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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 gate-keeping 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 deliberatively, 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 various 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 distributing 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 classroom. 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

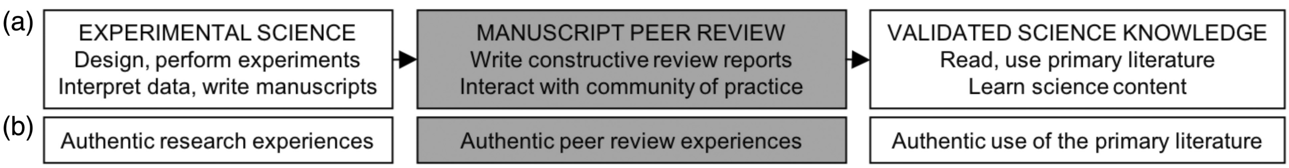

FIGURE 1 Overeview of the process of generating, validating and using scientific knowledge (a) and how undergraduates can be authentically involved (b). Undergraduate science education focuses on authentic research experiences and use of the primary literature (white boxes) but misses an opportunity 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 & Picó, 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 Implementation|Labs|ELife, 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 preprints 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 scholarly 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 sciences. … [This would] allow for the implementation of standardized, evidence-based pedagogy that is subject to community oversight. It would also make peer review training equally accessible 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 (Castelló 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 (Castelló 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

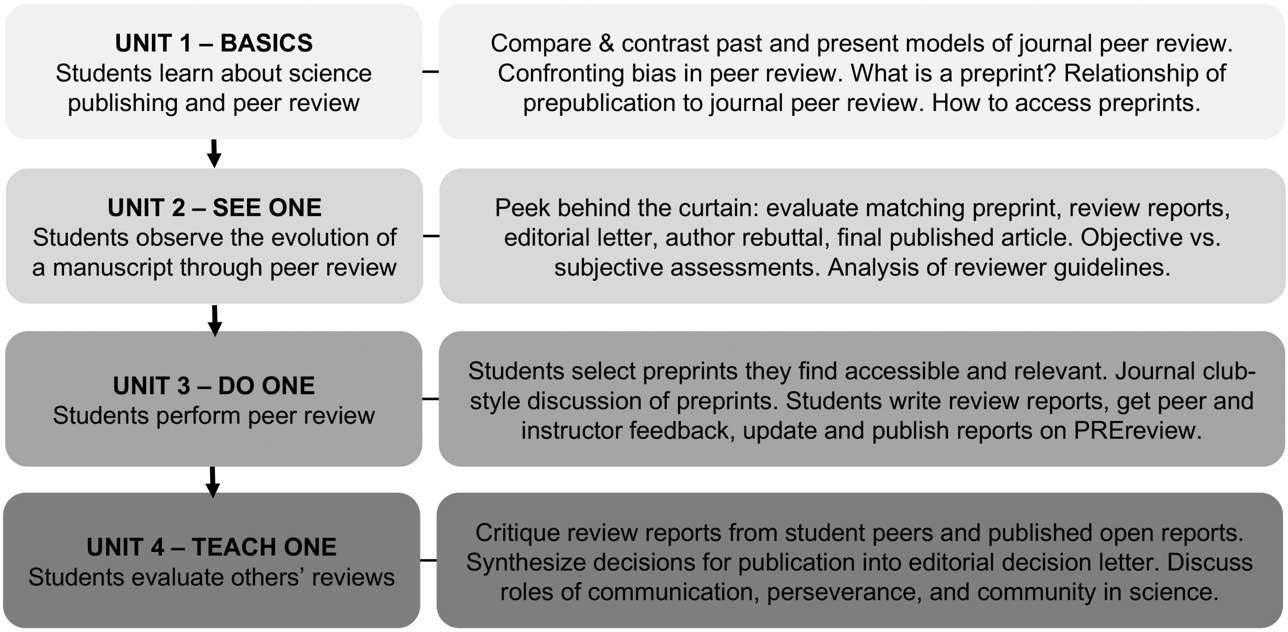

FIGURE 2 Overview of our modular curriculum designed to involve undergraduate students in authentic peer review using biology preprints. Evidence of the curriculum's impact on students' scientific literacy and scientific identity is currently being collected (NSF Award #2142108) and will be disseminated 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 opportunities to write and publish their own reviews on preprints. These peer review activities are scaffolded to transition the student 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 students' 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 scholarship 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 undergraduates 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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