Doing peer review and receiving feedback: impact on scientific literacy and writing skills

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Geithner CA, Pollastro AN. Doing peer review and receiving feedback: impact on scientific literacy and writing skills. Adv Physiol Educ 40: 38–46, 2016; doi:10.1152/advan.00071.2015.—Doing peer review has been effectively implemented to help students develop critical reading and writing skills; however, its application in Human Physiology programs is limited. The purpose of the present study was to determine the impact of peer review on Human Physiology majors’ perceptions of their scientific literacy and writing skills. Students enrolled in the Scientific Writing course completed multiple writing assignments, including three revisions after receiving peer and instructor feedback. Students self-assessed their knowledge, skills, and attitudes related to science and writing in pre- and postcourse surveys (n = 26 with complete data). Seven survey items related to scientific literacy and writing skills impacted by peer review were selected for analysis. Scores on these survey items were summed to form a composite self-rating score. Responses to two questions regarding the most useful learning activities were submitted to frequency analysis. Mean postcourse scores for individual survey items and composite self-rating scores were significantly higher than precourse means (P < 0.05). Peer review was the most frequently noted among 21 learning activities for increasing scientific literacy and in the top 5 for improving writing skills. In conclusion, peer review is an effective teaching/learning approach for improving undergraduate Human Physiology majors’ knowledge, skills, and attitudes regarding science and scientific writing.

Peer review; scientific writing; science literacy; student perceptions; human physiology

Peer review is the process by which research findings are evaluated for quality, significance, and originality by experts in the field (3, 5, 29, 41, 44). It is vital to the practice and progress of science (2, 3, 26, 40, 51); however, it is not without well-documented flaws (3, 6). The quality control that peer review provides over what gets added to the body of knowledge in a field is only as good as the reviewers (19). In addition to reviews being prone to human errors and limitations (24), there is no standardized approach to review (28), and there is the potential for bias and prejudice in the review process (3, 26, 35).

Effective peer review requires a broad array of capacities, including content knowledge, familiarity with the standard components and critical content of scientific papers, ability to critically read the primary literature, knowledge of the characteristics of effective writing, the ability to identify strengths and weaknesses, and the ability to provide effective feedback (3, 6, 17, 23, 39, 45, 49, 56, 57). Peer review is a professional responsibility (19, 20, 24), and working scientists are regularly engaged in providing and receiving peer review (33), yet many reviewers do not receive any formal training in peer review (19, 20, 26, 28). Students in the sciences and beginning scientists may not have adequate skills to effectively read and review manuscripts (24, 45), nor may they understand the significance of the peer review process or the process or format of scientific writing (21).

The literature on teaching undergraduate science students how to do peer review was somewhat limited until about a decade ago (21, 30, 31, 39, 46). Although peer review has been incorporated into several thousands of courses across a wide variety of science disciplines (42a), teaching peer review in undergraduate human physiology programs is much less common (5, 30, 38, 45). Given that students pursuing a major in Human Physiology are generally oriented toward careers in medicine (e.g., physician or physician’s assistant), the health sciences (e.g., physical and occupational therapy), or exercise physiology, these students stand to benefit from the benefits that peer review has to offer. Peer review at the college level has had positive, formative effects on student learning (36, 54). It aids students in developing an understanding of the peer review process as a vital function in the scientific community and a major accountability mechanism in producing and publishing science (52), developing critical reading and reasoning skills (10, 21, 51), improving content knowledge (38, 46), engaging students in working as a learning community, and developing their writing and revision skills (10, 21, 36, 55).

Although peer review has multiple positive student learning outcomes and has been shown to be valid and reliable (11, 43) and as stringent as faculty review (32), some negative student perceptions have been observed. Kaufmann and Schunn (27) found that students had concerns about the fairness and accuracy of peer assessment (i.e., students felt their peers were unqualified), mainly in classes where instructors didn’t participate in the grading process or when input from an expert was not included. Several researchers have advocated for explicit instruction regarding what constitutes useful feedback (e.g., Refs. 21, 36, and 51), including providing a handout or a checklist of criteria (2, 7, 51) to help students provide useful and constructive criticism and building in student accountability for providing useful feedback to peers [e.g., multiple-choice quizzing in an online tutorial (17) and providing grades for students’ peer reviews (51)].

Providing feedback through peer review leads to self-assessment (51), a useful skill for any undergraduate student, and critical self-judgment is viewed as central to the development of lifelong learning (4). Several researchers have suggested that formative feedback from peer review results in greater student learning (51, 54) because it affords students the opportunity for direct and immediate application of new ideas and perspectives. Receiving feedback and reflecting on it are highly valuable in the learning of writing (8, 31), as evidenced by higher scores on revision papers compared with original sub-
missions or drafts (10, 21, 30, 36, 40). Instructor feedback on writing assignments, however, has shortcomings. First, it provides only one person’s perspective, and, second, it is often summative rather than formative, allowing students no opportunity to apply the feedback received in a revision or to benefit fully from an iterative process of learning (46). Third, providing feedback is a very time-consuming process (24), particularly as class sizes increase (21, 46). Peer review offers benefits that counter the limitations of instructor feedback. It can be used to create a sense of audience (36) and to provide feedback from multiple perspectives, increasing the perceived validity of the feedback (27). In addition, it is in language from the student perspective, which may be more readily accessible for students (9), and it can be provided more frequently, especially in the context of larger classes and/or multiple writing assignments.

The Next Generation Science Standards (1) call for active engagement in science, which includes sense-making and language use, i.e., participating in scientific discourse. Helping students make connections between and among direct experience with science practices and reading, writing, speaking, and listening can enhance their science literacy (37, 48). Providing instruction of science process skills early in an undergraduate curriculum helps prepare students master science literacy and writing and revision skills in a Human Physiology program. Information literacy, effective communication (oral and written), and dissemination of scientific research are three of the student learning outcomes in the undergraduate Human Physiology program at Gonzaga University. The Scientific Writing course is a required, writing-intensive course that attempts to address these outcomes and integrates the scientific process, content, and writing [similar to a freshman-level course in biology described by Coil et al. (12) and a third-year chemistry course described by Glaser (18)] with the practice of peer review. The Scientific Writing course is taken in the second semester of the sophomore year after the Experimental Research Design and Data Analysis course (also known as statistics, using SPSS) and precedes junior-level coursework and laboratories in the Exercise Physiology and Human Kinetics courses and junior- and senior-level small-group research projects in physiology and biomechanics. Little formal assessment or research had been done on the Scientific Writing course since its development and inclusion in the Bachelor of Science in Human Physiology degree program at Gonzaga University. Thus, the purpose of the present study was to determine if doing peer review was an effective means of enhancing students’ perceptions of their abilities to critically read and understand primary literature, provide peer review, and incorporate feedback in their writing. In addition, we were interested in finding out if peer review affected students’ appreciation for receiving feedback and their sense of being part of a scientific learning community.

MATERIALS AND METHODS

Participants

The Institutional Review Board of Gonzaga University approved the protocols used in this study in advance of data collection. All 54 students who were enrolled in the 2013 offering of the Scientific Writing course were invited to participate in the study by the instructor (C. A. Geithner). All agreed to have their writing assessments and pre- and postcourse survey data included except for one student. Thus, this student’s data were eliminated from the analyses. Of the remaining 53 students, 2 additional students were excluded, one student on the basis of age (a nontraditional student who was 41 yr old, returning to college coursework after a long hiatus) and the other student due to a different major of study (Psychology). Thus, neither of these two students was representative of Human Physiology majors. The final sample was composed of 51 students, the characteristics of whom are shown in Table 1.

Pedagogy

An experiential, blended pedagogical approach incorporating a variety of learning activities was used to teach the Scientific Writing course. The foci, topics, and learning activities (including small-group activities, writing assignments, and peer review assignments) are shown in Fig. 1. The general flow of information followed a fairly regular sequence or “rhythm” (18), with the introduction of a topic via a short PowerPoint presentation with examples from the primary literature, a small-group activity modeled after the process-oriented guided inquiry learning (POGIL) approach (50), one or more writing assignments (in small groups, drafts, and nongraded and graded), and a peer review. Students were presented with selected research articles in their entirety, however, each writing assignment and peer review focused on only one component or section of a scientific paper to build students’ knowledge, skills, and confidence incrementally.

| Table 1. Characteristics of the entire sample of students in the 2013 cohort of the Scientific Writing course and the subgroup of students with complete survey data |
|-----------------|-----------------|
|                  | Sample          | Subgroup        |
|                  |                 |                 |
| *n*              | 51              | 26              |
| Age, yr (n)      | 20.3 ± 1.0 (45) | 20.2 ± 0.7 (23) |
| Sex              |                 |                 |
| Female, n (%)    | 31 (60.8)       | 14 (53.8)       |
| Male, n (%)      | 20 (39.2)       | 12 (46.2)       |
| Race             |                 |                 |
| Caucasian/White, n (%) | 44 (86.3)       | 23 (88.5)       |
| Asian, n (%)     | 5 (9.8)         | 2 (7.5)         |
| Hispanic, n (%)  | 1 (2.0)         | 1 (3.8)         |
| Hawaiian Pacific Islander, n (%) | 1 (2.0) | 0 (0.0) |
| Career choice (top 4 by frequency) |                 |                 |
| Physical therapy, n (%) | 23 (46.9)       | 13 (52.0)       |
| Physician’s assistant, n (%) | 5 (10.2)       | 2 (7.7)         |
| Other, n (%)     | Medicine: 9 (18.4) | Occupational therapy: 1 (4.0) |
|                  | Occupational therapy: 2 (4.1) | Nutrition/dietetics: 2 (4.1) |

n, Number of students.
throughout the semester. The culminating experience of the course was to complete individual and small-group peer reviews of a manuscript in its entirety, bringing the process full circle.

A hypothetical experimental research study was used in the course on a topic that the instructor thought might be of interest to and understood by the students: the impact of diet and exercise on body mass and composition (as the Scientific Writing course is generally taken in the same semester as the Human Anatomy and Physiology II and Nutrition and Metabolism courses). The research study was introduced in week 6 of the 16-wk semester, and the instructor provided students with fabricated data for a sample of hypothetical college students including sex; initial body mass, height, and percent body fat; treatment protocol (control/no treatment, diet, and diet and exercise); and posttreatment weight, height, and percent body fat. The fabricated data were used due to time constraints (i.e., little time for actual data collection) and were provided solely for the purposes of education and practice with SPSS data analyses and the presentation of data (e.g., transforming data and creating new variables, such as fat mass and fat-free mass; running descriptive analyses and comparing means; and presenting results in a table and a figure). The fact that
data were fabricated and the rationale for this were explicitly communicated to students along with the clear understanding that this was an example of an ethical breach in doing science and not acceptable in real life! The Figure Facts approach (42) was incorporated to help students use a data-centered approach to reading relevant primary literature. Activities involving groups of two to five students were used to establish a culture of group work and create a community of learners. Small-group guided inquiry learning activities based on the POGIL approach (50) were developed around major components of a scientific paper: the Abstract and Title, Introduction, Materials and Methods, Results (Text, Tables, and Figures), and Discussion and Conclusions. In addition to the small-group activities, multiple writing assignments and peer reviews focused on the parts of a scientific paper, in sequential order throughout the semester. Writing assignments and peer reviews were incorporated to help students think like scientists and to enhance their scientific literacy. Students incorporated feedback from peers and the instructor on their drafts in revisions of three writing assignments.

Founded in Nuthall’s (34) premise that students learn a considerable amount of what they learn from their peers, in addition to several years of positive experience using peer review in the teaching of scientific writing and research methods, peer review was an important pedagogical approach and learning activity in the Scientific Writing course. As such, it was presented to students in a very intentional way to foster positive student perceptions about the process and the value of their feedback. At the beginning of the course, peer review was defined, and examples of peer review in science and other disciplines were provided along with an explanation of the roles and values of peer review in the process of writing and disseminating scientific research and publication. This introduction to peer review was accomplished via a short PowerPoint presentation, which was posted on Blackboard so that students could refer to it over the course of the semester. Students were reminded throughout the semester that the point of peer review was to provide specific, helpful, and critical yet respectful feedback that would enable the recipients to improve their scientific writing skills.

Peer review was stressed as a professional responsibility in which members of the scientific community participate. Students were provided with an article by Benos et al. (2), which included criteria for the review of a manuscript and helped students learn the content that should be included in each section of a scientific paper. Peer review was then used to help students critically read selected articles from the scientific literature. More specifically, students were given iterative opportunities to read and critically evaluate individual components of several published scientific papers in activities structured after the POGIL approach with questions that guided them to identify critical content.

In addition, students were provided with the same assignment-specific rubrics used by the instructor (see APPENDIX I in the Supplemental Material for sample rubrics).1 Students were asked to address critical content [similar to assignment-specific rubrics developed by other researchers; see Timmerman et al. (53), Table 1] and to identify strengths and weaknesses and/or offer specific suggestions as to how to improve the content or the clarity, brevity, and flow of writing. Students were given multiple opportunities to provide and receive feedback from their peers and the instructor throughout the semester, both online, using their laptops in class for single-blind reviews set up as Peer Mark assignments in Blackboard (e.g., outlining the Introduction, research questions and hypotheses, Methods draft, and Results text), and on hard copies of assignments in class (e.g., research questions and hypotheses, Results table and figure). Students also received feedback on their peer reviews of other students’ writing assignments by the instructor to help them better understand what to look for and how to provide helpful critical feedback on another’s writing. Overall, the introduction to, training in, and practice of peer review provided to students were aimed at improving the accuracy and usefulness of feedback given by relatively novice reviewers. The initial presentation and revisiting of peer review and the use of common rubrics for peer and instructor feedback on writing assignments throughout the semester were aimed at creating an atmosphere of trust in and appreciation for the peer review process.

For the final peer review, each student completed a written individual review of the same full manuscript (a peer-reviewed publication in a major journal) using a rubric consisting of a detailed set of criteria (see APPENDIX II in the Supplemental Material). Both the individual and group peer review rubrics contained the same criteria for rating the different components (i.e., sections) and critical content of the manuscript. After students submitted their individual peer reviews, they were assigned to small groups to discuss their individual reviews and to come to a consensus recommendation, as if for submission to an editor. Each group had to identify the strengths and weaknesses of the manuscript and justify their decision to accept as is, accept with minor revisions, revise and resubmit, or reject the manuscript. The group discussion and consensus recommendation represented additional activities that the individual peer review did not include.

Data Collection

Indirect assessment of student learning was accomplished via pre- and postcourse surveys (see APPENDIX III in the Supplemental Material). The surveys were constructed by the instructor based on what she wanted to know about the impact of the Scientific Writing course and specific learning activities on students’ knowledge, skills, and attitudes related to scientific writing and science and to the learning outcomes established by the Department of Human Physiology faculty.

Students self-assessed their abilities reflecting four domains: knowledge, general writing skills, scientific writing skills, and attitudes related to science and writing. Students rated themselves using a 5-point Likert-type scale (where 1 = none to minimal and 5 = very high to excellent; later coded numerically as 1–5). Seven of the thirty survey items were identified by the authors as related to scientific literacy and writing skills and impacted by peer review (see Table 2 and APPENDIX III in the Supplemental Material, survey items 4 and 23–28). One survey item was adopted from those used in previous studies, and most were adapted or developed specifically for the course in the present study. Sources of survey items are shown in Table 2. All participants completed the precourse survey in class at the beginning of the semester and the postcourse survey during the final exam period at the end of the semester (Fig. 1). In addition to the survey items used in the present study, the following open-ended questions [adapted from questions used by Balster et al. (1a) and Hoskins et al. (23a)] were included in the postcourse surveys:

1. Which two to three activities and/or assignments were the most helpful to you in increasing your knowledge and understanding of science?

2. Which two to three activities and/or assignments were most helpful in increasing your scientific writing skills (your capacity to write effectively in a scientific format)?

Students were asked to place an “X” in 2–3 blanks to mark their choices from a list of the 21 learning activities included the course.

Experimental Design and Data Analyses

We used a pretest/posttest comparative design to examine changes in students’ perceptions over time via self-ratings on pre- and postcourse surveys. Data for student self-ratings on seven survey items related to scientific literacy and writing skills and impacted by peer review were considered ordinal data and, therefore, were compared from pre- to postcourse surveys using a

1 Supplemental Material for this article is available at the Advances in Physiology Education website.
Table 2. Students’ self-ratings on each of seven items impacted by doing peer review from pre- and postcourse surveys completed by students in the Scientific Writing course

<table>
<thead>
<tr>
<th>Survey Item</th>
<th>Precourse</th>
<th>Postcourse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability to critically read scientific literature</td>
<td>2.8 ± 0.6</td>
<td>4.1 ± 0.7*</td>
</tr>
<tr>
<td>Ability to identify critical content of different components of a scientific paper or laboratory report</td>
<td>2.8 ± 0.8</td>
<td>4.2 ± 0.6*</td>
</tr>
<tr>
<td>Ability to provide peer review</td>
<td>3.1 ± 0.7</td>
<td>4.0 ± 0.6*</td>
</tr>
<tr>
<td>Ability to incorporate feedback in rewriting/revision</td>
<td>3.5 ± 0.6</td>
<td>4.2 ± 0.6*</td>
</tr>
<tr>
<td>Appreciation for peer review and feedback</td>
<td>3.6 ± 0.6</td>
<td>4.6 ± 0.5*</td>
</tr>
<tr>
<td>Ability to effectively and collaboratively work with peers</td>
<td>3.6 ± 0.6</td>
<td>4.7 ± 0.5*</td>
</tr>
<tr>
<td>Sense of being part of a scientific learning community</td>
<td>3.4 ± 0.6</td>
<td>4.5 ± 0.5*</td>
</tr>
<tr>
<td>Composite self-rating score (sum of seven survey items)</td>
<td>22.8 ± 2.3</td>
<td>32.0 ± 2.6*</td>
</tr>
</tbody>
</table>

Values are means ± SD. Data shown are for students for whom there were complete data for all seven survey items on both the pre- and postcourse surveys (n = 26). 1Adopted from survey items used by Brownell et al. 2013 (5a): “Ability to understand primary scientific papers” and Hoskins et al. (23a). 2Adapted from the strategy used Corradi (13a) in which a sample practical report was used to facilitate writing in the scientific style. Corradi assessed the usefulness of the sample practical report via an anonymous survey later in the year. 3Adapted from survey items used by Guilford (21): “I learned to review and assess other people’s work” and “I will change the way I write.” 4Adapted from Rangachari (40): “Now, I better appreciate the complexities of the peer review process.” 5This item is specific to a student learning outcome in the Department of Human Physiology at Gonzaga University: “To work cooperatively, professionally, and ethically with others towards a common goal.” 6Related to the student learning outcome identified in footnote 5 and based on a finding of Buchwitz et al. (5b) regarding a deepening of students’ understanding of the value of learning communities. 7Postcourse self-rating scores were significantly higher than precourse self-rating scores, P < 0.05.

DISCUSSION

Our study sought to determine if doing peer review is an effective means of enhancing students’ perceptions of their abilities to critically read and understand primary literature, provide peer review, and incorporate feedback in their writing. In addition, we investigated whether peer review affected students’ appreciation for receiving feedback and their sense of being part of a scientific learning community.

It is interesting that the smallest improvements from pre- to postcourse surveys were in students’ self-ratings of their ability to provide peer review and ability to incorporate feedback in rewriting/revision, considering that students indicated that peer review and revision assignments were the most helpful learning activities in improving their scientific literacy and writing skills. These findings may reflect that students view writing and providing feedback on writing as complex skills that take...
more practice than reading scientific papers and identifying their components and related critical content.

Our finding of a significant pre- to postcourse improvement in students’ self-rating of their ability to provide peer review is consistent with the observation of Smith et al. (47) that repeated practice with peer review has been shown to enhance students’ confidence in peer assessment over time. In our study, students made revisions to their papers after receiving feedback from both their peers and the instructor, and their self-ratings of their ability to incorporate feedback in rewriting/revision improved significantly from the precourse to postcourse. Our findings are consistent with those of other researchers (13, 21, 30), in which peer review seemed to be an important factor in students improving their writing skills based on student responses on postcourse surveys and changes in scores on papers and presentations after peer review. Our data also support the observation by Flower et al. (16) that revising can help students to “re-see” and make substantial changes to their writing. Thus, revising is viewed as a key to good writing and is “a powerful, generative process” (16).

In addition, students were provided with feedback on their peer reviews from the instructor and received grades on the peer reviews they provided on other students’ papers, to hold them accountable, to help them better understand how to give constructive criticism, and to improve the quality of their peer reviews. Students were not graded on the peer reviews they received on their writing assignments, and this practice may have helped counter any negative perceptions regarding the fairness and accuracy of peer assessment found in previous studies (e.g., Ref. 27).

It is worth noting that only 26 of 51 students had complete data for the pre- and postcourse survey items related to scientific literacy and peer review, although the magnitude of the changes in self-ratings from the precourse to postcourse differed by 0.1 or less on a 5-point Likert-type scale between the entire sample and subgroup. The missing data on the precourse survey may have been a reflection of students not knowing how to rate their abilities in areas in which they lacked experience. That is, they didn’t know what they didn’t know. Even so, students rated their “ability to provide peer review” and their “appreciation for peer review and feedback” significantly higher on the postcourse survey than on the precourse survey, consistent with the findings of Rangachari (40).

Providing students with rubrics and a checklist for review processes for the writing assignments and for the final peer review of an entire manuscript in our study appeared to be effective in increasing their perceived “ability to identify critical content” and their “ability to critically read scientific literature,” as evidenced by significantly higher self-ratings on postcourse surveys. Thus, the improvements in students’ perceived abilities to critically analyze scientific literature and critique manuscripts in our study are consistent with the findings of Seals and Tanaka (45). The rubric used in the Scientific Writing course for the final peer review assignment contained similar elements to the universal rubric created by Timmerman et al. (53). Our approach to the final peer review was similar to that of Mulder and Pearce (31), who found that training in peer review and the use of a review form with structured yes/no questions targeting important aspects of each section of a scientific paper improved the quality of peer reviews and resulted in greater student satisfaction with peer reviews received. Having students use the same rubrics used by the instructor for reviewing papers in our course [like Timmerman and Strickland (51)] may have improved students’ understanding of the instructional goals, although this was not assessed in our study.

Students’ perceptions of their “ability to effectively and collaboratively work with peers in the peer review process” (as most noticeably evidenced in the final peer review) and “sense of being part of a scientific learning community” increased from the precourse to postcourse by 1.1 points on the 5-point Likert-type scale (n = 26; Table 2). These positive outcomes are similar to the results of Guilford (21), who found that 90% of students found working with other students in peer review enjoyable and less work and that 91% of students responded favorably to peer review. Similarly, Rangachari (40) found that students developed an appreciation for group work and the importance of peer review as a result of writing perspectives papers on issues in small groups. Both the group review assignments used by Rangachari (40) and the individual and group peer review assignments used in the present study provided students with opportunities to work effectively and collaboratively with each other and to critically discuss and contemplate new ideas. In doing so, students had the opportunity to experience the sense of being part of a scientific learning community.

The course content and some of the methods (i.e., writing-intensive approach and peer review) used in the Scientific Writing course were fairly novel to the students. The authors feel that the in-class learning activities involving small groups provided peer support and may have contributed to the significant increases in students’ self-ratings of their abilities related to scientific literacy as well as their ability to work effectively and collaboratively with peers and their sense of being part of a scientific learning community. Iterative opportunities in providing and receiving peer review may have contributed to the significant increase in students’ self-ratings of their ability to provide peer review and to incorporate feedback in rewriting/revision as well as their appreciation for peer review and feedback.

Limitations and Strengths

Limitations. Limitations of the present study are as follows: 1. The course- and assignment-specific surveys and rubrics were created by the instructor. However, the approach to survey construction and use in our study is consistent with that in previous studies in that most survey items seem to be written with the purpose of assessing learning outcomes of interest to the researchers. For example, Hoskins et al. (23a) indicated that their survey was designed based on previous experience with using the primary literature as a teaching tool, and they focused on issues identified as problematic by students. The survey used in our study was piloted in two previous cohorts of students taking the Scientific Writing class, and the results provided useful information about impactful learning activities and approaches. Some of the survey items in the present study were adopted or adapted, in part, from those used in surveys and student self-assessments by other researchers to gauge the effectiveness and/or impact of teaching-learning approaches (1a, 5a, 5b, 13a, 21, 23a, 40). We found only two cases in previous studies where surveys used were piloted and revised.
students design, implement, and write up their own experiences (31), and, when used in an undergraduate program, it may provide an opportunity to benefit from both reflective and iterative learning activities in improving their scientific writing skills.

3. Bias or subjectivity in evaluating writing styles and skills is inherent in peer review at some level (21). Attempts to reduce bias in evaluating student writing were made in the form of explicit instruction and training in doing peer review and in the use of the same rubric by students and the instructor in providing feedback on students’ writing assignments.

4. Analysis of the quality of peer reviews was not done, although students were given training and iterative opportunities in doing peer review and were given feedback (and grades) on their peer reviews by the instructor. Therefore, the authors were unable to determine whether the quality of students’ peer review improved over the course of the semester.

Strengths. The strengths of the present study are as follows:

1. Including peer review as part of a blended pedagogical approach to learning is consistent with a number of previous studies (2, 18, 21, 30, 39, 40, 45, 49, 53). Incorporating different forms of peer review (single blind and open as well as individual and group) along with writing assignments is a practice consistent with the admonitions of Hanauer and Bauerle (22) to include a range of assessment tools and both formative and summative assessments in undergraduate science courses and the charge to academics from Fellenz (14) to design meaningful assessment activities that support higher level learning.

2. Our study may be the first to assess the combined impact of feedback from peers and the instructor on students’ perceptions of their scientific literacy and writing skills.

3. An experiential, writing-based approach to learning (i.e., doing peer review in addition to hearing and/or reading about it) is consistent with two of four recommendations of Jones (25) to science academics to ensure that “undergraduate science curricula are founded upon teaching approaches that foster active learning.” Students’ identification of peer review as the most helpful learning activity in increasing their knowledge and understanding of science and as one of the most helpful learning activities in improving their scientific writing skills is consistent with the merit accorded peer review by others who have done research on using peer review as a teaching-learning tool in the undergraduate sciences (12, 18, 21, 30, 40).

4. Early exposure to primary literature and writing skills combined with giving and receiving peer review allows for progressive development of skills inherent in scientific literacy, including being able to critically read and understand scientific papers and identify the critical content of different components of a scientific paper. This approach provided students with the opportunity to benefit from both reflective and iterative learning (31), and, when used in an undergraduate program, it may also pay off in benefits in culminating experiences in which students design, implement, and write up their own experiments (56), as they do in the Human Physiology program at Gonzaga University.

5. Receiving feedback from multiple sources, specifically from peers and the instructor, and a variety of perspectives may have positively impacted writing quality, similar to the results of Cho and Schunn (10), although improvement in students’ writing skills was not directly assessed in our study.

A few caveats offered by other researchers are worth reiterating. The approaches to teaching peer review and scientific writing should be selected based on the desired outcomes of the course, the circumstances (including class size), and available resources (21, 30, 40). In addition, if peer review is to be successful, i.e., students appreciate the feedback from peer review and perceive it as accurate and/or useful, instructors need to take time to present it explicitly and thoughtfully so that students understand why and how it will be used (31, 51). Finally, instructors should providing training in, rubrics for, and multiple practice opportunities with peer review (2, 21, 51, 53).

Conclusions

Changes in student’s perceptions of their scientific literacy and writing skills were measured indirectly through self-assessments on pre- and postcourse surveys in an undergraduate Scientific Writing course. Students’ self-ratings on seven survey items addressing abilities impacted by peer review improved significantly, as did composite survey scores ($P < 0.05$). The largest pre- to postcourse changes were observed in students’ perceptions of their abilities to critically read the scientific literature and identify critical content of different components of a scientific paper, consistent with findings of other studies using peer review in undergraduate science programs. Peer review also had significant and positive impacts on students’ perceptions of their ability to effectively and collaboratively work together and their sense of being part of a community of scientific learners. Students identified the final peer review (individual and group reviews of a manuscript) as being the most useful learning activity in enhancing their knowledge and understanding of science. The revision of the Results table and figure assignment was identified as most helpful in improving students’ scientific writing skills, and the final peer review assignment was among the top five learning activities. Thus, doing peer review and receiving feedback in a scientific writing course can be an effective means of achieving outcomes related to scientific literacy and improving students’ scientific writing skills. More broadly, active engagement in peer review can help students better appreciate the peer review process and its value in the scientific process, in the quality of publications within their discipline, and in their future careers.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

Author contributions: C.A.G. conception and design of research; C.A.G. performed experiments; C.A.G. and A.N.P. analyzed data; C.A.G. and A.N.P. interpreted results of experiments; C.A.G. prepared figures; C.A.G. and A.N.P. drafted manuscript; C.A.G. and A.N.P. edited and revised manuscript; C.A.G. and A.N.P. approved final version of manuscript.

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