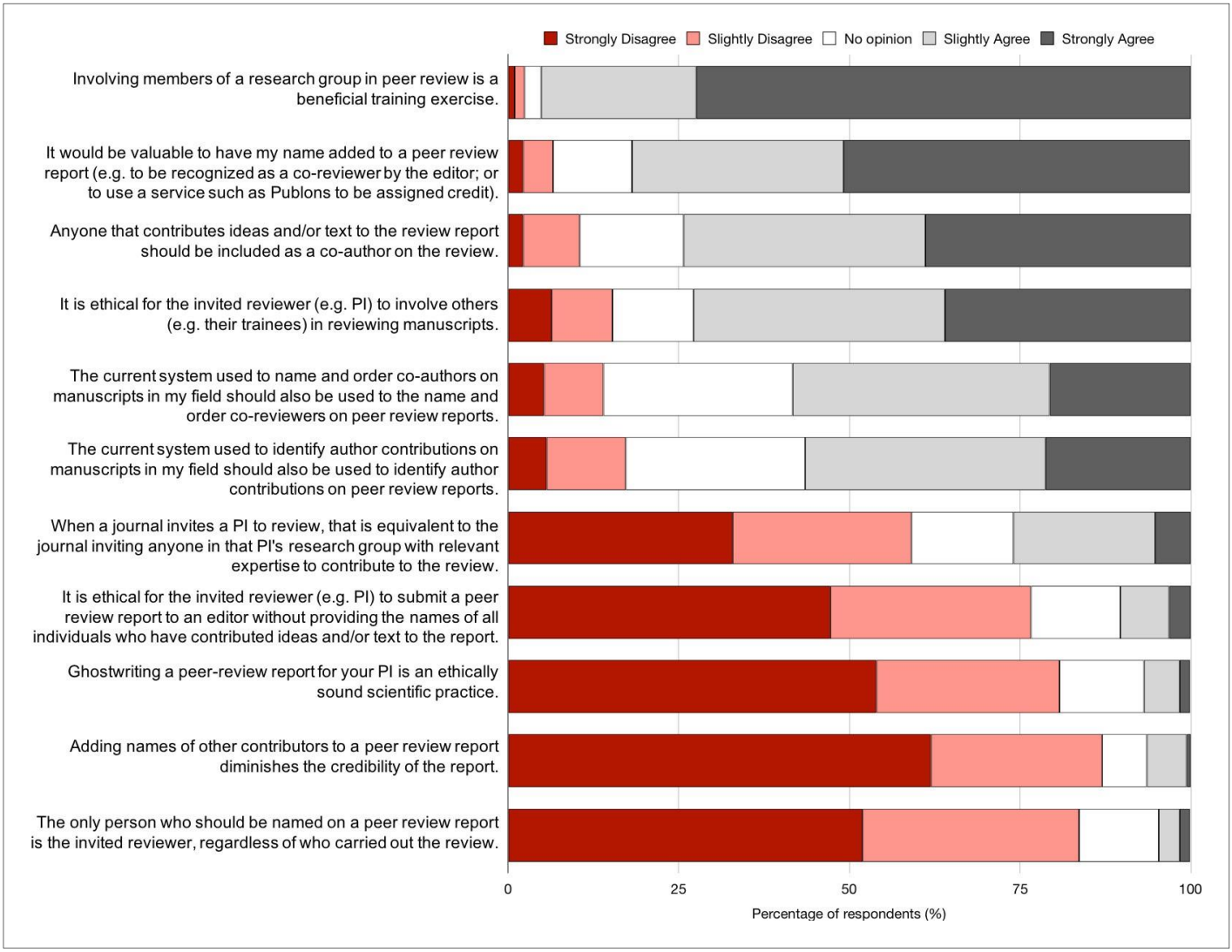

Figure 5. Views on co-review, ghostwriting, and other aspects of peer review. Responses to the question: “Please indicate how strongly you agree with the following statements.” Data represent the opinions (not experiences) of all respondents regardless of whether or not they had participated in peer review. Respondents were also provided with a textbox to submit comments to expand and/or clarify their opinions.

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The following source data is available for figure 5:

Source data 5. Opinions on co-review and ghostwriting.

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occurs. Reducing ghostwriting requires decoupling it in the zeitgeist from the beneficial training of ECRs through co-review. We therefore separate our discussion of the motivations for co-reviewing and ghostwriting in an effort to find solutions to ghostwriting that simultaneously support ECR co-reviewing as training in peer review.

Co reviewing by ECRs as valued training or delegation of scholarly labor

Survey respondents clearly find that co-reviewing by ECRs has significant benefits and is not inherently problematic when the issue of named credit is set aside. Co-review is considered an ethical (73% agree) and beneficial training exercise (95% agree), explaining why co-reviewing is the second most commonly reported source of training in peer review. These data should be weighed heavily when considering journal policies, since any policy that prevents co-reviewing

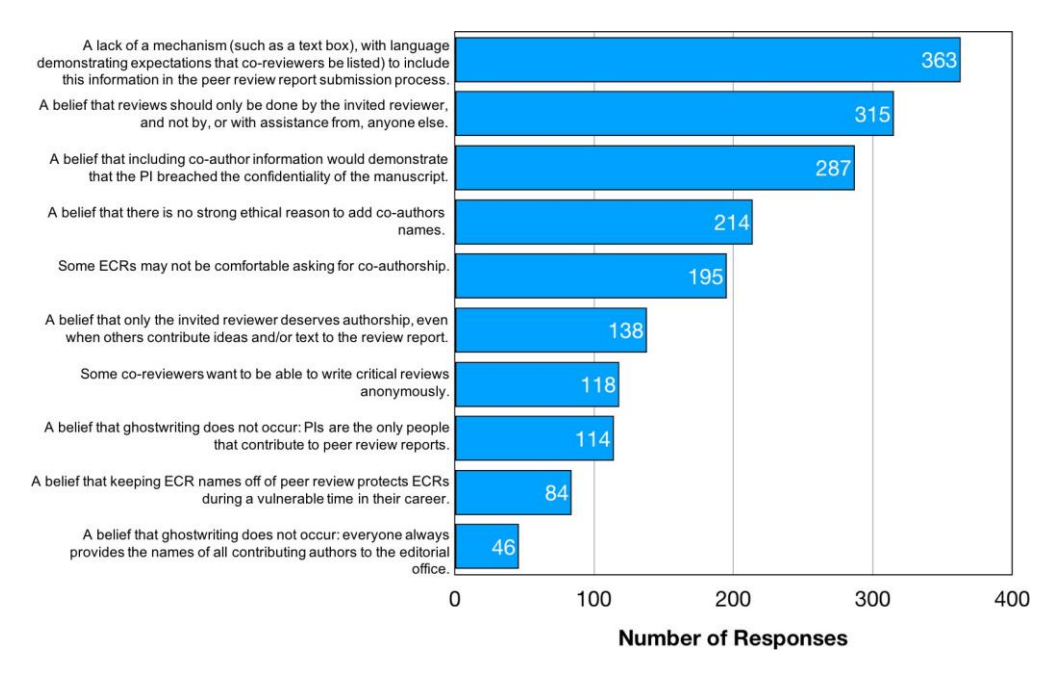

Figure 6. Reasons why journals might not know about co-reviewers. Responses to the question: "What do you think are the reasons why the names of co-authors on peer review reports may not be provided to the editorial staff?." Here our intent was to ask the respondents about the barriers that might cause names to be withheld (rather than asking whether they thought co-reviewers should be named). Respondents were able to select as many answers as they felt applied. The frequencies do not allow us to assess how important the barriers are, and respondents were not asked to rank barriers, but simply to surmise which ones they felt were relevant to the current practice of ghostwriting.

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by ECRs would remove a common and valuable training exercise in peer review. We support the adoption of policies that specifically embrace ECR co-review as training (e.g., eLife, 2019). The Transpose project is also compiling a crowd-sourced database of journal policies on peer review, co-reviewing and preprinting (*Transpose, 2019*).

"ECR training" is not a sufficient justification for co-reviewing for the half of survey respondents who have written a peer review report without any interaction with their PIs. In these cases, co-reviewing devolves into a delegation of scholarly labor that benefits the invited reviewer, often an overburdened PI in a hypercompetitive research environment (*Alberts et al., 2014*). This environment incentivizes the use of ECRs as cheap labor to fulfill productivity requirements, especially as the growth of the ECR population outpaces the growth of independent academic positions to employ them (*Heggeness et al., 2017*; *Heggeness et al., 2016*). These market forces provide a second explanation, beyond ECR training, for why co-reviewing is commonplace. Our survey respondents agree, sharing sentiments like "apparently this duty is part of my job description" (*Table 6*). The delegation of scholarly labor to ECRs is not necessarily, nor intentionally, exploitative, although it can easily become so given the power dynamics and documented lack of communication between mentors and mentees (*Van Noorden, 2018*). Any successful intervention to address concerns about the ethics of co-reviewing by ECRs must take into account that it is commonly an unstated expectation that ECRs carry out peer review on behalf of their PI, and that ECRs may not feel they have the freedom to decline even if they feel it is unethical to participate.

Limitations to depending on co-reviewing as training

Survey data suggest that training in peer review is determined by a small number of individual experiences outside of evidence-based training structures and community oversight. "Receiving reviews on my own papers" only gives a limited number of examples of how others review and is

Table 3. Statements for which the differences in the responses of the ECR and PI populations were statistically significant.
We calculated the mean degree of agreement by setting 1 as Strongly Agree through to 5 as Strongly Disagree, and 3 set as No Opinion. The higher the mean value calculated for the group, the closer the group feels to disagreeing with statement. “No opinion” responses, coded as 3, are included in these means. A 2-tailed student’s t-test for equality of the means was used to calculate p values. Due to the difference in the percentage of ECRs and PIs with "no opinion" for the third question, we removed "no opinion" responses and recalculated the mean scores: the difference between the mean scores was reduced but remained significant (ECRs: 1.57 ± 0.05 (n = 365); PIs: 1.88 ± 0.15 (n = 64); p=0.048).

Statement	ECR Mean Score	PI Mean Score	*p* value	% ECRs with no opinion	% PIs with no opinion
Involving members of a research group in peer review is a beneficial training exercise.	1.32 ± 0.03 (n = 405)	1.54 ± 0.10 (n = 81)	p=0.033	2.5	2.5
It is ethical for the invited reviewer (e.g. PI) to involve others (e.g. their trainees) in reviewing manuscripts.*	2.06 ± 0.06 (n = 406)	2.37 ± 0.14 (n = 81)	p=0.029	11	15
It would be valuable to have my name added to a peer review report (e.g. to be recognized as a co-reviewer by the editor; or to use a service such as Publons to be assigned credit).	1.71 ± 0.05 (n = 405)	2.11 ± 0.13 (n = 81)	p=0.003	10	21

*Indicates that p value was calculated assuming equal variance according to Levene’s test for Equality of Variances.
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a passive form of learning that lacks individualized or iterative feedback from a mentor. Since it is a common complaint that reviews are overly critical (*Schneiderhan, 2013*), it seems counterintuitive for this to be the main example by which ECRs learn how to review. Training provided by one’s PI may benefit from a personalized teaching relationship but depends on the PI’s own training. The resulting trickle-down training is likely to be self-reinforcing and highly variable in quality and content. The small sample size of these different personal experiences may also reinforce bias, including selection bias where one’s few experiences may not be representative of the population, memory biases where negative experiences (e.g. from receiving harsh reviews) are more readily remembered and so taught (*Kensinger, 2007*), and gender or other demographic biases currently being studied in the peer review process (*Murray et al., 2018*).

These results highlight an area of opportunity to improve and standardize training in peer review of manuscripts as a critical scholarly skill (Appendix 1). Since the top two reported forms of training involve PIs either as manuscript reviewers or ECR mentors, interventions to ensure PIs have received training in peer review and in communicating this skill to ECRs may also be appropriate. A lack of “training the trainers” was cited as a main reason for why pairing experts with new peer reviewers failed to improve review quality in one of the few randomized controlled trials of this practice (*Houry et al., 2012*). Given their key role as the main source of training in peer review, it is important that PIs make deliberate efforts to teach their trainees this skill and to provide their trainees with feedback. Mentorship from PIs may be complemented with, but not replaced by, journal clubs where ECRs gain experience in reviewing published manuscripts or preprints (see, for example *Avasthi et al., 2018* and *PREreview, 2019*). Since these ad hoc reviewing experiences with PIs and journal clubs may vary in their availability and quality, all ECRs should be offered standardized, evidence-based training in peer review. For example, peer review courses that are compulsory and ubiquitous in graduate schools would ensure that all PhD-holders are appropriately trained to perform constructive peer review.

A lack of communication about authorship of peer review reports

Even in the best case scenario for co-reviewing, when training is taking place and is effective, its benefits can still be confounded by ethical lapses such as ghostwriting. The most common explanation for ghostwriting was that authorship was simply not discussed (*Table 4*; 73% of responses from those who knew their names had been withheld). 47% of respondents have had the experience of “I read the manuscript, wrote a full report for my PI, and was no longer involved” (*Table 2*), a concerning breakdown in communication between invited reviewers and those actually writing the peer review report. At best, writing a peer review report without receiving feedback from one’s PI is a missed opportunity for training. At worst, a peer review report that is written by one person and submitted to

Table 4. Reasons given by PIs for not naming co-reviewers to the journal editor.

Responses to the question: “Consider cases where you contributed to a peer review report and you know your name was NOT provided to the editorial staff. When discussing this with your PI, what reason did they give to exclude you as a co-reviewer?” In addition to the possible answers provided by the survey, respondents were also provided with a textbox to add write-in responses.

Reasons given by PIs for not naming co-reviewers	Number of Respondents
Did not discuss with my PI	210
Co-authorship is for papers, not for peer review reports; Intellectual contribution not deemed sufficient	33
Journal requires prior approval to share manuscript, which was not obtained; Journal does not allow ECRs to review	30
Write-in answers citing mechanistic barriers (e.g. lack of a text box to enter co-reviewer names)	3

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the journal under the name of another person is a breach of academic integrity.

Power imbalances may prevent an ECR from feeling able or willing to initiate this conversation with their PI. 39% of respondents think that ghostwriting occurs because "some ECRs may not be comfortable asking for co-authorship" (*Figure 6*). As one write-in states: “you don’t want to piss off the boss.” Ghostwriting, therefore, may be a symptom of the larger problem in academia that ECRs are extremely dependent on the good will of their PI for retention in the hypercompetitive research environment (for example, for letters of recommendation throughout their career or immigration status). Another reason that authorship may not be discussed is that not naming co-reviewers is the expected status quo: “[PI] didn’t think of including me" and "they forgot" (*Table 6*). One postdoc added: “I’d never really thought about this before. I just assumed it was part of the process. But it is very time consuming and I do believe that all reviewers should receive credit for the review.” If ghostwriting arises from PIs and ECRs simply not thinking to include co-reviewer names vs. intentional withholding of names, then building awareness should encourage more conversation about this issue and better mentoring practices will help overcome such miscommunication. PIs could be further incentivized to name ECR co-reviewers by accounting for this practice when they are evaluated for grant funding or tenure. For example, perhaps PIs who pay the salaries of their trainees from grant budgets should demonstrate in grant progress reports how those ECRs are being trained, which might include a list of which trainees were listed as co-reviewers.

An expectation that co-reviewers do not deserve credit regardless of what they contribute

Ghostwriting is also driven by a cultural expectation that co-reviewers do not deserve named credit to the journal regardless of how much they contribute. 43% of ghostwriting experiences were explained by “co-authorship is for papers, not for peer review reports” or “intellectual contribution not deemed sufficient.” 28% of respondents surmise that ghostwriting occurs due to "a belief that only the invited reviewer deserves authorship, even when others contribute ideas and/or text to the review report." These rationales for ghostwriting contradict community opinion about whether this should be the case, with 83% disagreeing that “the only person who should be named on a peer review report is the invited reviewer, regardless of who carried out the review” and 74% agreeing that “anyone that contributes ideas and/or text to the review report should be included as a co-author on the review.” Ghostwriting could therefore be reduced if cultural expectations were shifted to reflect consensus opinion that co-reviewers deserve to be named to the journal.

Prohibitive journal policy is out of alignment with current practice

Many journals have policies that prevent invited reviewers from sharing manuscripts with anyone else and/or policies that prevent ECRs from serving as reviewers or co-reviewers without prior permission from the editor (*Transpose, 2019*). These policies are the other most common justification for ghostwriting. 58% of respondents surmise that ghostwriting occurs because of “a belief that including co-author information

Table 5. Reasons for why ghostwriting may occur.

Themes and supporting examples of write-in responses to the question: "What do you think are the reasons why the names of co-authors on peer review reports may not be provided to the editorial staff?"

Theme	Example write-in responses
Cultural expectations	"A belief that ghostwriting does occur, but everyone accepts that it's just the way it is."
	"The belief it has always been like this so why doubt/change the process"
	"PIs simply don't think of it because they're used do doing things this way"
	"PIs think this practice is okay."
Training	"A belief that this is 'how it is done,' and inviting trainees to contribute to reviews is important for their training, but it is not necessarily important for them to get credit for it."
	"PI feels while the ECR is being trained in doing the review should not be listed as co-author of the review."
"I don't understand it"	"Either as a reviewer or as an editor, I would have no problem with a co-review. I'm not really sure why more people don't do it. They absolutely should."
	"I have no idea why this is not common practice."

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would demonstrate that the PI breached the confidentiality of the manuscript" and 63% surmising that ghostwriting occurs because of "a belief that reviews should only be done by the invited reviewer, and not by, or with assistance from, anyone else." These policies derive from guidelines developed by the Committee on Publication Ethics (COPE): "supervisors who wish to involve their students or junior researchers in peer review must request permission from the editor and abide by the editor's decision" (*COPE Council, 2017*). Yet it seems that, in practice, invited reviewers often do not seek prior permissions, continue to involve ECR co-reviewers, and instead choose to withhold co-reviewer names upon submission. Indeed, 39% of ghostwriters who discussed with the invited reviewer the possibility of including their name cite "journal requires prior approval to share manuscript, which was not obtained" or "journal does not allow ECRs to review" as the reason why their names were withheld. In these cases, adding co-reviewer names to a peer review report is equivalent to admitting that journal policies were disobeyed. Given how frequently ghostwriting occurs based on survey data, and how commonly journal policies are cited as the reason for ghostwriting, it seems that current policies that require invited reviewers to gain permission prior to involving ECRs in peer review are not effective deterrents for ghostwriting. Instead, these policies may have the opposite, if unintended, consequence of preventing invited reviewers from feeling free to add co-reviewer names upon submission. Journals should acknowledge that peer review is often performed by ECR co-reviewers and remove barriers that prevent ECRs from being named to the editor (*Rodrı´guez-Bravo et al., 2017*).

The naming of co-reviewers would be facilitated by, for example, a mandatory text-box on the page that reviewers use to submit their review: this page could also contain language asking for co-reviewers be listed. 73% of respondents surmise that ghostwriting occurs because of a lack of such a mechanism. However, when asked to reflect on their own experiences, only 4% of ghostwriters gave this as a reason (though that might be due to a limitation in the design of this question, which did not include this answer in the drop-down menu and instead relied on respondents to write it in). Even with this consideration, these data reveal a difference between the cultural perception of this barrier (73%) and actual experience (4% or more), so any practical solutions (such as adding a text-box) must be accompanied by changes that make it clear that journals expect all co-reviewers to be named.

It is in the best interests of journals to provide mechanisms for ECR co-reviewers to be easily named (*Mehmani, 2019*). If a journal does not know who is reviewing a paper, it cannot be sure that there are no competing interests among the reviewers. Editors may also see an increase in accepted invitations to review once PIs feel free to share the burden of reviewing with their trainees without ethical concerns.

Table 6. Reasons given by PI for withholding ECR name.

Themes and supporting examples of write-in responses to the question: "Consider cases where you contributed to a peer review report and you know your name was NOT provided to the editorial staff. When discussing this with your PI, what reason did they give to exclude you as a co-reviewer?".

Theme	Example write-in response
Sin of omission	"They forgot"
	"Didn't think of including me; didn't know how to do so"
	"He was in a hurry and he couldn't figure out the journal's website"
Cultural expectations	"This was not explicitly discussed, but the PI implied this is "common practice" and normal for ECRs to gain experience"
	"[PI] said only [they] would be invited to review for such a prestigious journal and "we" need this for future submissions"
	"Apparently this duty is part of my job description"
	"I was told this is how one gets to train to review papers and grants"
A good way to train	"Reviewing papers as [an] ECR is part of the ECR training"
	"It's good experience for me."
	"It was good for my career to practice."

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Journals would also benefit from enlarged reviewer pools by including previous ECR co-reviewers and/or consulting existing lists of ECR reviewers (*Burgess, 2018*). Ultimately, journals are responsible for ensuring that all aspects of peer review are fair and ethical. Ghostwriting is neither fair nor ethical, so the evidence for ghostwriting reported here suggests that journals need to update their policies in this area.

Value judgments about naming co-reviewers

Two hypotheses for why ghostwriting is commonplace were refuted by our data. 82% of respondents disagree that there is no benefit in naming co-reviewers. Co-reviewers, especially ECRs, may value having their name provided to the journal for many reasons, including the ability to be "known" to scientific editors and potential colleagues; the ability to have their work acknowledged by a third party (e.g. Publons) for career advancement; and/or the ability to demonstrate eligibility for residency or visas. ECRs agree more strongly than PIs that there is value in receiving credit or being known to the journal editorial staff as a co-reviewer (*Table 3*), perhaps because invited reviewers are already known as experts in their field. In the words of one write-in response: "PI surprised I would be interested in being acknowledged, and seemed like too much trouble to acknowledge my contribution. There was no box in the online form to declare it." The ambivalence of PIs towards giving due credit for co-reviewers likely derives from a position of relative privilege. When people of privilege are the only participants in decision-making (for example, on journal editorial boards), they may create policies that fail to consider differing values of less privileged members of the community, like ECRs. We support the growing effort to include more diverse voices in leadership roles in science (such as the "Who's on board" initiative of Future of Research, and the Early-Career Advisory Group at *eLife*).

87% of respondents disagree that ghostwriting occurs because researchers see value in withholding co-reviewer names, perhaps because of a perception that adding co-reviewer names diminishes the review by providing evidence that someone other than the invited reviewer contributed. These data align with results of an ongoing experiment in co-reviewing at the Elsevier journals, in which editors did not rate the co-reviewed reports as low quality, and more than half were considering co-reviewers to serve as invited reviewers on future manuscripts (*Mehmani, 2019*). Research suggests that reviewers who are earlier in their careers may be perceived by editors as better reviewers (*Black et al., 1998*; *Callaham and Tercier, 2007*; *Evans et al., 1993*) and that being closer to bench research, rather than having more experience in reviewing itself, may be a key determinant of this trait (*Stossel, 1985*). Another reason for a perceived value in withholding co-reviewers names is to protect ECRs during a vulnerable time in their careers.

Occasional write-in comments allude to this: "[being named on a peer review report] may give certain ECRs a bad reputation if they review things really harshly" but, on the whole, only 17% of respondents believe protectionism drives ghostwriting. Taken together, respondents find added value in naming co-reviewers and also see no loss of value to peer review when co-reviewer names are added. Finally, the null hypothesis that "a belief that ghostwriting does not occur" was selected least frequently by respondents, demonstrating that ignorance or denial that ghostwriting occurs is rare (*Figure 6*).

Conclusions

Ghostwriting undermines the integrity of peer review. It is pervasive because many see it as an obligatory feature of peer review training or a necessary delegation of labor. Some don't think to discuss or feel able to discuss authorship on peer review reports. Others are deterred by vague journal policies that do not reflect the status quo – that involving ECRs as co-reviewers is common and considered valuable and ethical. To encourage naming co-reviewers to the editors, journals must clarify their expectations and reporting mechanisms for the participation of ECRs in peer review. These logistical changes should be coupled with an adjustment of cultural expectations for co-review as a training exercise and not exploitation. At a minimum, invited reviewers should discuss with co-reviewers how credit will be given for peer review work. Ideally, they should also ensure that co-review involves feedback so that it is effective training. Changing journal policies and cultural expectations to recognize and value the work of ECRs will benefit the peer review system and all of its constituents.

Methods

Systematic literature review

Search procedures

The following procedures were used to perform a systematic review of the peer-reviewed literature for any research on the topic of ECR participation in manuscript peer review. These procedures were developed under the guidance of a professional librarian (author SO) and were based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria (*PRISMA Group et al., 2009*; *Figure 1—figure supplement 1*). The databases that were searched cover peer-reviewed literature across the life sciences, public policy and social sciences and were comprised of: PubMed, PsychInfo, Web of Science, and PAIS International. These databases were then searched using the following keyword search strategy: ("early career researcher" OR "graduate student" OR "post-doc" OR "fellow" OR "contingent faculty" OR "adjunct" OR "lecturer" OR "instructor" OR "technician" OR "junior scientist" OR "trainee" OR "lab member" OR "research scientist" OR "postdoctoral fellow" OR "research fellow" OR "teaching fellow" OR "junior researcher" OR "mentee") AND ("peer review" OR "refereeing" OR "invited reviewer" OR "referee" OR "reviewer" OR "co-reviewer" OR "first time reviewers" OR "reviewer training" OR "review partners" OR "contributing author" OR "co-reviewing" OR "reviewing" OR "journal reviewer policy" OR "reviewer guidelines" OR "instructions for reviewers"). These search terms were designed to be broadly inclusive so as to capture any research article with possible relevance to the topic of ECR involvement in manuscript peer review. The resulting collection of 2103 records were imported into the RefWorks 3 bibliographic management database, and duplicate articles were identified and removed using the "Legacy close match" de-duplication filter, resulting in a de-duplicated set of 1952 articles.

Relevance screening

Collected articles underwent two rounds of relevance screening. In the initial round, article titles and abstracts were screened independently by two study authors (JG and GM). Both authors used the same inclusion criteria to sort search results into "relevant," "maybe relevant," and "not relevant" categories. The criteria for article inclusion were: written in English, published in a peer-reviewed journal, mention of ECRs, and mention of peer reviews of manuscripts. Any article that did not meet the inclusion criteria above was excluded as well as database hits for conference proceedings and dissertations.

118 unique articles remained in the "relevant" and/or "maybe relevant" categories at this stage of screening (*Supplementary file 1*). Articles categorized as "relevant" by both initial screeners were selected for full text review (n = 3). Articles categorized as "maybe relevant" by both initial screeners and articles that were differentially categorized as "relevant" vs. "maybe relevant" or "not relevant" by the initial screeners (n = 51) underwent a second round of evaluation by a third, independent screener (author RL) to either confirm categorization as

"relevant" or recategorize as "not relevant" to the topic of ECR participation in the peer review of manuscripts. A resulting list of 36 "relevant" articles underwent a full text reading with specific attention being paid to: research question, motivation for article, method of study including details concerning study participants, relevant results and discussions, discussion of peer review and ECRs, and possible motivations for author bias. Of the articles that were found to be "not relevant" to the topic of ECR participation in the peer review of manuscripts for publication in a journal, most discussed other forms of peer review outside the scope of publishing manuscripts (e.g. students engaging in peer review of each others written work in a classroom setting as a pedagogical exercise).

Survey of peer review experiences and attitudes

Survey design

We designed a survey to evaluate the peer review experiences of researchers with a specific focus on ghostwriting of peer review reports. The survey was verified by the Mount Holyoke Institutional Review Board as Exempt from human subjects research according to 45CFR46.101(b)(2): Anonymous Surveys - No Risk on 08/21/2018. All survey respondents provided their informed consent prior to participating in the survey. The survey comprised 16 questions presented to participants in the following fixed order:

- 6 demographic questions that collected data on their professional status (current institution, field of research, and career stage) and personal information (gender identity, race/ethnicity, and citizenship status in the United States);
- 7 questions that collected data about their experience participating in the peer review of manuscripts for publication in a journal: these questions included 2 questions about their experience with independent reviewing vs. co-reviewing; 4 questions about receiving credit for reviewing activities; and 1 question about whether and how respondents received training in peer review
- 3 questions that collected data about their opinions about co-reviewing and ghostwriting as practices, regardless of whether they had personal experience with these practices: these questions included 1 question about their degree of agreement on a 5-point Likert scale (*Strongly Disagree; Slightly Disagree; No Opinion; Slightly Agree; Strongly Agree*) with 11 statements about the ethics and value of co-reviewing and ghostwriting; 1 question asking their opinion about why ghostwriting as a practice may occur; and 1 exploratory future direction question asking if their opinions would change if the names of peer-reviewers were made publically available ("open peer review").

Throughout the survey, there were many opportunities to provide write-in responses in addition to the multiple choice answers. The full text of the survey can be found in the *Supplementary file 2*.

Survey distribution, limitations, and future directions

The survey was distributed online through channels available to the nonprofit organization Future of Research including via blog posts (*McDowell and Lijek, 2018*), email lists, social media, and word-of-mouth through colleagues. The main survey data collection effort was from August 23 to September 23, 2018. The survey had gathered 498 responses at the time of data analysis.

We recognize that conclusions drawn from any survey data are limited by the size and sample of the population that is captured by the survey. We sought to address this limitation first by collecting as large and geographically and institutionally diverse of a population of ECRs as possible within the month-long timeframe we set for data collection. Secondly, we wished to preemptively address the concern that our survey distribution efforts were inherently biased towards those with strong opinions on the subject and/or those who self-select to receive communication from Future of Research (e.g. listservs, Twitter followers). We therefore attempted to create a "negative control" comparison group of participants who received our survey from channels independent of Future of Research. We created a separate survey form asking identical questions and personally asked 25+ PIs known to the authors, as well as organizational collectives of PIs, to distribute this survey link to their own networks (e.g. lab members, departments). Both surveys were live during the same month-long time period; however, the PI-distributed survey gathered only 12 responses and so was not sufficient to be used in the analyses presented here. Since the goal of the second, PI-distributed survey was to be independently distributed outside of our efforts, we

are not able to determine whether it garnered so few responses because of a lack of genuine distribution or because the populations it reached were not motivated to participate in the survey. Therefore any conclusions drawn from this study reflect the 498 experiences and perspectives of those individuals so moved to participate in the survey distributed by Future of Research and our results should be considered in this context. One possible future direction for this study is to reopen the survey in conjunction with publication of this manuscript in an effort to broaden and diversify the sampled population, to compare subsequent rounds of responses to our initial 498 responses, and to improve clarity on survey questions (Appendix 2).

Survey data analysis

Survey data were analyzed using Microsoft Excel, Version 16 and IBM SPSS Statistics for Macintosh, Version 25 (SPSS Inc, Chicago, IL, USA). Whenever statistical analyses were used, the exact tests and p values are reported in the appropriate figure legend and/or results text. A p value of less than 0.05 was considered significant.

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Additional files

Supplementary files

- Supplementary file 1. Results of relevance screening for literature review.
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- Supplementary file 2. Text of The Role of Early Career Researchers in Peer Review – Survey.
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- Transparent reporting form DOI: https://doi.org/10.7554/eLife.48425.019

Data availability

Literature review results are shared in supplementary materials; De-identified source data for Figures 1 and 5 have been provided in response to editorial request. Raw data from the survey are not shared to protect respondents' confidentiality.

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Appendix 1

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Literature on ECR involvement in peer review as a training exercise and examples of formalized training in peer review

Many of the articles uncovered by our systematic literature review on the topic of ECR involvement in peer review of manuscripts that *did not* address our desired topic of ghostwriting instead discussed ECR involvement in peer review of manuscripts as a training exercise for the ECR. Here, we summarize their findings. We also give some examples of formalized training in peer review.

Peer review training programs with positive outcomes

Trends from the literature indicate several components of a successful peer review training program and where such programs are currently in process. Authors studying the peer review training process for new reviewers tend to conclude that students of peer review learn best by participating themselves in the review process while receiving feedback from more senior reviewers. Successful training programs, in which the reviewers expressed that they had benefited from the training or were evaluated and determined to have benefited from the training, tended to include participation in several rounds of review followed by feedback and revising. Additionally, successful programs often expanded feedback by directing the expert reviewers to report on the same manuscripts as the trainees. This method provided trainees with specific written feedback as well as a pertinent example report to reference. Authors of successful program studies and authors with general policy recommendations for peer review training strategies conclude that a hands-on, iterative process of peer review training with regular and specific feedback are components which positively benefit the peer review trainee (*Castelló et al., 2017*; *Doran et al., 2014*).

Peer review training programs without positive outcomes

However, one reviewer training study in the pool generated negative results: Houry, Green and Callaham found that after a period of training involving mentorship from an expert reviewer to a new reviewer, no differences in mean reviewer quality scores between the mentored and unmentored groups was found (*Houry et al., 2012*). The study goes on to conclude that this similarity in group quality scores is dependent on the mentoring relationship: the expert reviewer mentors were not given any training on how to offer feedback to the trainees. This aspect of the program was deliberately constructed in an attempt to model a training program in which there would be minimal stress on the expert mentors. However, it appears that this ultimately led to an inconsequential training program. Accounting for this information, Houry et al. conclude that a mentorship program should include training and guidelines for mentor-mentee communications which allow for regular feedback from expert to trainee.

Institutions where peer review training takes place

Sources mentioned two primary institutions where training in peer review may take place. Training institutions were identified, with undergraduate education as the first opportunity for training, followed by graduate programs. Journals were the other institutions identified. The majority of training programs represented in the sources take place within a journal setting. Journal programs tend to include ECRs, such as undergraduate or graduate students, joining the editorial board for a set time period or acting as a reviewer (*Castelló et al., 2017*; *Doran et al., 2014*; *Harrison, 2009*; *Houry et al., 2012*; *Navalta and Lyons, 2010*; *Patterson and Schekman, 2018*; *Picciotto, 2018*).

Training may also take place within undergraduate or graduate institutions. We found one study about training in peer review in an undergraduate setting. Despite the lack of associated literature, Riehle and Hensley determined that undergraduate students are interested in learning about the peer review process (*Riehle and Hensley, 2017*). In a training study, the Calibrated Peer Review system was employed in two undergraduate classes to facilitate students to peer review the work of their classmates while minimizing the extra workload such an exercise might otherwise entail for the professor (*Prichard, 2005*). The participating students were in two separate courses, an introductory neuroscience course and a more advanced neuroscience course. Students in the advanced class did not perform better on peer review exercises than the introductory students, suggesting that until that point, advanced students had not been exposed productively to peer review practice. Authors deemed this to be a successful method for exposing undergraduate students to the peer review process while requiring a realistic time commitment from the course instructor.

While no papers were found detailing the effectiveness of peer review training within graduate institutions, several sources did indicate graduate student perceptions about their program peer review training. In a study including psychology masters and PhD students, a large proportion of participants indicated that their education had lacked in providing information on the peer review and revision process as well as information about how to practice review (*Doran et al., 2014*). These students indicate that this was a negative aspect of their programs, saying more opportunities for peer review practice should be made available. Authors of this article do indicate that this information may not be generalizable to graduate students as a group because the participating students were found when they pursued a journal review program, something students with adequate peer review education may not be likely to do.

Self facilitated training

Merry et al. provides a list of recommendations for ECRs to facilitate their own training of peer review (*Merry et al., 2017*). Authors advise working with the mentoring faculty as well as contacting journals directly to seek out peer review opportunities. If mentors are able to give consistent feedback regarding the trainees peer review, it seems that this could be a positive environment in which to learn the skill.

Roadblocks to positive outcomes in training programs

Papers discussing journal training programs cite feasibility as the largest roadblock to success (*Castelló et al., 2017*; *Houry et al., 2012*). As discussed, it is recommended that peer review training programs for ECRs feature a system which provides regular, specific feedback from expert reviewers. Such programs require high levels of labor, involving organization and time commitment from program leaders and expert reviewers. This is a significant investment for a business which may be in conflict with the desire to maximize journal profit. One possible solution presented involves student-run journals hiring increased numbers of student reviewers and editors so experience may be gained in the field (*Doran et al., 2014*; *Patterson and Schekman, 2018*). However, this solution does not address the recommendation for expert reviewers to provide feedback.

Examples of formalized training in peer review

Some graduate programs, scientific societies and journals already provide materials for training in peer review. For example, the American Chemical Society provides a free course designed by editors, researchers and publication staff (acsreviewerlab.org). GENETICS, a journal published by the Genetics Society of America, provides a peer review training program with virtual training sessions for ECR members (genetics-gsa.org/careers/training_program.shtml). Nature also provides an online course on peer review (masterclasses.nature.com/courses/205). Publons (which provides a mechanism for recording and crediting peer review

activity) has an online peer review academy (publons.com/community/academy/). The Journal of Young Investigators provides training at the undergraduate level (jyi.org).

We also found a number of examples of courses and classes that train graduate students in peer review. These include: a class run by Needhi Bhalla at the University of California Santa Cruz; Class 230 in the PhD Program in Biological and Biomedical Sciences at Harvard; a class on critiquing papers at University of California San Diego; a class in the graduate program in Systems Biology at Harvard Medical School; and a requirement to review a paper as a final exam recently introduced at the Graduate Field of Biochemistry, Molecular, and Cell Biology at Cornell University. The University of Texas Southwestern is experimenting with an advanced course combining peer review, literature review, debate and commentary communication and lay-audience oriented writing. A number of journal clubs also review preprints and send comments to authors (*Avasthi et al., 2018*).

Appendix 2

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Future directions for survey questions

Opinions on open peer review reports and public naming of reviewers

The final (16th) question of the survey provided respondents with an open comment box in which to reflect on whether any of their opinions would change if either the *contents* of peer review reports or the *names of reviewers* were openly published to journal readership. This question is a stark contrast to the rest of the survey questions, all of which instead only ask about naming co-reviewers to the journal staff and editors but not openly to the public readership. We included this question as a test balloon for future surveys that might focus on open peer review vs. traditional models of closed peer review. Due to its tangential relationship to the goals of the current study on ghostwriting and due to the question's open-ended, write-in nature, we did not perform a systematic analysis of responses as with the other questions. A qualitative summary of responses is below.

61% of respondents chose to write a response to this question, and of these approximately one third reported that no, their opinions would not change if the peer review reports nor names of reviewers were openly shared with the public readership (it should be noted that these comments mostly, but not necessarily, endorsed the specific open peer review features suggested in the question). The remaining respondents expressed a variety of concerns, mostly surrounding the loss of anonymity of reviewers rather than what appeared to be the less controversial concept of publishing the contents of peer review reports. Respondents' hesitations about anonymity often centered on the effect that naming ECRs and URMs might have on these vulnerable populations. These responses reflect other conversations about open peer review (*Polka et al., 2018*; *Ross-Hellauer, 2017*; *Ross-Hellauer et al., 2017*; *Tennant, 2017*) and in the context of recent data about referee behavior in open peer review (*Bravo et al., 2019*) warrant further analysis beyond the scope of this manuscript.

Improving clarity in survey questions

One survey question that would benefit from disambiguation in future iterations of the survey is: "Agree/Disagree: When a journal invites a PI to review, that is equivalent to the journal inviting anyone in that PI's research group with relevant expertise to contribute to the review." It was brought to our attention by respondents' emails and write-in comments during the survey response period that there was confusion about this statement. We had hypothesized that we might find agreement with the statement; however, we found a substantial amount of disagreement which may be due in part to the various ways the question may have been interpreted. Our intention was to determine if respondents agreed that, in practice, it could be reasonable for all engaged in journal publication and peer review to expect that an invited reviewer would have various motivations to share a manuscript with the relevant expertise in their research group, particularly in cases where a postdoc is likely more familiar with the literature or experimental techniques than a Principal Investigator overseeing a number of projects. However it became apparent that this question was quite open to various interpretations as described in write-in comments received on the question, including:

- Does the respondent believe this *should* be the case?
- Does the respondent believe this is what is *actually happening*?
- Does the respondent consider that journals have this intent when they invite reviewers?

This therefore renders interpretation of responses to this question difficult, and so we chose not to draw conclusions from this particular result. We aim to clarify this question should there be future iterations of this survey.

Another survey question that would benefit from future disambiguation draws from respondents' ability to select multiple responses for the question "When you were not the

invited reviewer, what was the extent of your involvement in the peer review process? Please select all that apply to your entire peer review experience (e.g. across multiple manuscripts)." and indeed the inability to discern whether respondents supplying only one answer were selecting that response because that comprised the totality of their experiences, or because they selected the most common experience. In comparing responses to this question with other questions, it may be that there are analyses that are affected by the assumption that it is possible to apply one response of many to a response to another question. We attempted to preemptively disambiguate responses by asking whether respondents had "ever" experienced certain things in subsequent questions.

How to bring peer review ghostwriters out of the dark

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ABSTRACT Early career researchers are frequent and valuable contributors to peer review. Systemic changes that acknowledge this fact would result in ethical co-reviewing, peer reviews of greater quality, and a reduction in peer reviewer burden.

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INTRODUCTION

In February 2018, academic researchers, funders, editors, and publishers met to discuss Transparency, Recognition, and Innovation in Peer Review in the Life Sciences (https://asapbio.org/peer-review/summary; Polka *et al*., 2018). Crucially, conference organizers also invited early career researchers (ECRs, such as graduate students and postdocs) to participate, including ourselves (G.S.M., then Executive Director of the Future of Research and R.S.L., then Chair of the Harvard Medical Postdoctoral Association). Meeting attendees heard from the Early Career Advisory Group at eLife, whose survey data showed that most ECRs had carried out peer review with no assistance from their supervisor, and the most common source of "training" was reading reviews of their own papers, not mentoring from their supervisors (Inside eLIFE, 2018).

To ECRs such as ourselves, this was of no surprise. These data aligned with our personal experiences and those of the thousands of ECRs we represented in our leadership roles. One of us had written a commentary prior to the meeting on this exact issue—that ECRs commonly "ghostwrite" reviews at the behest of their supervisors by reading the manuscript, writing the peer review report, and passing that back to their supervisor, who submits it under their name with or without edits or feedback to the ECR (McDowell, 2018). But this was apparently a revelation for many senior academics in the room, who interrupted the presentation to insist that this couldn't possibly happen.

In that moment, we were struck by the stark generational divide between who is perceived to be carrying out peer review and who is actually carrying it out. We resolved to directly enumerate researchers' experiences with and opinions of ghostwriting in peer review (McDowell *et al*., 2019a). Our study of 498 researchers, mostly postdocs in the life sciences, found three-fourths had co-authored a peer review report when they were not the invited reviewer (co-reviewed) and half had done so without being named to the journal editor (ghostwritten). These high rates of ECR participation in peer review were corroborated by a second international survey that found three-fourths of 1600 ECRs had experience responding to peer review (Jamali *et al*., 2019).

ECR participation in peer review is apparently the norm—so is that a problem? Current policies that attempt to keep manuscripts only in the hands of invited reviewers are clearly ineffectual. They are also out of alignment with the opinions of the research community, a majority of whom fnd co-review to be a benefcial training exercise (95%) and naming co-reviewers to editors to be valuable (82%) (McDowell *et al*., 2019a). Instead, we believe that supporting ethical co-review by ECRs is possible and pragmatic. It requires 1) aligning journal policy with current practice and opinion, 2) building expectations for co-review into routine conversation, and 3) standardizing training in peer review. Here we summarize specifc recommendations for systemic change to reduce ghostwriting in peer review

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Abbreviations used: ECR, early career researcher; PI, principal investigator.

FIGURE 1: Recommendations for how all key stakeholders can ensure the inclusion, training, and recognition of ECRs' scholarship in manuscript peer review (icons made by Pause08 from www.faticon.com).

which can be driven by all stakeholders—ECRs, invited reviewers, journals, and training institutions (Figure 1). We describe how adopting these common sense measures will benefit all parties and peer review (Figure 2). We also highlight key components of journal policy required to address co-review and ghostwriting by ECRs (Table 1 and Figure 3).

RECOMMENDATIONS: HOW TO NAME AND TRAIN CO-REVIEWERS

1. Align journal policy with current practice and community opinion

Peer review policies in general are not transparent. Confusion about whether ECRs are allowed to contribute is as much a driver of ghostwriting as outright bans (McDowell *et al*., 2019a). Many journals have policies that allow only invited reviewers to have access to the manuscript and perform the review (Klebel *et al*., 2020). ECR participation is discouraged through specifc language, or more often by failing to address ECRs and/or co-reviewing in written policies: a recent analysis of policies at 171 academic journals found that three-fourths did not clearly state whether co-reviewing was allowed (Klebel *et al*., 2020). Some journals use language closely aligned with the Peer Review Guidelines of the Committee on Publication Ethics (Committee on Publication Ethics, 2019; emphasis added below):

> "Do not involve anyone else in the review of a manuscript (including ECRs you are mentoring), without **frst obtaining permission** from the journal…The names of any individuals who have helped with the review should be included so that they are associated with the manuscript in the journal's records and can also receive due recognition for their efforts."

While this could be interpreted (and may be intended) to mean that co-reviews are welcome after prior approval, in reality prior approval is rarely requested. As a result, this language dissuades invited reviewers who have involved co-reviewers without prior approval from *acknowledging* that manuscripts have been shared. Thirty-nine percent of ghostwriters who *asked for authorship* were denied by the invited reviewer because "journal requires prior approval to share manuscript, which was not obtained" or "journal does not allow ECRs to review" (McDowell *et al*., 2019a).

New policies could favor transparency with explicit statements in reviewer guidelines and invitation letters that address the reality that co-reviewing occurs (even providing statements of support for the practice) over prohibitive language about sharing the manuscript (see example text in Table 1). It is not technologically trivial for journals to enforce that the manuscript is viewed only by the invited reviewer. Instead, it would be benefcial to accept, and assume, that co-reviewing will occur and create mechanisms to prevent ghostwriting, such as asking reviewers to answer "Who else contributed to this review with you?" or to confrm explicitly that the review was performed alone (Figure 3). This also ensures that the journal is not liable for any potential conficts of interest arising from the inclusion of unknown reviewers, a concern expressed recently by journal editors (Hamilton *et al*., 2020). Journals might even consider enacting policies that recategorize the ECR as the primary reviewer in their databases and the originally invited reviewer as the co-reviewer. This would bring the ECR to the editor's attention and make it more likely for the ECR to be invited as an independent reviewer on future manuscripts. Some individual journals are making these changes already (e.g., F1000Research; Fatone *et al*., 2020) and more might follow should COPE lead the way on aligning policy with current practice and opinion (Table 1).

2. Build awareness and discussion of co-review into routine conversation

Policy changes at journals must be accompanied by cultural shifts that normalize open discussion about co-reviewing. Co-reviewing by ECRs is commonplace and should be acknowledged as such. A lack of communication about this topic is still the norm and often the reason why co-reviewer names are not provided to the journal: 73% of co-reviewers reported that authorship was not discussed with the invited reviewer (McDowell *et al*., 2019a). As the mentor and expert invited by the journal, principal investigators (PIs) should initiate discussions with ECRs about peer review co-authorship and journal policies on confdentiality and conflict of interest (Figure 3). These should be routine conversations that accompany the handoff of the manuscript under review and the return of the peer review report. Editors should include discussion of co-review in their letters to invited reviewers, highlighting the journal's policy and providing clear instructions for how to ethically involve and name co-reviewers. These instructions might also prompt invited reviewers to discuss review authorship with the ECR and share feedback with them for training purposes. Figure 3 provides

Topic	Question	Example text
ECR status	Are graduate/medical students and/or postdocs allowed to participate in peer review? As invited reviewers? As co-reviewers with their PI?	"We recognize that invited reviewers may wish to involve their trainees in peer review. PhD/MD students and postdocs may participate in mentored co-review with an invited reviewer. Postdocs may also serve as independent invited reviewers."
Training in peer review	Are invited reviewers allowed to involve co-reviewers for the purpose of training? If so, how? May they contribute to the report? Should their names be disclosed to the editor and how? Are they subject to policies on manuscript confdentiality and confict of interest?	"Manuscripts may be shared with trainees of the invited reviewer for co-reviewing and/or training purposes and these ECRs may contribute text and/or ideas to the peer review report. If this occurs, the invited reviewer must disclose co-reviewer names to the editorial staff at the time of submission. All parties, including the invited reviewer and their designated trainees, must uphold the confdentiality of the manuscript and be free of conficts of interest."
Delegation of labor	If an invited reviewer wants their trainee to perform the review instead of them, what should they do?	"If you would like to recommend that your qualifed trainee performs the review in your place, please decline the invitation and provide their name and contact information for the editor [textbox]."

TABLE 1: Essential questions that journal policy should overtly address to bring ECR ghostwriters out of the dark.

an example of a co-reviewing workfow that could be posted in publicly available reviewer guidelines and shared in the invitation letter to guide invited reviewers through the journal's expectations for ethical involvement of ECRs in peer review. Once editors and PIs incorporate a discussion of co-reviewing into common practice, ECRs may feel more free to ask their PIs to share their names with the editors and to provide constructive feedback on their work.

Summary: How to Name Co-reviewers

Journals and COPE

- State clear policies that acknowledge and preferably embrace co-review by ECRs.
- Remove prior approval barriers to naming co-reviewers.
- Create unambiguous expectations and mechanisms (ex. text boxes in report submission system) to share co-reviewer names with the editor.

PIs

- Discuss co-review ethics with ECRs and editors throughout review process.
- Provide journal with co-reviewer names whether prompted or not.

ECRs

- Ask your PI to provide your name to the editor when submitting peer review reports.

Editors

- Discuss co-review policies routinely with invited reviewers to normalize expectations.

3. Improve and standardize training in peer review

Ghostwriting is often rationalized as acceptable because it is falsely equated with training (McDowell *et al*., 2019a). However, training is not a suffcient justifcation for the 39% of ECRs that report the experience "I read the manuscript, wrote a full report for my PI, and was no longer involved" (Inside eLIFE, 2018; McDowell *et al*., 2019a). When (unnamed) ECRs write peer review reports on behalf of an invited reviewer without feedback from that expert, it is exploitation, not education. Moreover, naming co-reviewers to a journal editor does not undermine training, no more than naming co-authors on an article undermines training in writing manuscripts. Therefore, the delegation of labor to ECRs without feedback or acknowledgement must be considered separately from true mentored co-review, which should be celebrated as a valuable teaching tool.

For co-review to be effective training, PIs must constructively critique their supervisees' work. Iterative feedback from "expert" to "new" reviewers leads to positive outcomes as measured by reviewers' beliefs and objective evaluations of review quality (Doran *et al*., 2014; Castelló *et al*., 2017). One effective pedagogical approach asked PIs to write a peer review report on a manuscript in parallel with their trainee, thereby creating an example that could be used for comparison to the trainees' report (Castelló *et al*., 2017). Quality feedback is critical: when expert reviewers are not well trained in how to provide feedback, pairing experts with novice reviewers is not suffcient to improve review quality (Houry *et al*., 2012). In that randomized control trial, experts were not trained in how to teach peer review to minimize burden and encourage their participation in the program. This speaks to the underlying problem that PIs are already overburdened by a hypercompetitive research environment that lacks concrete incentives to engage in time-consuming, quality mentorship. Structural reforms that incentivize PIs to name co-reviewers, as described above, would beneft from also including expectations that co-review be an interactive pedagogical exercise.

Peer review is integral to research and so teaching peer review should be integral to researchers' education. Graduate schools should ensure "Peer Review 101" is taught as one of the essential components of training in the sciences. Redirecting this responsibility from individual PIs to training programs allows for the implementation of standardized, evidence-based pedagogy that is subject to community oversight. This type of intervention is badly needed given that the most common form of "training" is reading reviews on one's own manuscripts (McDowell *et al*., 2019a), which is limited in scope, subject to bias, and likely to perpetuate the current trend toward overcritical reports (Schneiderhan, 2013). Many graduate programs already hold journal clubs that could be converted into peer review courses if ECRs also read peer review reports, write their own, and receive individualized, iterative, constructive criticism by experienced reviewers (some examples

are detailed under "Examples of formalized training in peer review" in McDowell *et al*., 2019b). Scientifc societies and journals could set discipline-specifc standards, distribute exemplar review reports or templates and offer peer review training. Indeed, some society journals are already flling the void left by graduate education by creating their own reviewer training (e.g., Genetics Society of America; Johnston, 2017; American Chemical Society [acsreviewerlab.org]). This benefts ECRs and the journal by creating a sustainable method for recruitment of new, qualifed reviewers and society members.

Coursework in peer review should lay the groundwork to support, not replace, individualized training from a PI through co-review. It would also make peer review training equally accessible to all ECRs, rather than a privilege available only to those with PIs providing quality mentorship. This would create an important safety net to ensure that all PhDs have been suffciently trained to perform thorough and fair peer review.

Summary: How to Train Co-reviewers

PIs

- Constructively critique your co-reviewer's work so they can learn from it.
- Provide your co-reviewer with previous or side-by-side examples of your reviews.
- Keep a record of your trainees that have co-reviewed as evidence of your mentorship.

ECRs

- Ask your PI for feedback on your peer review work and examples of their work.

Graduate programs

- Teach courses in peer review to all students using evidenced-based pedagogy.

Journals and scientifc societies

- Set discipline-specifc expectations for peer review content and tone.
- Distribute exemplar review reports or templates.
- Offer peer review training.

OUTCOMES: BRINGING GHOSTWRITERS OUT OF THE DARK BENEFITS EVERYONE

Increased review acceptance rates and diversity in the reviewer pool. Enacting policies and adopting behaviors that acknowledge and encourage credited co-review have practical benefts to all parties (Figure 2). Journal editors take care to assign reviewers based on their expertise and to prevent conficts of interest. This effort is wasted when ghostwriting obscures who is performing the peer review and how well. By encouraging co-reviewing, more invited reviewers may have the capacity to accept invitations (Mehmani, 2019). Including and naming ECRs in peer review will also increase the reviewer pool, ameliorating concerns about reviewer burnout (Kovanis *et al*., 2016). It will also diversify the reviewer pool, since most of the diversity of the academic population is concentrated in early career positions (Gibbs *et al*., 2016). These measures will address growing calls to tackle the lack of diversity (e.g., gender bias; Hagan *et al*., 2020) at all levels of the publication process (Day *et al*., 2020; Royal Society of Chemistry, 2020; Seery, 2020) including peer review and which has been exacerbated by the COVID-19 pandemic (Squazzoni *et al*., 2020).

Increased peer review quality. The participation of co-reviewers across career stages will also enrich peer review and the subsequent standard of published research (McDowell and Lijek, 2020), especially if deliberate training courses are provided in graduate education. Predictors of good review quality as judged by editors include being early in one's career (Evans *et al*., 1993; Black *et al*., 1998; Callaham and Tercier, 2007) and closer to active research but not years of reviewing experience itself (Stossel, 1985). In an ongoing experiment, Elsevier editors rated co-reviewed reports highly and thought favorably about inviting co-reviewers to serve as an independent reviewer on future manuscripts (Mehmani, 2019). Our survey respondents held similar opinions about how ECRs and co-review benefit peer review (McDowell *et al*., 2019a). Given the hidden nature of co-review, it is possible that studies of peer review quality already include co-reviewing activity and so underreport its utility. Peer review quality will also be improved once routine graduate school courses on peer review create new generations of uniformly trained reviewers.

Increased support for PIs and recognition for ECRs. Including ECRs in peer review also benefts PIs, who should be encouraged to include their trainees as credited co-reviewers. Invited reviewers are experts by defnition and so should be trusted to involve whomever

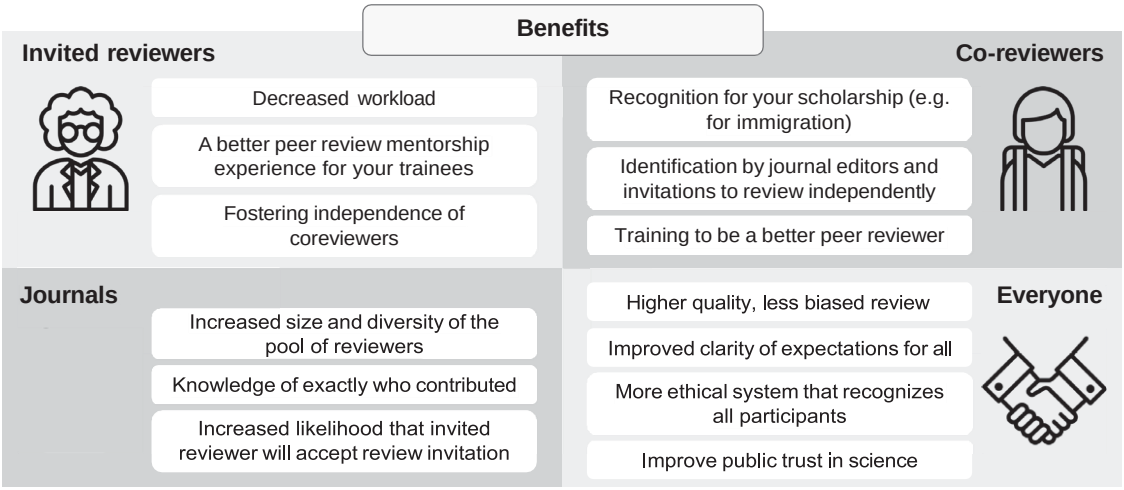

FIGURE 2: Benefits of adopting recommendations for all key stakeholders (icons made by Pause08 from www.faticon.com).

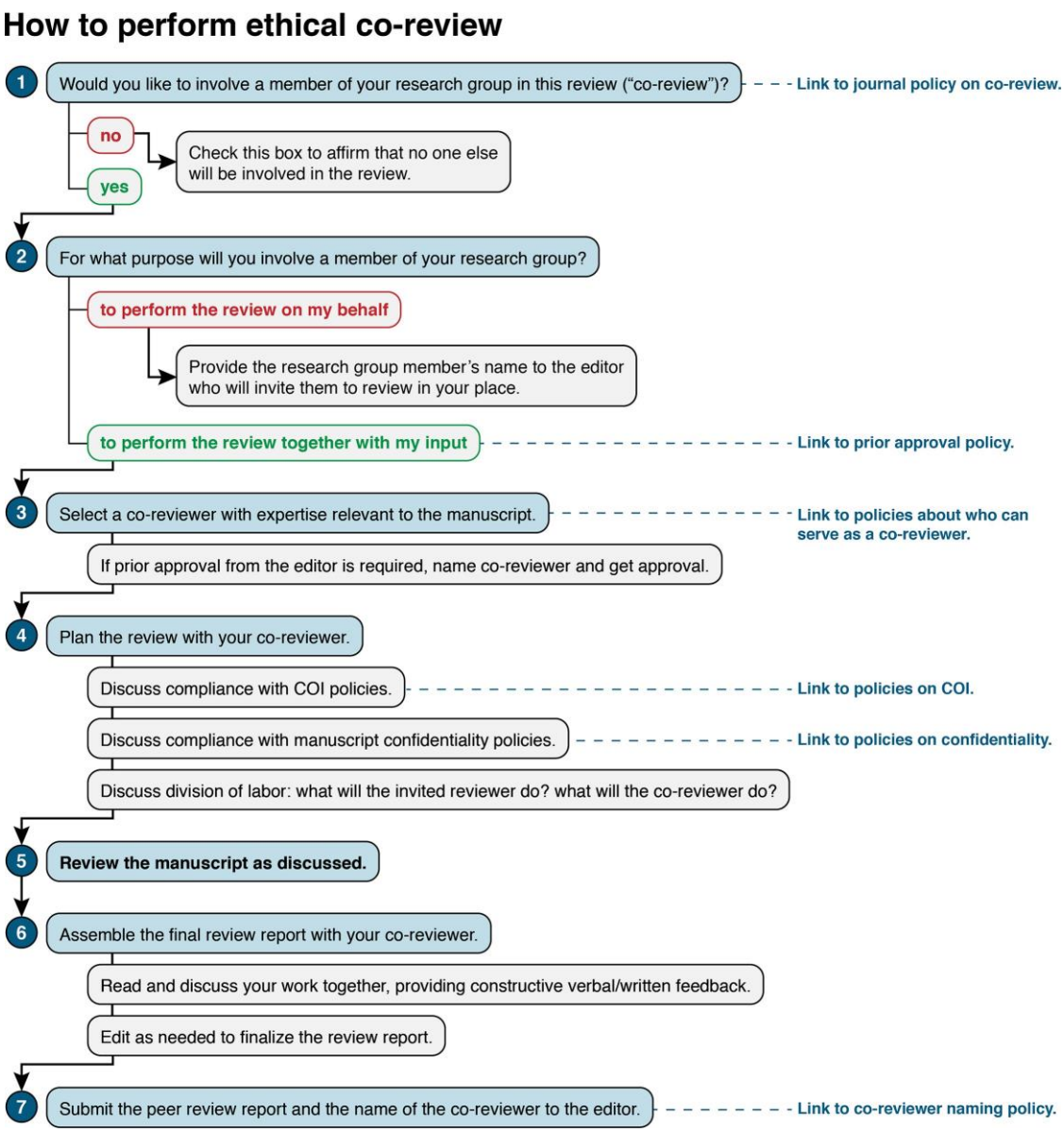

FIGURE 3: A co-reviewing workfow to guide invited reviewers through a journal's expectations for ethical involvement of ECRs in peer review. This workfow and an editable version are available on Zenodo for use by any interested party through an open license (https://zenodo.org/record/4441072).

they consider to be the best person in their research group to critique the research. PIs who provide feedback to the ECR and name them to the editor are right to consider co-review an integral part of quality mentorship. These examples of good mentorship should be better incentivized and formally recognized in PIs' career evaluation processes. Naming and tracking ECR co-reviewers would provide documentation of a PI's mentorship for their own evaluation portfolios. It may also encourage PIs to properly acknowledge co-reviewers' contributions in the frst place. When mentored co-review is not possible for an overburdened or uninterested PI, they should instead transparently delegate peer review to a qualifed member of their research group, either as a credited co-reviewer or better yet by suggesting that the editor extend the review invitation to the ECR directly (Figure 3), thus benefting both parties.

Credited co-review is also valuable as a credential that recognizes an ECR's expertise. Being known to academic editors carries weight for ECRs and being able to document reviewing experience, especially through third parties like Publons, matters for hypercompetitive jobs, and even U.S. immigration applications (North America Immigration Law Group; Publons Advance your career: Green Card for Outstanding Researcher). Indeed, a majority of co-reviewers fnd value in being identifed to the journal editor (McDowell *et al*., 2019a). Contributing ideas and/or text to a peer review report is work, for which authorship is a fair and reasonable reward.

NEXT STEPS: ADOPT SYSTEMWIDE CHANGES TO BRING EQUITY TO PEER REVIEW

Systemic problems require systemic solutions; individual action on the part of "good apple" PIs, ECRs, or editors is not suffcient. Journals, scientifc societies, and graduate programs must take the burden off of individual PIs, ECRs, and editors by creating unavoidable, incentivized, and transparent structures that name and train co-reviewers. When structures are casual and opaque, it is easy for

implicit biases to take hold. For example, simply including ECRs in reviewer databases does not result in their participation in peer review (eLife, 2019). Editors are human and as such are drawn to names in reviewer databases that they recognize, who are less likely to be ECRs. Through tracking what is taking place, and then reporting it publicly, eLife is able to hold itself accountable for identifying and addressing biases in who is involved in peer review, in order to work toward a more equitable and inclusive review process. We urge other journals and COPE to take a hard look at their policies, perhaps with the help of ECR and PI focus groups to check that readers' interpretations align with journal intentions. Do policies unambiguously defne how ECRs may or may not participate in peer review (Table 1)? Are there mandatory, incentivized structures to facilitate naming co-reviewers and are barriers to transparency removed? Scientifc societies, graduate programs, and institutional postdoc offces should also advocate for structural changes to peer review training to refocus the burden from individuals to the academic training system. Peer review training should not be an "extra" professional development activity that an individual ECR might choose to do in their free time; it must be integrated systemically into science education for all.

CONCLUSIONS

Peer review drives decisions about the publication and funding of research and inspires public confdence in scientifc fndings (Kelly *et al*., 2014). Striving for unimpeachable peer review is of utmost importance, especially in times of science denialism. Like manuscripts, peer review reports are often collaborations between PIs and their trainees. Journals should update their written policies and unwritten practices to recognize this reality. Encouraging PIs to more freely discuss co-reviewing and share co-reviewer names with editors will make peer review more transparent and fair. Naming and training everyone who contributes to peer review will beneft all parties and the integrity of peer review.

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OPINION PIECE

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Use of preprint peer review to educate and enculturate science undergraduates

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Key points

- Undergraduate science education should include education in scholarly practices like peer review.
- Authentic experiences in peer review increase science literacy and science identity.
- Peer review of preprints provides a means for undergraduates to be involved in peer review that is independent of journal gatekeeping processes.

Keywords: Peer review, undergraduate, STEM education, scholarship, scholarly communication, scientific identity, scientific literacy

INTRODUCTION: BROADENING THE DEFINITION OF PEER REVIEWER

Peer review of academic manuscripts is accepted as a fundamental scholarly activity to maintain the integrity of the scientific literature (Ross-Hellauer, 2017; Scott, 2007). In its most broad definition, it refers to the evaluation of scholarly work by an author's peers (Baldwin, 2018; Tennant et al., 2017). Who gets to be considered a 'peer'? In definitions of peer review, the term 'peer' is closely linked to the term 'expert'. Since the majority of peer review in science is currently organized by journals (Stern & O'Shea, 2019), a journal editor's subjective decision of who is a suitable 'expert' is central to the processes of creating and selecting from peer reviewer databases. Such decisions are informed by knowledge of established researchers in one's field and/or personal networks. This decision-making is situated in academia's strong hierarchical and inequitable structures that value name recognition, institutional affiliation, network connections, geographic location of institutions, and other signifiers of prestige as proxies for peer review qualifications (Gingras & Khelfaoui, 2017; Leimu & Koricheva, 2005). As a result, reviewer selection leans on name recognition and having a senior academic position with a publication history in the subject matter of the manuscript. Are we satisfied with these selection criteria as being sufficiently comprehensive, equitable and effective at reviewing all domains that need review in scientific manuscripts? Expertise in one domain—for example, command of the literature—can lead to incorrect assessment of one's performance in other domains, such as assessment of novel methodology or statistical analysis, or ability to write an actionable and constructive

TABLE 1 Definitions for terms that we use in this manuscript.

Term	Definition
Scientific identity	The composition of self-views as someone who knows about, uses, and contributes to science as part of the scientific community.
Scientific literacy	The ability to know how scientific knowledge is generated and used to make evidence-based claims, and how to make authentic scientific content.
Peer review	The process of writing critiques of scientific research manuscripts to evaluate and improve their validity, integrity, and clarity. (Note: Our definition of peer review does not include those steps specific to *curation* by journals).
Authentic peer review	The written review of scientific manuscripts in process, such as preprints or manuscripts submitted to a journal. We use this term to distinguish from instances of 'practice peer review,' such as when students evaluate other students' classwork (not manuscripts authored by practicing scientists) and when students critique articles that have already been published in a journal.
Preprint	A scientific research manuscript that the authors openly share on a free, online server, which can occur prior to or instead of journal-organized peer review and curation.

review (Kruger & Dunning, 1999). When status-related proxies are used for reviewer selection criteria, a vast swath of knowledgeable participants in science are excluded from the definition of expert peer reviewer.

Instead, a domain-specific approach to peer review reframes the question from 'who is an expert?' to 'who has expertise?', opening up peer review to a broader population. Indeed, attendees at a 2021 conference on innovation in peer review defined a reviewer as 'anyone participating in science willing to think delibera-tively, critically, and constructively about the work' and stated that 'the act of doing peer review (preprint or journal review) is what creates peer reviewers, not a faculty title' (*Public Preprint Review as a Tool to Empower the next Generation of Socially-Conscious Peer Reviewers*—ASAPbio, n.d.). Within one manuscript, there may be var-ious domains of expertise that need assessment from different individuals with expertise in such domains. This is already appreciated through the current use of reviewers to specifically assess statistical analyses (Hardwicke & Goodman, 2020), computing code (Easing the Burden of Code Review, 2018), or the inclusion of patient and public reviewers at medical journals (Schroter et al., 2018), thus dis-tributing the review of various aspects of a manuscript to reviewers with relevant expertise or desired perspectives. In this model, a reviewer with relevant expertise is anyone with training and/or experience in a particular domain who can then judge and assess someone else's ability to function in that same domain, regardless of career stage or other status-signifiers.

Early career researchers (ECRs, including postdocs, graduate students and undergraduates) often lack status-signifiers and so are rarely invited to review, despite their considerable domain-specific expertise. ECRs are at the forefront of scientific inquiry, often troubleshooting and becoming experts in methodology, data analysis and interpretation. Today's ECRs also receive explicit training in responsible conduct of research, scientific writing and experimental design. We have argued elsewhere for the inclusion of postdocs and graduate students in journal peer review processes and for the improvement of peer review training at all stages in science education (McDowell et al., 2019a, 2019b, 2021). Here, we turn our attention to some of our youngest colleagues—undergraduate science students—and discuss the potential value to both the students and to science of including them in authentic peer review (Table 1). We define *authentic* peer review as the written critique of real scientific manuscripts in progress (such as preprints or articles submitted to journals), where feedback from reviewers may be incorporated by authors or publishers. This is different from practice peer review activities, such as journal club discussions of already-published journal articles (where feedback does not result in changes to the article) and when students peer review other students' classwork instead of real scientific work in progress with an ultimate goal of publication (Table 1). Here we describe our framework for developing an evidenced-based curriculum for using authentic preprint peer review in the undergraduate class-room. In sharing these experiences, we aim to demonstrate the interconnected importance of increasing access to peer review and educating students in peer review, and we argue that improving education and access would strengthen the peer review process.

POTENTIAL VALUE OF AUTHENTIC PEER REVIEW EXPERIENCES FOR STUDENTS AND SCIENCE

Similar to designing experiments and analysing data, participating in peer review is part of the typical, expected work of an academic. Thus, just as early authentic research experiences help undergraduates form a scientific identity (Hunter et al., 2007) and develop scientific literacy (Mishra et al., 2018) (Table 1), so too could early authentic experiences in peer review. Evidence shows that teaching students about the nature of science through inquiry activities, often in laboratory courses, is insufficient for students to learn how professional scientists engage in inquiry (Abd-El-Khalick & Lederman, 2000; Schwartz et al., 2004). As a result, scientists' experiences of science, and what students in classrooms learn about the process of science, are demonstrably different (Chinn & Malhotra, 2002; Phillips & Norris, 2009; Wong & Hodson, 2009). Notably missing from undergraduate science education is explicit teaching about disciplinary literacy (Fig. 1). Disciplinary literacy—what it means to think, read, communicate, and use information

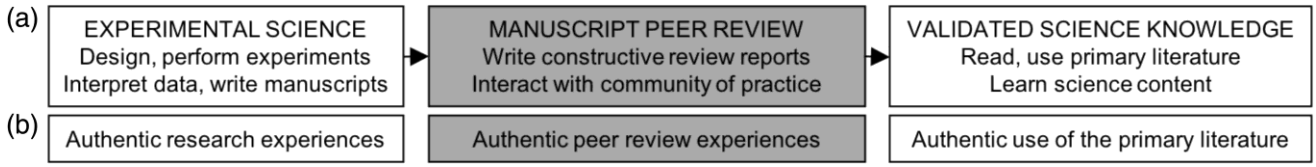

FIGURE 1 Overeview of the process of generating, validating and using scientific knowledge (a) and how undergraduates can be authentically involved (b). Undergraduate science education focuses on authentic research experiences and use of the primary literature (white boxes) but misses an opportunity to engage students in authentic peer review experiences (grey box).

like an expert—is essential to the scientific process as practiced by scientists (Shanahan & Shanahan, 2012; Yore et al., 2004). Disciplinary literacy practices go beyond the simple transmission of information to engage scientists in a communal cycle of knowledge construction and revision through the use and production of primary literature. In order for undergraduate students to develop a better comprehension of the nature of science and how knowledge is constructed, these disciplinary literacy skills should be considered part of developing scientific inquiry knowledge for students (Balgopal et al., 2018).

We posit that undergraduates' participation in peer review ought to occupy a central role in the development of science students (Fig. 1), in the same vein as education about and participation in experimental research (Austin, 2002; Kuehne et al., 2014). Students who engage in peer review also bring an important domain of expertise, ensuring that scientific papers are accessible to a broader range of readers. Though student engagement with already-published literature is important for developing disciplinary knowledge, it overlooks the growth processes prior to publication (Fig. 1). Published literature gives students a retrospective narrative of scholarship, instead of the more realistic view of science as a constant work-in-progress in which failures and corrections are common. Undergraduates may struggle to reconcile this final polished work with their personal experiences with science: failed experiments, negative or anomalous data, unsupported hypotheses. This disconnect could in turn negatively affect their sense of belonging in science and their understanding of the nature of science.

Fundamental knowledge about how research is published forms part of the hidden curriculum in academia—assumed skills and knowledge that are untaught yet required for success in courses and careers—that hinders efforts to broaden participation (Margolis, 2001). Hidden curriculum is a particular barrier to success for students who are Black, indigenous, people of colour (BIPOC), low-income, and/or first-generation is STEM. As such, enculturating prospective scientists into peer review is a social justice issue. Students without the privilege of previous experience, resources, personal connections or in-group confidence are disadvantaged from the get-go and caught in a downward cycle of disenfranchisement. Subsequently, some students may not feel prepared to persist in science when they do not feel prepared for further studies (e.g., Limeri et al., 2020). This forms a bottleneck to pursuing early research experiences, important credentials for a career in STEM. Early research experiences tend to be extracurricular and so not available to all students (Fisher et al., 2021), and often overlook the role of peer review in the generation of scientific knowledge (Fig. 1). Therefore, we believe it is important to explicitly teach all students about peer review through coursework that authentically engages them in it to develop their scientific identity and literacy. We predict that a long-term outcome of explicitly teaching disciplinary literacy to undergraduates, for example, through peer review, will be increased persistence in science, given that this is strongly correlated with self-efficacy and scientific identity (Chemers et al., 2011).

It is also critical that students understand and experience the mechanisms that are used to question and validate scientific knowledge, and how the mechanism of peer review leads to more reliable scholarship, in order to be able to practice critical analysis of literature in the future (Fankhauser & Lijek, 2016; Lijek & Fankhauser, 2016, Rodriguez et al., 2022). Including authentic peer review experiences earlier in science education would therefore contribute to academic and scientific workforce preparedness. Given current concerns about a lack of peer reviewers (Kovanis et al., 2016; Tite & Schroter, 2007), increasing the pool of reviewers by including ECRs who are currently engaged in experimental inquiry and are familiar with the practical aspects of current technologies would help alleviate these issues and likely improve the quality of reviews.

More broadly, education and transparency about the peer review process is an important step in creating a scientifically literate public. Even for professional publishers, peer review is fraught with a mix of definitions, mechanisms and conceptions (Klebel et al., 2020; Tennant et al., 2017; Tennant & Ross-Hellauer, 2020). With such a mix of ideas that even the scholarly publishing community struggles, we cannot expect students to develop a progressive understanding of the peer review process without explicit engagement and instruction in the process itself. Worse, much of the public is ill-equipped to appreciate the ever-changing landscape of information or discriminate between validated scientific knowledge and misinformation (Braund, 2021). Given that scientific literacy is a positive predictor for disbelief in pseudoscience, a better understanding of scholarly publishing and peer review could immunize undergraduates against pseudoscience beliefs (Fasce & Pico., 2019) and address low science literacy in US students (Lederman et al., 2019).

USING PREPRINTS TO PROVIDE AUTHENTIC PEER REVIEW EXPERIENCES FOR STUDENTS

New experiments in publishing practices open up exciting opportunities for providing authentic peer review experiences for

individuals who are excluded from journal peer review, such as ECRs (Stern & O'Shea, 2019; Tennant et al., 2017). Depositing articles as preprints on servers has long been a normal practice in fields such as physics and mathematics, and has recently grown in popularity in our discipline, the biological sciences (Bhalla, 2016; Pulverer, 2016). At the same time, experiments in open and pre- and post-publication peer review (Ross-Hellauer, 2017; Ross-Hellauer et al., 2017; Teixeira da Silva et al., 2016) have created preprint review platforms such as Review Commons (ASAPbio & EMBO, n.d.), Early Evidence Base (EMBO Press, n.d.), Society (eLife Science Publications Ltd, n.d.), Peer Community In (Bourguet et al., 2018), and PREreview (PREreview, n.d.), co-founded and directed by co-author DS). PREreview in particular centres participation by ECRs in a space that encourages constructiveness and prioritizes safe participation (PREreview: Applying an Equity Lens to Tool Design and ImplementationjLabsjELife, n.d.). Students and other researchers can post their preprint reviews anonymously or using their real name, individually or in groups. These reviews receive a digital object identifier (DOI) and are linked to the original preprint, thereby creating a permanent record of reviewers' scholarly contributions. Many preprint servers, such as bioRxiv.org and OSF Preprints, also offer platforms for publishing reviews alongside the preprint. A comprehensive, living list of ways to publish preprint reviews can be found at ReimagineReview (https://reimaginereview.asapbio.org/).

Peer review on a manuscript that is deposited on a preprint server and on a manuscript submitted to a journal's reviewing workflow are both authentic peer review experiences where reviewers write critiques of real scientific manuscripts-in-progress that have the potential to impact a future version of the manuscript. A key difference is that preprint reviews can circumvent the gatekeeping and 'invitation to take part in the process that occurs at many journals. This ability to carry out authentic peer review on pre-prints delivers reviews directly to authors and so removes peer review from the exclusive realm of journals, increasing participation and re-defining engagement in the peer review process. Graduate students have already begun to engage in activities such as preprint journal clubs (Avasthi et al., 2018) where there is an opportunity to develop peer review skills and shape ongoing work of scientists who seek feedback on posted manuscripts. In contrast to participating in traditional journal club activities using already finalized and published journal articles, undergraduate students—who are not usually invited to review articles for journals—can instead have the opportunity for authentic peer review experiences by engaging in preprint review. By seeing real work in progress, they can experience the joy of working to improve the integrity and clarity of scientific manuscripts.

DEVELOPING AN EVIDENCE-BASED CURRICULUM THAT EDUCATES AND INCLUDES UNDERGRADUATE BIOLOGY STUDENTS IN AUTHENTIC PEER REVIEW

We propose leveraging these new opportunities in preprint review to develop new ways of educating and including students in peer review. Changes in the peer review training landscape are badly needed: our recent survey of early career researchers (by co-authors GS and RL) revealed that formal, evidenced-based instruction in peer review is rare (McDowell et al., 2019b). When 498 survey respondents were asked: 'How did you gain training in how to peer review a manuscript?', the most common source of peer review 'training' was 'from receiving reviews on my own papers' (61%). This lack of explicit, evidenced-based training in peer review drives ECRs to teach themselves this essential schol-arly skill by ghostwriting reviews on behalf of their advisor, the invited reviewer. 79% of postdocs and 57% of PhD students in the survey reported writing a peer review report when 'the invited reviewer is the PI for whom you work'. Of these, 52% were not involved in any editing process with their PI, and 47% answered 'I read the manuscript, wrote a full report for my PI, and was no longer involved.' We argue that the current ad hoc approach to peer review training comes too late to only a privileged few, lacks evidenced-based pedagogy, and harms early career researchers' sense of belonging in science by devaluing their scholarly labour (McDowell et al., 2021). As we recently published (McDowell et al., 2021): 'Peer Review 101 should be taught as one of the essential components of training in the sci-ences. … [This would] allow for the implementation of standard-ized, evidence-based pedagogy that is subject to community oversight. It would also make peer review training equally acces-sible to all students, rather than a privilege available only to those in labs with PIs providing quality mentorship'.

How should peer review be taught? We systematically reviewed the extant 2000 journal articles on ECRs' involvement in peer review to find best pedagogical practices. Of these, only 35 articles describe evidence for *how to train* peer reviewers (appendix 1 in McDowell et al., 2019b). Most trainings are offered by journals or graduate programs and target PhD students and postdoctoral fellows and few have been rigorously evaluated. All reviewer training programs that were evaluated and found to have positive outcomes take a constructivist approach that embeds novices in the review process paired with more experienced reviewers (Castello, et al., 2017; Doran et al., 2014; Harrison, 2009; Houry et al., 2012; Navalta & Lyons, 2010; Patterson & Schekman, 2018; Picciotto, 2018). Iterative rounds of review followed by feedback and revision were required for success (Castello, et al., 2017; Doran et al., 2014). In the only randomized controlled trial of peer review training, no difference was found in the quality of the reviews from novices who were mentored by experienced reviewers versus those that received no mentorship (Houry et al., 2012). The authors explain that this was because the *mentors* were not provided with any training or curriculum in an effort to minimize burden and encourage their participation in the program. They conclude that successful training programs must include support for the educators and a structured curriculum (Houry et al., 2012). None of these published peer review training programs were designed for or tested in undergraduates. There *is* a literature on undergraduates reviewing *each other's* work, for example, Calibrated Peer Review (Prichard, 2005), which is distinct from our goal of

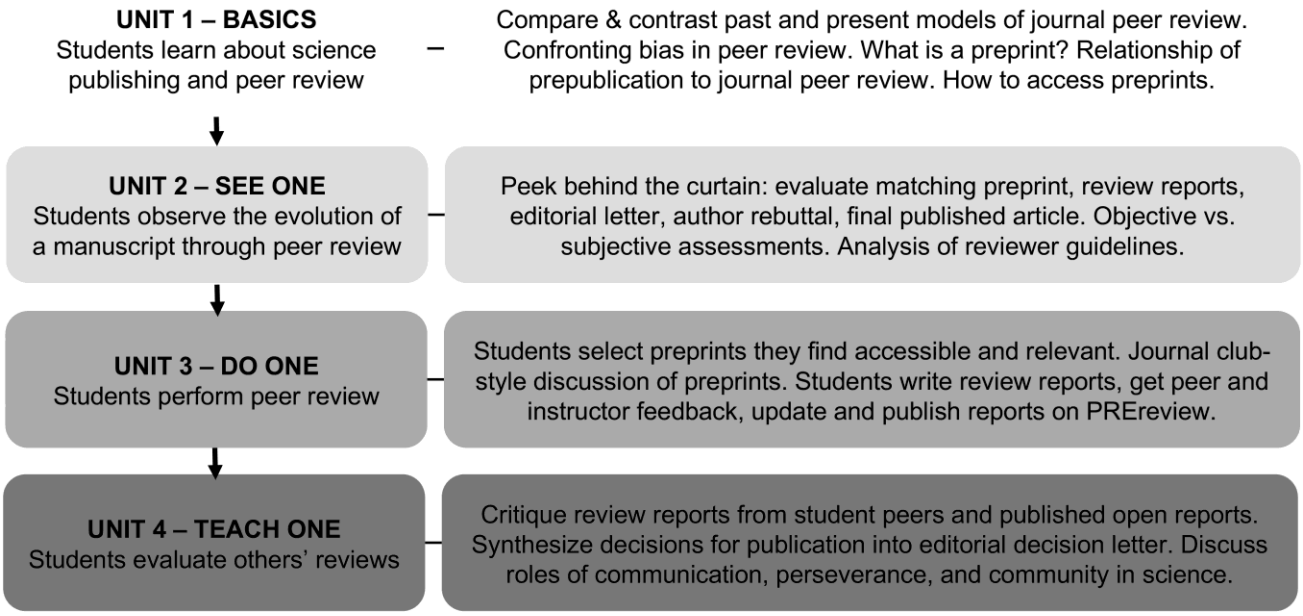

FIGURE 2 Overview of our modular curriculum designed to involve undergraduate students in authentic peer review using biology preprints. Evidence of the curriculum's impact on students' scientific literacy and scientific identity is currently being collected (NSF Award #2142108) and will be disseminated to support future pedagogy and research on peer review.

engaging undergraduates in authentic peer review of manuscripts authored by practicing scientists. Undergraduates in an advanced class did not perform better on Calibrated Peer Review than undergraduates in an introductory class, suggesting that traditional college science coursework that lacks explicit teaching about peer review does not effectively educate students how to review (Prichard, 2005). Therefore, there is a need for evidenced-based pedagogy in peer review to be developed and disseminated, especially for undergraduates.

One of the most direct and inclusive ways to involve students in peer review is to incorporate it into an existing educational framework, like undergraduate courses. Historically, this has been challenging because peer review was inaccessible to undergraduates due to a lack of journal-curated peer review opportunities (McDowell et al., 2019b, 2021; McDowell & Lijek, 2020). Since 2017, co-author RL has experimented with using preprints to integrate peer review lessons and assignments into undergraduate courses at Mount Holyoke College, a liberal arts college for women and gender minorities. These activities were well-suited to remote instruction during the COVID-19 pandemic when traditional in-person laboratories were not accessible. Students found it especially meaningful to write reviews of COVID-19 biology preprints because it allowed them to contribute to pandemic-space science (see Aries et al., 2022; Lijek et al., 2022 for examples of COVID19 preprints reviewed by undergraduates).

With this in mind, we have begun work as part of a US National Science Foundation Improving Undergraduate STEM Education (NSF IUSE) Award to evaluate a modular curriculum designed to involve undergraduate students in authentic peer review using biology preprints (NSF Award #2142108). In our curriculum, outlined in Fig. 2, students are explicitly taught about the importance and mechanisms of peer review, and given oppor-tunities to write and publish their own reviews on preprints. These peer review activities are scaffolded to transition the stu-dent from a novice, to a practitioner, to a mentor through four

units (Fig. 2), based on the clinician training paradigm of 'see one,

do one, teach one' (Kotsis & Chung, 2013) and the gradual release of responsibility model of literacy education that uses the

framing 'I do, we do, you do ' (Kong & Pearson, 2003). Units can be used alone or together depending on course needs and stu-dents' previous experience. A critical part of the authenticity of the curriculum is that students review preprints freely available on servers and can publish their reviews to document their schol-

arship and serve the scientific community (e.g., Aries, 2022; Lijek, 2022). Students in the Spring 2022 iteration of the course

also co-created a rubric to evaluate preprint reviews, which fills a gap in the literature since few resources made for and by under-

graduates exist to guide preprint peer review (Dresler et al., 2022). We also created a Preprint Peer Reviewer Toolkit

that specifically addresses practical steps for undertaking and posting peer review reports of preprints for an undergraduate

audience (McDowell, 2022).

CONCLUSIONS

In this article we describe our vision for educating undergraduate students about peer review and empowering them to participate in authentic reviewing experiences like preprint review. Free,

online preprints and preprint review platforms can broaden early career researchers' participation in peer review beyond the model of journal-centric invited peer review. Current career-stage gatekeeping of invited peer review has the potential to negatively affect identity and belonging in the academy, reduce the ability to have constructive scholarly discussions about works, and reinforce biases in the diversity of reviewers and therefore of peer review itself (Hausmann et al., 2018; Helmer et al., 2017). Instead, we believe there are strong motivations for including authentic peer review in educational settings and so we are developing an evidence-based peer review curriculum for undergraduate science courses. We are evaluating our curriculum at multiple institutions to test its impact on undergraduates' science literacy and science identity and aim to disseminate materials broadly to support future pedagogy and research on peer review. We predict that providing explicit education and participation in peer review at the undergraduate level will support the development of students' scientific identity and scientific literacy, and will prepare the science workforce for skills in the critical evaluation of research.

AUTHOR CONTRIBUTIONS

Rebeccah S. Lijek conceived of and administered the project; Rebeccah S. Lijek and Gary S. McDowell developed the methodology and wrote the original draft; Meena Balgopal, Daniela Saderi, and Sarah Fankhauser contributed to manuscript review and editing. All authors contributed to funding acquisition.

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Special Series: Scientific Literacy

JMBE Journal of Microbiology & Biology Education

Preprint Peer Review Enhances Undergraduate Biology Students' Disciplinary Literacy and Sense of Belonging in STEM

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Education about scientific publishing and manuscript peer review is not universally provided in undergraduate science courses. Since peer review is integral to the scientific process and central to the identity of a scientist, we envision a paradigm shift where teaching peer review becomes integral to undergraduate science education. We hypothesize that teaching undergraduates how to peer review scientific manuscripts may facilitate their development of scientific literacy and identity formation. To this end, we developed a constructivist, service-learning curriculum for biology undergraduates to learn about the mechanisms of peer review using preprints and then to write and publish their own peer reviews of preprints as a way to authentically join the scientific community of practice. The curriculum was implemented as a semester-long intervention in one class and, in another class, as an embedded module intervention. Students' scientific literacy and peer review ability were assessed using quantitative methods. Student's perceptions of their scientific literacy and identity were assessed using thematic analysis of students' reflective writing. Here, we present data on the improvement in the peer review ability of undergraduates in both classes and data on the curriculum's interrelated impact on students' development of scientific literacy, identity, and belonging in peer and professional discourse spaces. These data suggest that undergraduates can and should be trained in peer review to foster the interrelated development of their scientific literacy, scientific identity, and sense of belonging in science.

KEYWORDS peer review, science literacy, disciplinary literacy, science identity, sense of belonging, community of practice, STEM

INTRODUCTION

Undergraduate science education often focuses on how experiments are carried out and the knowledge generated by the resulting research literature, but it misses an opportunity to engage students in the critical validation process that translates one into the other, the peer review of primary scientific literature. Authentic laboratory experiences (e.g., course-based undergraduate research experiences, independent research) are known to be important to undergraduate science education as they enculturate students in the science community and increase understanding about the principles of experimental research (1). The value of early research experiences depends on them being authentic and within a community of practice (CoP) (see Table 1 for definitions of terms) (1–3). Moreover, implicit teaching of scientific inquiry through experimentation is insufficient for students to learn how scientists engage in inquiry (4, 5). As a result, there are demonstrable differences between what scientists experience and what students learn about regarding the process of science (6–8). Missing from many undergraduate research experiences are opportunities to learn how scientists communicate through scholarly publishing and peer review. We posit that providing undergraduates with explicit instruction in real-world forms of scientific communication, like peer review, will develop their scientific literacy and disciplinary literacy (Table 1).

One way in which undergraduates can learn about and engage in authentic scientific conversation with a community of practicing researchers is by participating in the peer review of manuscripts. Peer review is integral to the scientific process, yet scholarship experiences for undergraduates (such as writing and publishing manuscript reviews) are rare, highlighting the novelty of our curriculum. The process

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TABLE 1
Definitions of terms used

Term	Definition
Community of practice	A model for studying learning and identity development of individuals who share ways of thinking, communicating, or doing as they develop mastery of knowledge and skills through participation in the community (1).
Scientific literacy	The ability to know how scientific knowledge is generated and used to make evidence-based claims and how to make authentic scientific content.
Disciplinary literacy	What it means to think, read, communicate, and use information like an expert in a particular discipline
Authentic peer review	The process of writing critiques of scientific research manuscripts to evaluate and improve their scientific integrity and clarity. We use the modifier "authentic" to distinguish this process from when students evaluate other students' classwork, which was not the focus of this study.
Constructivist	An approach to education based on learning through experience, which acknowledges that learning is an active and socially constructed process.
Service learning	The integration of academic activities with community needs, combining service with reflection in a structured learning environment.
Preprint	A scientific research manuscript that the authors openly share on a free, online server, usually prior to journal-organized peer review and curation.
Scientific identity	The composition of self-views as someone who knows about, uses, and contributes to science as part of the scientific community.

of peer review is the backbone of scientific inquiry and a central component of the identity of a scientist (9). It justifies public confidence in scientific results and drives decisions about what research is published and funded. Therefore, education about peer review and participation in authentic peer review (Table 1) ought to occupy a central role in undergraduate science education, in the same vein as education about experimental research and participation in laboratory research (10, 11). Peer review is a form of disciplinary literacy (Table 1), and as such peer review is often reserved for those perceived as experts (e.g., faculty) and explicitly excludes students (12, 13). Yet, how can students develop disciplinary literacy, i.e., what it means to think, read, communicate, and use information like an expert in a particular discipline, if they are not provided instruction and practice in this essential skill? Therefore, peer review represents part of science, technology, engineering, and math (STEM) education's "hidden curriculum" of unstated norms, values, skills, and expectations that are untaught yet required for success (14). Since peer review is integral to the scientific process and central to the identity of a scientist, we envision a paradigm shift that makes teaching peer review integral to undergraduate science education (15). Just as early research experiences help students form a scientific identity (16) and develop scientific literacy (17), so too can early scholarship experiences in peer review.

To this end, we developed and assessed a novel constructivist, service-learning curriculum for undergraduates to learn about the mechanisms of peer review, then write and publish their own peer reviews as a way to join the scientific community of practice. This contrasts with the traditional didactic model of peer review education in current practice, where a professor invited to review for a journal might engage a single trainee in one review exercise, with or without explicit instruction, feedback and/or disclosure to the journal editor (12). Our recent analysis of early career scientists revealed that formal, evidenced-based instruction in peer review is rare (12), so there is an unmet need to develop curricula on this topic. The new curriculum was designed with the goal of positively contributing to student learning, pedagogical research, and society (Fig. 1). We leveraged an innovation in scientific publishing, preprints, which are scientific manuscripts uploaded by the authors to a free, public server, often at the same time as submission to a peer-reviewed journal (18). Depositing articles as preprints on servers prior to journal submission has long been a normal practice in fields such as physics and mathematics, and it has recently grown in popularity in the biological sciences (19, 20). At the same time, experiments in open and pre- and postpublication peer review (21–23) have created preprint review platforms such as Review Commons (24), Early Evidence Base (25), Sciety (26), and PREreview (27). These platforms remove peer review from the exclusive realm of journals to increase participation in the peer review process. In contrast to participating in traditional journal club activities using already-finalized and published journal articles, undergraduate students in our curriculum now have the opportunity to engage in genuine peer review experiences, see work in progress, and experience the joy of working to improve the integrity and clarity of scientific manuscripts.

When students read published journal articles, they are not aware of the growth that occurs through peer review prior to publication. They see a retrospective narrative of scholarship, instead of the more realistic view of science as a constant work

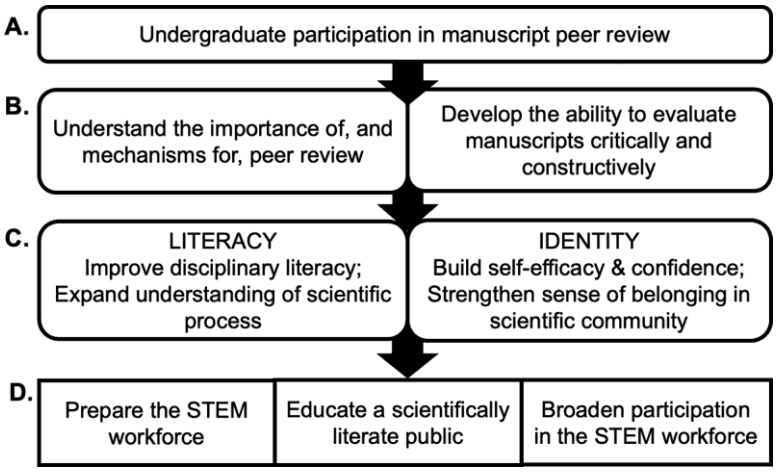

FIG 1. Proposed impact of the curricular intervention (A) on student learning goals (B), research outcomes (C), and benefits to society (D). By explicitly teaching students about peer review and engaging them in it, we hypothesized that this curriculum would develop students' disciplinary literacy (the ability to think, read, communicate, and use information like an expert in a particular discipline) and scientific identity (the composition of self-views as someone who knows about, uses, and contributes to science as part of the scientific community).

in progress in which failures and corrections are common. Undergraduates may struggle to reconcile final polished work with their personal experiences with science, such as failed experiments, negative data, or unsupported hypotheses. This disconnect could, in turn, negatively affect their sense of belonging in science and their understanding of the nature of science. To address this problem, our curriculum teaches students about peer review using preprints which are live, first-draft manuscripts. Reviewing preprints gives students an opportunity to help professional scientists improve their work by sharing their reviews with the authors. Another novel feature of our curriculum is that it provides students with the opportunity to publish their peer reviews of preprints on open-access, journal-independent internet platforms as a way to authentically engage with the scientific literature and the scientific community of practice.

Using an apprenticeship model from the pedagogy literature (16), our curriculum was designed to facilitate students' self-development and self-expression within a community of practice, both within peer discourse spaces (e.g., by engaging with peers in the classroom) and professional discourse spaces (e.g., by engaging with preprint authors by publishing reviews in professional online forums). Here, we present findings from an exploratory study (n = 19 undergraduate upperclassmen) that used mixed methods to measure the interrelated impact of our curricular interventions on students' sense of science identity, literacy, and belonging in peer and professional discourse spaces. We hypothesized that this curriculum, by explicitly teaching students about peer review and authentically engaging them in a community of practice, would improve students' disciplinary literacy (specifically, peer review ability) and foster a sense of scientific identity and belonging in the scientific community.

METHODS

Context: intervention and participants

In a research liberal arts college for female, transgender, and nonbinary students (Mount Holyoke College), we implemented a curriculum on peer review in two different contexts: (i) as a full 14-week seminar course (Course 1, Peer Review in Biology) or (ii) as a single unit of peer review activities embedded within a disciplinary biology course (Course 2, Vaccines). Both courses were offered as upper-level electives and taught by the same instructor (R.S.L.) in the same semester (Spring 2022). In Course 1 (n = 9), peer review activities were scaffolded to facilitate students' movement to a more legitimized science identity through four units, based on the clinician training paradigm of "see one, do one, teach one" (28) and the gradual release of responsibility model of literacy education that uses the framing "I do, we do, you do" (29). Figure 2 provides a conceptual overview of the full curriculum taught in Course 1. In Course 2 (n = 10), only one minimal unit (i.e., "do one," where students perform peer reviews) was implemented to complement a discipline-specific course on vaccine biology. In both classes, the instructor and/or students selected biology preprints of interest to review, critically analyzed the preprints in writing and in discussion using guiding questions provided by the instructor, and then wrote peer review reports as a professional peer reviewer would do (see "Context: peer review activities," below, for further detail). Students submitted weekly reflection journals in response to prompts about their perceptions of their performance, sense of self-efficacy, and understanding of disciplinary literacy in the context of peer review. A majority of students indicated their intention to publish their reviews publicly online to document their expertise and participate in the professional CoP. All students interacted with

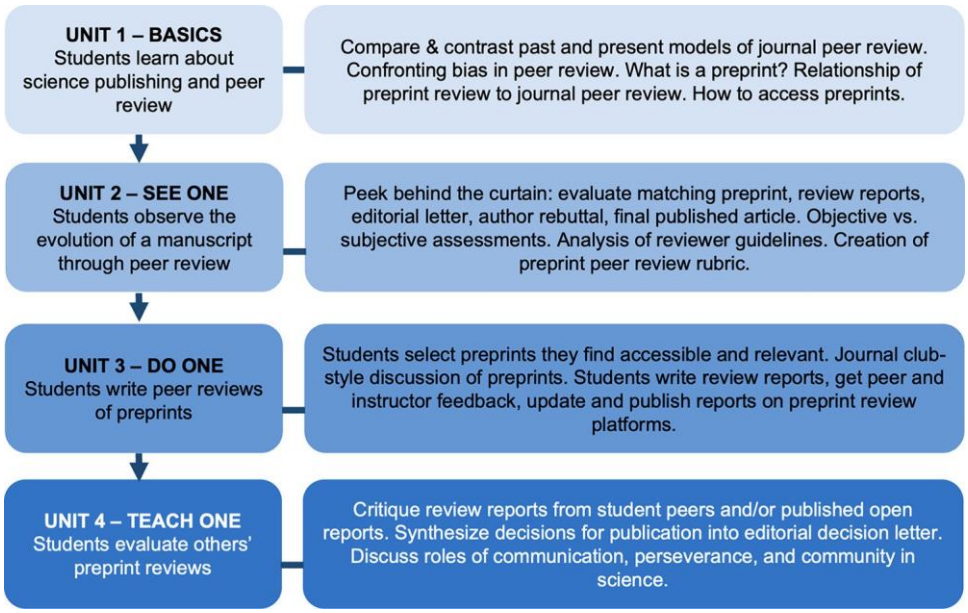

FIG 2. Peer review curriculum. In this constructivist service-learning curriculum, peer review activities are scaffolded to transition the student from an apprentice to a more legitimized science identity through 4 units, loosely based on the clinician training paradigm of "see one, do one, teach one" (28) and the gradual release of responsibility model of literacy education that uses the framing "I do, we do, you do" (29). Educators can choose to use a unit(s) alone or together depending on course needs and students' previous experience. Throughout the curriculum, students review preprints freely available on servers and have the opportunity to publish their reviews to document their scholarship and serve the scientific community. (The curriculum schematic was adapted from our previous publication [15].)

preprint authors and other experts in peer review through e-mail and video interviews.

All students provided informed consent to participate in the study, which was verified by the Mount Holyoke Institutional Review Board as exempt according to 45CFR46.101(b)(1, 2): (1) Educational Research, (2) Tests, Surveys, Interviews, on 12 October 2021.

Context: curriculum and peer review activities

Students in the full curriculum (Course 1, Peer Review in Biology) engaged in four peer review events throughout the semester (Fig. 2):

1. Review 1: individual review on a manuscript selected by the instructor. The initial, baseline event was assigned as individual homework after the first class meeting, after an initial discussion of the concept of peer review but before students had carried out any in-depth training in the course. All students reviewed the same manuscript, selected by the instructor for its accessibility to a general biology audience. The manuscript was written by precollege students, submitted to the *Journal of Emerging Investigators* (30), and ultimately published (31).
2. Review 2: individual review on a preprint selected by student groups. The next event took place in Unit 3, after 6 weeks of explicit teaching about peer review (Fig. 2, Units 1 and 2) and after students cocreated a rubric to evaluate preprint peer reviews (32). Students were grouped by interest in biological topics (e.g., cancer, the 2019 coronavirus disease pandemic), and then each group selected one preprint to review, which was approved by the instructor as being accessible. Manuscript accessibility was determined as a collaboration between the student and instructor, based on the preprint's usage of methodology, jargon, and statistical analyses. When most of the article was deemed accessible but specific components were not (e.g., advanced statistical analyses in an otherwise-approachable study), then students reviewed all but the inaccessible component and made a disclaimer at the top of the review. Each group member individually carried out peer review of the same preprint as homework. Students were not provided with detailed written instructions for how to write a peer review; instead, they were asked to create their review based on their learning from Units 1 and 2. Guiding questions for peer review were provided as an optional resource, but answers were not required to be provided in the assignment.
3. Group review: group review ona preprint selected by student groups. Students shared their individual review 2 with their group members, then spent time in class discussing their individual reviews and the instructors' feedback on them. Then, they synthesized

their individual reviews into one group review (the third review event). After completing the group review, students reread their individual reviews and self-graded using the rubric they cocreated (32).

4. Review 3: individual review on a preprint selected by individual students. The fourth review event was assigned to students as individuals, as a final assessment after the completion of the curriculum. Without any input from the instructor, each student selected a preprint of interest and wrote an individual review.

Students in Course 2 (Vaccines) engaged in a single module of the curriculum (Fig. 2, Unit 3) and three peer review events:

1. Review 1: individual review on a manuscript selected by the instructor. The baseline event was assigned as individual homework after a 30-min discussion of the concept of peer review and after 6 weeks of disciplinary lessons on vaccinology. All students reviewed the same preprint, selected by the instructor for its accessibility to a general vaccinology audience (33). Because this course did not involve explicit lessons on peer review in class, students were instead provided with detailed written instructions for how to perform a peer review, including guiding questions which were required to be answered as part of the assignment.
2. Review 2: individual review on a preprint selected by student groups. Students were grouped by interest in vaccine topics, and then each group selected one preprint to review, which was approved by the instructor as being accessible. Each group member individually carried out peer review of the same preprint as homework, using the same detailed instructions and guiding questions as Review 1.
3. Group review: group review on a preprint selected by student groups. Students shared their individual reviews (Review 2) with their group members, then spent time in class discussing their individual reviews and the instructors' feedback on them. Then, they synthesized their individual reviews into one group review (the third review event).

Assessment of disciplinary literacy: peer review quality

All peer reviews written by students were deidentified by the instructor (R.S.L.) and provided to the independent researcher (G.S.M.). The researcher generated four metrics of peer review ability (instruments) using three unique tools:

The Review Quality Instrument (RQI) (34), which consists of eight Likert-scale questions (ranging from 1 to 5). One question asks the evaluator's overall opinion of the review, and this question is reported here as the RQI (range, 1 to 5). The other seven questions ask about components of the review, and we have combined these and report them as the "RQI total" (range, 7 to 35).

The PREreview review assessment rubric (35).

A rubric for evaluation of preprint reviews was generated by the students in course 1 (32). This consisted of a series of scores of 0 to 4 being awarded to different sections of the review, which were then converted into a percentage, reported here as "MHC".

Scores on each instrument were normalized to percentages (i.e., divided by the total possible score for that instrument and multiplied by 100) to allow for comparisons between the instruments, since the maximum score varied between each instrument. A repeated-measures two-way analysis of variance (ANOVA) was performed to evaluate the impact of instrument and each chronological review event (independent variables) on normalized peer review scores (dependent variable). Tukey's multiple-comparisons posttests were used to make pairwise comparisons between review events. All statistical analyses were performed using GraphPad Prism version 9.4.

Additionally, scientific literacy more broadly defined was assessed using Gormally et al.'s TOSLS survey (36) administered before and after each of the two interventions (see Appendix S1 in the supplemental material for more details).

Thematic analysis

Students completed weekly reflection journals, which were deidentified by the instructor (R.S.L.), assigned pseudonyms to retain anonymity, and provided to the independent qualitative researchers (J.L.O., M.M.B.). Deidentified reflection journal entries were uploaded to MaxQDA (ver. 22.2.1) and coded by thematic analysis (37) (see Appendix S2). Thematic analysis used students' science literacy, science identity, and sense of belonging within the scientific community to inform initial latent codes. Initial themes corresponding to science literacy included the following: understanding science content, using science skills to help others, talking about science with others, and practicing science now and in the future. These codes were then collapsed into the following overarching themes: knowledge (understanding and communication about science), practice (applying or performing science skills and knowledge), and value of practice (understanding the use and need of science). We also identified personal and environmental variables corresponding to a student's identity that were then organized as professional identity (pursuing a science career or internship and interacting with science professionals) and personal identity (systemic and structural barriers and access to resources). Finally, we divided codes related to belonging into presence, absence, or facultative (i.e., a sense of belonging in some contexts but not others). To identify differences between each course context, we compared codes across courses. To establish

trustworthiness, two team members separately coded 20% of the students' reflections and ensured a minimum 90% interrater reliability. We also engaged in expert debriefing to discuss the alignment between our themes and our theoretical framing.

Inclusion and exclusion criteria

Only data from students who completed all assignments were included in the analysis. This represented all 9 students in Course 1 and 10 of 11 students in Course 2. In Course 2, one student did not complete reflection journal entries, and so that student's data were excluded from the thematic analysis. Another student did not complete the peer review exercises on time or the postsurvey for TOSLS, and so this student's data were excluded from those analyses.

RESULTS

Peer review curriculum enhances undergraduates' disciplinary literacy

Student's peer review ability, a form of disciplinary literacy, improved in a statistically significant and dose-dependent manner as a result of the full curriculum ($P < 0.0001$ by ANOVA) (Fig. 3A) and the embedded module ($P < 0.0001$ by ANOVA) (Fig. 3B). Baseline levels of peer review ability were established by the first review event in each course, where students wrote an initial review with absolutely no prior instruction (full curriculum) or with only 30 min of introduction to peer review (embedded module). Increases in peer review ability were observed regardless of which assessment tool was used (Fig. 3 and Tables 2 and 3). Multiple assessment tools were used as a way to reduce the subjectivity of the assessment, since each tool places different emphasis on elements of the review such as importance, originality, ability to identify of strengths and weaknesses in various sections of the manuscript, constructiveness of comments, ability to interpret results, balancing of positive and negative comments, and ability to distinguish and articulate major and minor issues. For example, the PREreview assessment focuses on tone and constructiveness of critique, and since no undergraduate students wrote harmful or offensive comments and since all made clear efforts to provide constructive feedback and readable prose, scores in their initial reviews were already approaching a saturation point. When using the RQI, an overall score out of 5 is given after evaluating a range of specific components; as this adds an extra layer of subjective opinion (i.e., the overall impression of the evaluator), both this final overall score and an average of the combined scores across all individual components were reported (Tables 2 and 3 and Fig. 3).

Overall and depending on the measurement tool used, the full curriculum resulted in a 25 to 42% increase in students' peer review ability (Table 2, bottom row), which was comparable to the 14 to 40% improvements seen as a result of the embedded module (Table 3, bottom row). Measurement of improvement was lowest on the PREreview assessment, because many reviews were close to the ceiling on this tool. At the final peer review event, which occurred after completion of the interventions, students' reviews in both classes earned 80 to 97% of the total maximum score possible for each assessment tool. This result is remarkable because the RQI and PREreview tools were designed to assess the quality of reviews written by experts, not undergraduates or other learners. Many students elected to publish their reviews (38–42), implying that they were proud of the final products (see next section on perceptions). These data suggest that while the baseline quality of peer reviews written by an untrained undergraduate is mediocre as might be expected, these disciplinary literacy skills can be developed through an intentional curriculum that offers explicit instruction, iterative practice, and opportunities to authentically participate in a community of practice.

Peer review curriculum enhances undergraduates' perceptions of science literacy, identity, and belonging

Student's perceptions of their own development were captured in both courses through weekly reflection writing in response to specific prompts (see Appendix 3). Results from this analysis demonstrated that students developed an affiliation with the science CoP over the course of the interventions (Fig. 4). While many students were science majors (hence, early career scientists), a few used the course as an opportunity to engage in and learn about science as non-practitioners. Therefore, prior to the intervention, students identified as novices (termed "apprentices" in the CoP model) (Fig. 4) or even as outsiders (in the periphery) (Fig. 4). As they participated in the peer review curriculum, students' reflections on their literacy, identity, and belonging within the CoP demonstrated progression toward mastery (Fig. 4). Table 4 provides a componential analysis of the overarching themes of literacy, identity, and belonging achieved by students upon completion of an intervention, with each discussed in detail below.

(i) Literacy. In both courses, the peer review curriculum improved students' perceptions of their own scientific literacy. Scientific literacy included the students' understanding of how scientific knowledge is generated, their engagement in science practices, and how they perceived the value of these practices. For example, students coded as scientifically literate were able to describe the peer review process and its value, as well as feel confident about performing a peer review. This was seen in Sam's journal entry when she commented on her confidence in performing peer review after the intervention: "After thoroughly reviewing the standard requirements for a publication, as well as the scientific theory supporting the article, I felt surprisingly well-equipped to offer constructive feedback on the assigned preprint."

A nuanced development and then strengthening of scientific literacy was seen in the full curriculum (Course 1)

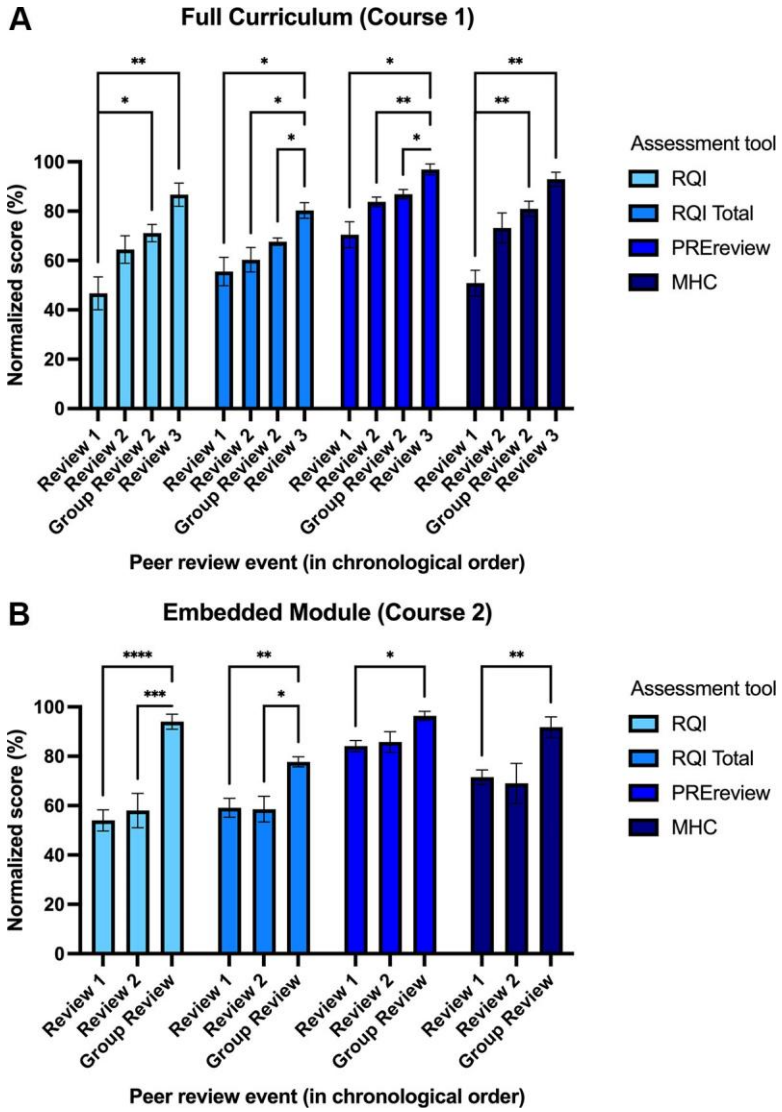

FIG 3. Improvements in peer review quality as a result of the full curriculum (A) (n = 9) and embedded module (B) (n = 10). Students' deidentified peer reviews were assessed by an independent researcher using four metrics: RQI, the single question in the Review Quality Index (34), where the researcher gives an overall assessment of the review; RQI total, the combined score for all questions in the RQI; PREreview's assessment tool (35); and MHC, the grading rubric created by students in Course 1 (32). Review events are presented on the x axis in chronological order in the curriculum. Scores on each instrument were normalized to percentages to allow for comparisons between the instruments, since the maximum score varied between each instrument. Data are presented as means ± standard errors of means and were analyzed by two-way repeated measures ANOVA (P < 0.0001 for review event in both the full curriculum and embedded module) and by Tukey's multiple-comparisons posttests for pairwise comparisons between review events. All statistically significant comparisons are indicated: *, P < 0.05; **, P < 0.01; ***, P < 0.001; ****, P < 0.0001.

over each of the four units (Fig. 2). In Units 1 and 2, students were asked to reflect on their new understanding of what peer review is, who engages in peer review, and how to conduct one as part of establishing a baseline measure of their disciplinary literacy. In their early journal entries, students shared many of the misconceptions that they held about peer reviews, including that reviews were done after publication and that authors were responsible for recruiting reviewers themselves. This was seen in Kiara's reflections when she stated, "I had this idea that there was not an editor involved, but rather that the author of the study themselves was responsible for reaching out and facilitating the process." Students went on to refute these misunderstandings, even explaining why they were wrong.

TABLE 2
Changes in peer review quality as a result of the full curriculum (Course 1)[a]

Measure	Review(s) analyzed	RQI	RQI total	PREreview	MHC
Score range		1–5	7–35	1–5	0–100%
Avg score	Review 1	2.33	19.4	3.52	50.8%
	Review 2	3.22	21.1	4.18	73.2%
	Group review	3.56	23.7	4.33	81.0%
	Review 3	4.33	28.1	4.84	92.9%
Change per event	Δ(1!2)	0.18	0.05	0.13	0.22
	Δ(2!3)	0.22	0.2	0.13	0.2
	Δ(1!3)	0.4	0.25	0.26	0.42

[a]Students carried out 3 individual reviews as described in Methods, with review 2 being used to generate the group review. Changes in scores between different reviews are reported as Δ[Review#]![Review#] and were normalized to give a range of change, from −1 (maximum decrease) to +1 (maximum improvement), with 0 signifying no change in peer review quality. Review quality was assessed by an independent evaluator using four metrics: RQI, the single question in the review quality index, where the evaluator gives an overall assessment of the review; RQI total, the combined score all questions in the RQI; PREreview reviewer's assessment rubric score; and MHC, the grading rubric created by students in Course 1.

Within this unit, students also shared their perceived value of the peer review process. Most students suggested superficial benefits, such as the ability to proofread articles prior to publishing them, but did not yet demonstrate a sophisticated understanding of the value of peer review plays for science (43). In Unit 3, during which students completed Review 2, the first review after instruction, all students discussed feeling confident, comfortable, or prepared for the assignment. Students explained that the course activities and materials helped to clarify what was expected of their review. In Unit 4, when students evaluated others' reviews, there were obvious improvements in students' depth of knowledge of the value of peer review. Several students were able to elaborate on the importance of reviewers in producing high quality publications. Kiara shared the following: "This feature is incredibly valuable to the process as it allows for the most amount of feedback for the author . . . as the more feedback that is provided for the review, the better the review can potentially be." Kiara's comments demonstrated an understanding that the review process contributes to how scientific knowledge is disseminated. Students in Course 2 were also seen to strengthen their literacy through critique of discipline-specific papers (e.g., on vaccines) and offering constructive feedback on peer presentations that occurred outside the embedded peer review module.

Finally, students in both courses mentioned that through reading and critiquing reviews made by their peers, they were able to sharpen their own skills in preparation for their final reviews. Many students discussed their plans for their final review, each noting unique areas of improvement. Kiara was inspired by her classmates' use of a peer review rubric to keep track of necessary comments, stating that she would remember to use it in the future. Over the course of the semester, students first developed their knowledge, value, and practice of peer review and then further strengthened these points through repeated writing and critiquing of reviews.

TABLE 3
Changes in peer review quality as a result of the embedded module (Course 2)[a]

Measure	Review(s) analyzed	RQI	RQI total	PREreview	MHC
Range of scores		1–5	7–35	1–5	0–100%
Avg score	Review 1	2.78	21.0	4.17	72.6%
	Review 2	3.00	21.0	4.35	69.9%
	Group review	4.78	27.6	4.87	93.9%
Change per event	Δ(1!2)	0.04	0.00	0.04	0.03
	Δ(2!group)	0.36	0.19	0.10	0.24
	Δ(1!group)	0.40	0.19	0.14	0.21

[a]Students carried out 2 individual reviews as described in Methods, with review 2 being used to generate the group review. Changes in scores between different reviews are reported as Δ[Review#]![Review#] and were normalized to give a range of change from −1 (maximum decrease) to +1 (maximum improvement), with 0 signifying no change in peer review quality. See Table 2 for description of the instruments used.

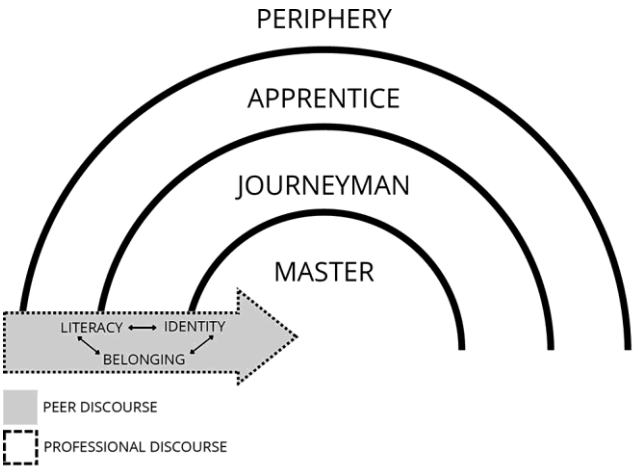

FIG 4. Community of practice conceptual model (based in part on ideas from reference 1). Students' progression from "apprentice" toward "master" is influenced by their sense of belonging within both peer and professional discourse spaces. Belonging is seen to bridge literacy (knowing and applying science) and identity (feeling like a scientist).

(ii) Identity. In both courses, students' perception of their science identity was influenced by their own personal and professional identities. Students who demonstrated a strong science identity talked about science with others in and out of class, described the ways in which their newly learned skills could be applied to their academic and postgraduate careers, and expressed their validation in the science field because of others who looked like them. Madi wrote, "The critical thinking skills I gained from this peer-review course have really started kicking in. I also feel confident that if my experiment works, I will be able to write about it for a manuscript." Earlier in her reflection, Madi explained how learning to analyze and critique research data helped her to overcome a roadblock in her research lab: "I am also considering writing a thesis for my senior year because of the confidence I have gained in research, reading, writing, and reviewing." Madi demonstrated that through reflection of her own experiences, she planned to engage in future disciplinary literacy activities that will likely further solidify her professional science identity. Although Madi was noted as developing her professional science identity, she also shared perceived disadvantages of her personal identity. As a first-generation international student, Madi acknowledged underrepresentation of those with marginalized identities in science and the bias they face due to their nationality and race. Similarly, Gianna shared, "Being a non-native English speaker, I know how [language could] be the largest barrier in science research." Both students, among others, recognized systematic and structural barriers that inhibit individuals with certain identities from participating in or contributing to the scientific community.

(iii) Belonging in the peer CoP. Students reported that their sense of belonging changed as a result of the intervention in what we identified as two "discourse spaces." The peer discourse space consisted of in-person and virtual classrooms, where students interacted with one another. The professional discourse space was where students interacted with science professionals (e.g., preprint authors, journal editors, expert reviewers). Engaging with classmates through discussion and cowriting peer reviews reinforced students' sense of belonging within the peer discourse space. A few students felt they belonged in some contexts, but not in others. For example, Isabella explained, "I think discussing the paper in class with people who are on the same level as me really helped." Here, Isabella explained that the context of a classroom felt safe, but she went on to explain that in other contexts, where she perceived that there were some members who were different from her, she did not feel as confident. "In the past, I have done journal clubs with graduate students, which have been much more difficult for me to feel confident in sharing my thoughts. Today's class really helped me gain more confidence about my ability to review primary research independently." Hence, some students expressed confidence in peer discourse spaces but not in professional ones prior to the intervention and implied that the confidence gained through the intervention could improve feelings of belonging in professional discourse spaces in the future.

(iv) Barriers to belonging. Students in both courses most often identified illiteracy (i.e., inadequate knowledge and practices) as a barrier to belonging. This was evident in Alex's journal entry when they mentioned feeling like a "wallflower," or on the periphery (Fig. 4), because of their lack of science experience: "I still don't really feel I am part of the scientific community. It is a huge field and looking at a few papers makes me feel like I am more of a wallflower than anything else . . . with my very limited experience I don't think it would be right to say that I am part of the community. I am still going through the initiation rites." Although Alex described feeling like they were on the periphery of the CoP, they described their experience as part of an "initiation" period, which implies that they may have seen themselves as belonging sometime in the future.

(v) Belonging in the professional CoP. Emailing with preprint authors, interviewing editors, and expert reviewers during the interventions allowed for students in both courses to feel they belonged in the professional discourse space. Madi described how experts helped to foster her belonging within a group of scientists when she wrote, " . . . firstly I was able to make a conversation with a professional and deliver my question in a way that did make sense to them. The points they were making made me feel familiar with other jargon and issues surrounding the process of peer review I did not feel inadequate or less knowledgeable during these conversations." Madi found the experience of interacting with others valuable in shaping her sense of being a member of a CoP. Likewise, Kiara wrote about how she perceived others to perceive her: "She [professional scientist] saw me as a student and as a scientist I so often do not feel seen or understood in the STEM field so

TABLE 4
Componential analysis of the overarching themes of literacy, identity, and belonging achieved by students upon completion of the intervention, after either the full curriculum (Course 1) or the embedded module (Course 2)[a]

Course no.	Student	Science literacy			Science identity		Science belonging	
		Knowledge	Practice	Value	Personal	Professional	Academic	Professional
Course 1	Kasper	NO	✓	✓	,+	✓	✓	NO
	Kori	✓	✓	✓	,+	✓	✓	✓
	Gianna	NO	✓	✓		✓	✓	NO
	Niki	✓	✓	✓		✓	✓	✓
	Dani	✓	✓	✓	+	✓	✓	✓
	Aaliyah	✓	✓	✓		✓	✓	✓
	Kiara	✓	✓	✓		✓	✓	✓
	Zara	✓	✓	✓		✓	✓	✓
	Madi	✓	✓	✓		✓	✓	✓
Course 2	Sam	✓	✓	✓		✓	✓	✓
	Alex	NO	✓			✓	✓	NO
	Amara	✓	✓	✓		✓	✓	✓
	Isabella	✓	✓			✓	✓	NO
	Sofie	✓	✓	✓		✓	✓	✓
	Kris	✓	✓	✓	+	✓	✓	✓
	Riley	✓	✓			✓	✓	✓
	Jocelyn	✓	✓	✓		✓	✓	✓
	Aneta	✓	✓	✓		✓	✓	✓
	Lotte	✓	✓			✓	✓	✓

[a]A checkmark indicates a student was coded as being scientifically literate, possessing a professional science identity, or having a sense of belonging within the science community. NO indicates student was coded as not possessing scientific literacy, identity, or belonging. Cells are left empty when student responses did not address aspects of literacy, identity, or belonging. , indicates aspects of a student's personal identity that the student perceived as a disadvantage; +, indicates aspects of a student's personal identity that the student perceived as an advantage. Pseudonyms are used to maintain students' privacy.

having this moment to talk to her allowed for me to feel valid in our field." In other words, Kiara's sense of belonging was strengthened through positive reinforcement by those who she saw as experts in the professional science CoP. In their responses, Madi and Kiara pointed to their science literacy and identity being validated through engaging with experts within the CoP. Overall, these data demonstrated that belonging in peer and professional discourse spaces contributes to the development of students' scientific literacy and identity, which then facilitates their progression from "apprentice" toward "master" in the scientific CoP (Fig. 4).

DISCUSSION

This study demonstrates that undergraduates are capable of being taught how to perform effective peer review of scientific manuscripts, a critical scientific skill and a form of disciplinary literacy often overlooked in STEM education. Our novel peer review curriculum resulted not only in improvements in disciplinary literacy, but also, importantly, in undergraduates' perceptions of their scientific literacy, scientific identity, and belonging in STEM. These results were generated by both formats of the curriculum: a peer review course (full curriculum) and a short peer review module embedded into a disciplinary course. Therefore, instructors who are not able to offer a full course on peer review might still consider incorporating a module into a preexisting science course as a way to intentionally develop students' disciplinary literacy, scientific identity, and sense of belonging in STEM.

We attribute the efficacy of the peer review intervention to three critical features: (i) explicit instruction that unmasks part of STEM's hidden curriculum, (ii) iterative practice, feedback, and peer collaboration, and (iii) opportunities to authentically participate in a community of practice. Our curriculum explicitly teaches undergraduates how professional scientists evaluate primary literature and engage in discourse with the community of scientists through peer review and publishing, two features of STEM's hidden curriculum that are rarely taught even to graduate students.

Instead of reserving this knowledge and skillset for the privileged few who have quality independent research mentorship, our classroom-based instruction provides access to this information at an earlier stage, so that any science undergraduate can become savvy about professional practice. Explicit instruction can be effective in the form of class lessons (as was done in the full curriculum) or written, granular guiding questions (as was done in the embedded module). Both formats allowed students to see how manuscripts evolved through peer review (Fig. 2, Unit 2), instilling a growth mindset in students that contrasts with the crystalline truths portrayed in textbooks and published articles. Students can then reconcile their imperfect lived experience with science and better identify their potential to be scientists themselves.

A second feature of the curriculum's success derives from iterative rounds of practice, feedback, peer collaboration, and revision. This was evident from the dose-dependent improvement in disciplinary literacy with each review event (Fig. 3), and the progression revealed in the thematic analysis of students' reflection writing. A particularly beneficial exercise appears to have been the group synthesis activity, where students wrote individual reviews on a shared preprint, received instructor comments on their written work, read each other's reviews, and then synthesized their findings into one group review, akin to an editorial letter in journal review. We attribute this benefit to the combination of individualized expert feedback (e.g., instructor comments on the review) and the safe spaces for growth created by peer discourse spaces (e.g., group revision and synthesis). The need for specific, written feedback on the reviews aligns with the findings of Houry et al. (44), who showed that the current model of pairing an expert and novice reviewer fails to train the novice when explicit feedback and/or a structured curriculum is not provided. The merit of student group work aligned with established knowledge on collaborative learning (45) and likely derived from the fact that groups were composed of peers engaged in the same training, removing hierarchical power dynamics based on career stage or previous review experience. Future work could focus on framing the group synthesis intentionally within a collaborative learning framework to examine contrasts to the traditional didactic training paradigm for peer review. When group work creates a peer community of practice, it may support students' transition to self-perceptions of a more legitimized scientific identity (i.e., apprentice to journeyman) and as valuable members of the professional community of practice, which may explain why these self-beliefs are predictors of persistence in STEM careers, especially for minoritized students (46, 47). One implication for these data is that individual-feedback-then-group-synthesis exercises could benefit peer review training in contexts beyond the undergraduate classroom, e.g., for graduate student education and for onboarding new invited reviewers at academic journals.

Our findings are consistent with prior work on the pedagogical benefits of peer review in the classroom (e.g., calibrated peer review, CREATE systems) (reviewed in reference 12), which found that students learn best by participating themselves in the review process and when there are multiple rounds of review followed by feedback and revising (48–51). Students in the CREATE model, which uses published articles (not preprints) for review, commented on the importance of personal connections with scientists, e.g., through interacting with the authors of the published papers that they read or viewing footage of a prior group's interaction (48). These students developed literacy about the practices of a CoP and expressed an increased interest in becoming scientists (48). Similarly, students in our curriculum reported increases in identity and belonging as a result of engaging with professionals, e.g., by e-mailing reviews to the preprint authors. Authors frequently replied to the students, expressing surprise and gratitude at the students' labor and encouragement for students to stay in STEM. Some authors said that students' reviews agreed with reviews from journals and would be implemented. Students reported that these interactions with the professional CoP contributed to a sense of joy and being valued members of STEM.

Given the importance of belonging in shaping students' science identity, and possibly also persistence in STEM (52), one implication of this work is an appreciation of the nuances between different levels of belonging (53). Our data suggest that belonging in a CoP is composed of two parts: a sense of belonging in the student's peer discourse setting (i.e., the classroom), in combination with a sense of belonging to the community of scientists (i.e., professional settings). The sense of classroom belonging appears to be important in creating a safe space for students to develop their literacy and explore their identity as scientists and their place in the wider scientific community. Other work has shown that a strong science identity predicts higher grades, with manipulation of belonging in college impacting the relationship between science identity and academic performance (47). Students have a clear understanding of what they are required to do to succeed academically, but what professional success looks like, and how they can achieve it, may be less clear (53). Addressing in an academic context how to move from the periphery to mastery in a professional CoP may be an important foundation in building professional scientific identity. This may have implications for retention in academia: moving instruction on how to be a practicing scientist away from later career stages and into earlier academic settings may allow earlier establishment of belonging in STEM. When greater attention is given to intentionally fostering a sense of belonging in the scientific community of practice, as was done in this novel peer review curriculum, undergraduate education may be more effective at developing a broader diversity in the next generation of STEM professionals.

A limitation of our study is that evaluating peer review quality in a standardized way is challenging. Reviews are subjective

assessments of a manuscript, and so evaluations of a review become a subjective assessment of a subjective assessment. This is further complicated by comparing reviews of different manuscripts, as the quality of the review depends on how much (or little) there is to critique. We endeavored to make up for this limitation by using four assessment tools representing all that are publicly available and allow for quantification. Though the tools vary in their emphases, all define a quality review as having a respectful tone that balances strengths with weaknesses, which speaks to the trend of harsh journal reviews (12). In contrast, students' reviews were never rude and frequently pointed out strengths, earning high marks for tone on the assessments. This may have been biased in our sample of Mount Holyoke College students, whose gender and/or early career stage identities are socialized to use respectful tone. Another major limitation of the assessment tools is that none evaluate the sophistication of the critiques (surface-level versus deep scientific analysis). For example, students requested that a clinical trial be rerun due to small sample size, without considering feasibility nor justifying what sample size would be required. One future direction of this work is to develop clearer standards for evaluation of peer reviews and, by extension, a rubric for peer review learning outcomes.

Despite seeing significant changes in disciplinary literacy (Fig. 3), we observed no significant changes in overall science literacy using Gormally's test of science literacy survey (TOSLS) (36) with a pre- and posttesting methodology similar to that of Cartwright et al. (54) (see Appendix S1). We attributed this to a combination of factors similar to the findings of Cartwright et al. (54). Correct response rates were high at baseline (in agreement with what Gormally et al. reported for private liberal arts colleges (36)) and left little room for demonstration of improvement. It may be that in populations with lower initial TOSLS scores, our peer review intervention could still improve science literacy. TOSLS may not capture changes over the course of only one semester and may be more appropriate for longer interventions or our future cross-site comparisons.

In ongoing work, we are investigating the transferability of the peer review curriculum to other educational contexts (e.g., a large land grant university, a 2-year college), more diverse student populations, different instructors, and larger class sizes. For example, the modular intervention is currently being tested in a 200-student lecture and laboratory course, where the review activities take place in the lab because student-to-instructor ratios are lower. This introduces a new variable of multiple lab instructors with various comfort levels with peer review (e.g., graduate student teaching assistants who need peer review training themselves). Focus groups with instructors will be used to identify pinch points and develop appropriate training for instructors. Ultimately, this work will create evidenced-based open educational resources on peer review that will be transferable to diverse educational settings and enhance students' interrelated development of scientific literacy, identity, and belonging in STEM classrooms and professions.

SUPPLEMENTAL MATERIAL

Supplemental material is available online only.

SUPPLEMENTAL FILE 1, PDF file, 0.1 MB.

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