A Model for Facilitating Peer Review in the STEM Disciplines: A Case Study of Peer Review Workshops Supporting Student Writing in Introductory Biology Courses

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Writing and peer review are essential features in all scholarly disciplines; these practices should be developed and encouraged, especially in undergraduate courses where students are just beginning to think critically in a new discipline. Writing and peer review feed into one another to promote essential elements of critical thinking, including conscious conceptualization, categorization, application, evaluation, and synthesis (Halpern, 2013). However, while writing is an essential feature of many undergraduate STEM courses, peer review is less frequent.

Writing is a powerful way to learn science (e.g., Reynolds, Thaiss, Katkin, & Thompson, 2012; Stout, 2011). Writing not only enables students and instructors to better discover when concepts are mastered (Campbell, Kaunda, Allie, Buffler, & Lubben, 2000) but also pushes students to synthesize material from lecture, reading, and lab (Beiersdorfer & Haynes, 1991). In fact, undergraduates report being more comfortable with scientific writing, proposing a research question, and designing an experiment after writing a research proposal (Stanford & Duwel, 2013). True synthesis of complex material often comes only as students write about it, such as when discussing experiment results (Lerner, 2007). Thus, writing is an important way to promote various aspects of critical thinking, including conceptualization, application, and synthesis.

However, many undergraduates focus on the technical aspects, or "rules," of scientific writing, such as section requirements and table formatting, rather than on writing as communication of scientific information or as a means of scientific discovery (e.g., Gladstein, 2008; Stout, 2011). Students' focus on the more technical aspects of writing may stem from the fact that many science writing guides focus on the rules of the discipline (e.g., Matthews & Matthews, 2007; Zeiger, 1999) or on writing as a way to communicate scientific information without adequate interpretation (e.g., Paradis & Zimmerman, 2002; Pechenik, 2010), instead of on writing as a "thinking and learning tool," a means to understand, evaluate, synthesize, and apply concepts (Stout, 2011, p. 2). Students need to be taught that writing in STEM is not simply conforming to technical standards but also a method of critical thinking.

While writing is a regular feature of many undergraduate STEM courses, peer review is less common, though increasing (Nicol, Thompson, & Breslin, 2014; Trautmann, 2009). Peer review involves students giving, receiving, or, most commonly, both giving and receiving critique about a shared assignment; peer review can be conducted in person, in writing, and/or online. Studies show that students who give and receive peer review revise more fully, write stronger manuscripts, feel more empowered to interpret information, better understand complex processes, and better comprehend the scientific writing process and the importance of peer review in science (Guilford, 2001; Rangachari, 2010; Trautmann, 2009). In fact, a study on co-authorship teams found that novice scientists discovered that the writing and revising process influenced the quality of the science produced (Florence & Yore, 2004). Because peer review asks students to repeatedly

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evaluate and judge their own work and that of their peers, a recent study argued that peer review is a "fundamental…skill" that should be taught explicitly (Nicol et al., 2014, p. 102). Thus, like writing, peer review helps students think critically, especially through improved conceptualization, synthesis, evaluation, and application of new information.

When used together, writing and peer review enable students to think more critically and understand scientific material more fully than they otherwise would (e.g., Quitadamo & Kurtz, 2007; Reynolds & Thompson, 2011; Stout, 2011). Students learn more when concepts are taught through a combination of writing and peer review than when taught with lecture alone (Pelaez, 2002). Writing and peer review also underscore the collaborative, iterative nature of the professional scientific community, as experiments and research articles are worked on by teams and go through many rounds of feedback and revision (FitzPatrick, 2004).

However, bringing more writing and peer review into STEM courses—particularly large, introductory courses—can be challenging, given that faculty generally have heavy workloads and large classes. Faculty often must rework their courses to make room for students to participate in writing and/or peer review, and/or take more time responding to student work (e.g., Guilford, 2001; Reynolds, Smith, Moskovitz, & Sayle, 2009; Reynolds & Thompson, 2011; Stout, 2011). Web-based peer-review is one strategy for incorporating more writing and peer review into courses without taking up substantial course or instructor time (Pelaez, 2002; Nicol et al., 2014), but the virtual environment can be challenging because reviews can be impersonal, without back-and-forth oral communication and idea exchange (Breuch, 2004). Writing programs provide another way to bring more writing and peer review into STEM courses, but this, too, has a cost, as it often requires, in order to be successful, a significant investment from the writing program. For instance, directors of one program asked students about their concerns and developed and delivered workshops to help students communicate their findings (Bayer, Curto, & Kriley, 2005). Others rely on lecturers from the writing program to directly assess student writing or to create rubrics to help faculty assess student writing (Lerner, 2009; Reynolds et al., 2009). Still other writing programs use trained peer writing tutors to conduct one-on-one or small group writing consultations (Franklin, DeGrave, Crawford, & Zegar, 2002; Gladstein, 2008).

In this report, we present a model for facilitating peer review of student writing assignments that requires comparatively less investment from the STEM department and from the writing program. These workshops provide a relatively easy way to incorporate writing and peer review into STEM courses—and thus perhaps also to promote critical thinking, which has been demonstrated to occur when students undertake writing and/or peer review. At our institution, Pomona College, peer review workshops tailored to specific introductory biology lab reports were led by peer writing fellows with STEM backgrounds, already trained by the writing program (all writing tutors are called writing fellows at Pomona). Thus, additional training for the workshop leaders was minimal. Biology faculty integrated the workshops into their syllabi and provided each assignment's grading rubric to facilitate peer review. The workshops were optional and took place outside of regular instruction time. This approach enabled faculty to cover the same amount of course material while underscoring the importance of writing and peer review. Student and faculty feedback show that these peer review workshops emphasized the importance of writing in biology and may have helped to improve the overall quality of introductory students' lab reports. In addition, as the workshops evolved from a more formal approach focused on science writing in general to a less formal, more student-centered approach, student satisfaction and attendance increased. This writing-in-the-disciplines program stressed the importance of writing and peer review, giving students a focused introduction to collaborative writing in a particular STEM

discipline (biology).We recognize that for an institution that does not yet have trained writing fellows with experience in STEM, such a program would be a nontrivial investment. However, the organized, section-by-section nature of lab reports lends itself to standardized, widely-applicable fellow training focused on underscoring the importance of argument and organization as students move from section to section (Gladstein, 2008).

Background and Methods

Pomona College is a small, private, selective liberal arts college with 1500 students. At this institution, writing in biology begins in the introductory courses (cellular biology, genetics, and ecology and evolutionary biology) and continues throughout the major. Most, but not all, students in the introductory courses are first-years and sophomores, and most are considering some kind of science major. (Students declare a major at the end of their sophomore year.) Pomona has always required students in introductory biology courses to take a concurrent lab section and to write extended laboratory reports (Genetics faculty).[1] However, the level of formality, length, and complexity of the reports has changed over time. In general, biology curricula are becoming more process-based (e.g., Treacy et al., 2011), and our biology major has followed suit. For instance, our cellular biology course used to have five shorter experiments but now has two longer ones (Cell biology faculty). Likewise, starting in 2008, the genetics faculty began to assign the reports in sections, progressing to more complete lab reports at the end of the semester, recognizing the need to introduce scientific writing in stages (Genetics faculty).

As lab reports in the introductory courses became more extensive, faculty recognized the need for more writing assistance (Genetics faculty). Students spent copious amounts of time asking how to write a lab report. Some professors started conducting a writing advising session, but that took up a large amount of class time. Moreover, the instructions provided in the laboratory manual were not sufficient, even with carefully explained details and expectations, because students needed an experienced writer to address unanticipated questions (Cell biology professor). Biology faculty members decided to have a renewed emphasis on the components of good writing, and one of the professors approached the writing program director for her ideas. At first, neither the biology professors nor the writing program director knew exactly how to best support students. Though one-on-one and small group consultations between trained peer tutors and science students have proven effective at other institutions (Franklin et al., 2002; Gladstein, 2008), the small number of trained science writing fellows and large number of introductory biology students made such strategies impractical at our institution. It was thus determined that the program would have to rely on a few science writing fellows to lead large student workshops. The science writing fellows, though, were prepared, as the previous semester they had interviewed faculty and prepared a student handout about successful science writing (Writing program director; Pomona College Writing Program, 2007).

Together, the biology department and the writing program created writing and peer review workshops to support students in the two largest introductory biology courses: cellular biology and genetics. The first workshop was held in Fall 2007 to assist students with lab reports in cellular biology and expanded to genetics in Spring 2008. Workshops have continued for both courses.

Because genetics is a prerequisite for the other introductory biology courses, it also serves as students' introduction to writing in the discipline. Students submit three written reports for genetics; for the first, they submit a title, results section, and responses to a few discussion questions; for the second, they add an introduction and a literature cited section; for the third, they write a full lab report with all the component sections. For genetics students, we offered three 90-

minute workshops (each repeated over several evenings), focused on each of the three different assignments. For students in cell biology, we offered one 90-minute workshop (again, repeated over several evenings) tailored to their assignment to write a complete lab report. Because genetics is a prerequisite for cell biology, students are therefore at least somewhat familiar with writing in biology when they enter the second course.

To investigate the origin and evolution of the writing workshops, in Spring 2011 Brieger conducted interviews with the biology faculty, the writing fellows who created the workshops, and the writing fellows who ran the workshops through 2011. She also asked the biology faculty to evaluate the workshops through an online survey. Student feedback was collected through a short exit survey; workshop evaluations, like most teaching evaluations, were completed right after a session; while there was likely an overly positive response from immediate survey completion, teaching evaluations have been found to be "reliable and stable…., relatively valid against a variety of indicators of effective teaching, [and] relatively unaffected by a variety of variables hypothesized as potential biases" (Marsh, 2007, p. 319). Student evaluations were collected in the last semester of the more formal workshop method (Fall 2009) and for the first three semesters of the less formal workshop style (Spring 2010, Fall 2010, and Spring 2011). This enabled us to compare student satisfaction with the workshops in two different formats.[2]

While there have been changes since the workshops began in 2007, much has remained the same. First, a common lab manual and a common grading rubric are used by all sections of each course, regardless of faculty member. Second, because of large enrollments, faculty are not able to provide feedback on student drafts. Third, workshops are always included in the syllabi and held in the evenings in the week before the lab reports are due, though due dates are sometimes staggered by lab section; faculty encourage students to attend earlier workshops. Fourth, since 2009, students have worked with a lab partner to conduct the experiments and write the reports. The pairs do not necessarily attend the workshop together, and each student is encouraged to take full responsibly for the collaborative report. Finally, while the workshops are integrated into the course, attendance is not mandatory and students do not receive extra points for attending, though we note that, at other institutions, such workshops could become mandatory, part of class participation, or associated with extra credit if desired.

Workshop Evolution

In consultation with biology and writing program faculty, the science writing fellows began by creating a classroom-style writing workshop. Designing the workshops from scratch was extremely challenging, as fellows had to determine the workshops' key goals and how best to accomplish them. Biology faculty wanted to be certain that the fellows would not provide students help with the science and that the workshops would help students take advantage of writing resources already available in the lab manual. Students were asked to arrive at the workshop with their draft. Fellows spent the first part of the workshop walking students through the different sections of a lab report, using the chalkboard and handouts to illustrate important points. With the lab manual as a guide, fellows explained what material should be in each section of the lab report; they also presented good and bad samples of each section, drawn from lab reports faculty had received in the past as well as published scientific papers. In the latter part of the workshop, fellows asked students to pair up and trade drafts. Students would note what their peers could improve on, based on the lab manual and the earlier workshop discussion, while writing fellows circulated around the room answering writing-related questions (Writing fellows). Thus, the first iteration of the workshops was classroom-based, where the fellows assumed more of a teacher-like role. There

was a "how to" presentation about science writing focused on each section, and opportunities for questions, followed by peer review.

After the first series of workshops, the writing fellows, with input from students and biology and writing program faculty, evaluated and revised the workshops. Over time, the fellows moved from a workshop model that began with more lecture, chalk talk, and discussion of good and bad examples to one that focused more on peer review.

Though changes took place gradually since the inception of the workshops, beginning in Spring 2010, we made three important changes. First, we re-structured the workshops to make them less instructional, with more opportunities for questions and discussion, enabling students to engage in peer review earlier in the session. Fellows did not begin with a formal discussion of what goes in each section. Instead, they started by introducing common errors to be wary of. Fellows did not show any examples of reports, good or bad, either, but instead encouraged students to use each other's drafts as models; toward the end of the workshop, fellows encouraged students to identify and share with the larger group particularly strong examples. Second, the workshops were more clearly tied to the courses. As in the earlier workshop format, students paired up and exchanged drafts, while fellows circulated around the room and answered writing-related questions. However, instead of using the lab manual as a guide for peer review, students used that lab's grading rubric as a way to assess each other's reports. Third, the group of fellows who led the workshops broadened. While the fellows leading the workshops all had a scientific background, they were no longer only biology or science majors with experience in biology. Though students with coursework in biology continued to be the lead fellows, other fellows with a non-biology STEM background, with a few hours of additional training, helped facilitate the workshops, which made staffing the workshops much easier. In the revised workshop format, science writing fellows talked with students informally about what made for an effective lab report; students then engaged in peer review, pairing up to trade reports, evaluating each other's papers, and noting possible areas for revision.

It is worth noting that the fellows themselves benefit immensely from leading the workshops. Particularly for those who hope to go on to teach in the STEM disciplines, guiding students through the writing and peer review process—and, necessarily, critical thinking—of laboratory reports was a valuable experience. Several fellows who have gone on to pursue doctoral degrees in the sciences reported that their communication and writing skills are highly valued by their research groups (Writing fellows); improved writing and communication skills are two of the major long-term benefits of working as a peer tutor, as noted in a cross-institutional study of former peer tutors (Hughes, Gillespie, & Kail, 2010).

In Fall 2013, the biology department took over running the workshops. Science writing fellows now train the department's student mentors to conduct the workshops; the advantage to this is that the mentors can help students who have questions about both writing and science. Because student mentors meet with the course coordinator on a regular basis, training the mentors to conduct the writing workshops has been included in one of these meetings. This change has meant that there has not been much more additional investment from the biology department and much less investment from the writing program. While the department now conducts the workshops, the overall mission for the workshops remains deeply rooted in writing pedagogy: by reading and revising drafts, students focus on, and hopefully improve, their own critical thinking and writing.

Results and Discussion

We gauged the overall success of the workshops through two methods: faculty feedback about the quality of student lab reports they received, and student feedback about, attendance at, and satisfaction with the workshops. We hope that, over time, these workshops will increase awareness of how writing and peer review function, both in biology and in STEM disciplines more generally.

Student Feedback

Direct student feedback provided one way to evaluate the success of the workshops. In evaluations of the Fall 2009 workshops, students commented that the workshops were "extremely useful" and even that "peer-review = great." In addition, students found the progressive assignment arc helped them feel more comfortable with science writing, given that the requirements of each section are so specific (Writing fellow). Fellows noted that students found the workshops helpful from the outset, and that students were very grateful to have a resource available outside class to help them with their lab reports (Writing fellows). However, students had complaints. Although workshops were "good on the specifics of format/structure/language," many students felt they were "too structured." Students felt that too much time was spent on the lecture-style portion where the fellows explained what was necessary for each section and went through examples of good and bad lab sections. Common challenges of peer review included students' difficulty taking it seriously and being critical of each other's work (Writing fellow); similar concerns have been noted in the divided literature in this area (Nicol et al., 2014). Since the change in format from a more formal, classroom-oriented workshop focused on lab report sections to a less formal workshop focused on guided peer review based on the lab's grading rubric, students have seemed to feel more comfortable. Allowing students to refer directly to the grading rubric helped emphasize what to look for in their peers' work; psychologically and socially, too, the rubric empowered students to constructively comment on peers' work with less risk of appearing hypercritical (Writing fellow).

Two specific indicators point to the workshops' growing success: increased attendance and increased student satisfaction, shown in Table 1.

Table 1 *Student Workshop Evaluations, 2009-2011*

Semester	Course	Enrolled students	Average Workshop Attendance	% of Enrolled Students Attending	% of Students Satisfied
Fall 2009	Cell Biology	101	40	39.6%	65.4%
Spring 2010	Genetics	111	69	62.5%	90.2%
Fall 2010	Cell Biology	114	70	61.4%	90.9%
Spring 2011	Genetics	151	103	68.4%	91.0%

Note. Fall 2009 was the last semester of the old workshop format. Spring 2010 was the first semester of the new workshop format. Average attendance is the average attendance at all the workshops in a given semester. Percentage of students satisfied with the workshops is the percentage of students each semester who responded "yes" when asked the question, "Did you get out of the workshop what you were hoping for?"

After the change to the workshop format, a larger percentage of enrolled students were attending the workshops and a larger percentage of students attending the workshops reported they were satisfied with their experience. The attendance and satisfaction data directly demonstrates that students increasingly sought the workshops out and found them helpful. Increased attendance

is particularly meaningful because students received nothing extra for coming to the workshops.

Faculty Feedback

Members of the biology faculty believe that the workshops have been successful in helping students improve their writing in biology. Many faculty interviewed in Spring 2011 noted that the overall quality of the lab reports they see has improved. As one of the fellows who helped originate the workshops explained, "the faculty I worked with noted immediate improvement in the writing quality following the workshops" (Writing fellow). In interviews, some professors noted that they can tell who has been to the workshops based on the quality of the reports. Several faculty members noted that, since the introduction of the workshops, there have been few truly terrible lab reports and fewer egregious errors, perhaps an indication that students are engaging in drafting and revision, rather than last-minute writing (Genetics and cell biology faculty). Faculty also reported that the overall quality of student writing has improved since the introduction of the workshops, though some feel this may not be the direct result of the workshops (Genetics and cell biology faculty). Faculty thus felt that the workshops have had a direct impact on the quality of the lab reports. There is strong departmental acceptance of the importance of the workshop model, with the biology department and the writing program collaborating each year to make sure the workshops still address student and faculty needs.

In the Spring 2011 survey, faculty rated their introductory students' writing on a scale of 1 to 5: Poor (1) – Fair (2) – Good (3) – Very Good (4) – Excellent (5). Faculty gave ratings of good or very good in all five categories: (a) proper style, formatting, tables, figures, etc.; (b) student responsiveness to professor instruction/feedback; (c) clarity of writing; (d) demonstration of mastery of scientific concepts; and (e) logical flow of ideas. In particular, we believe that the last three categories provide insight into students' critical thinking abilities; if, as the biology faculty agreed here, students have performed well in these categories, this is a testament to students' ability to conceptualize and categorize information and apply, evaluate and synthesize concepts. Given the complaints that faculty had about the quality of student writing before the institution of the workshops, it is reasonable to see the Spring 2011 faculty ratings as an indication of students' writing improvement.

Limitations and Conclusions

Faculty noted they were frustrated that more students do not take advantage of the workshops, as the students who attend generally have better reports. However, we recognize it is possible that students who attend are simply overachievers to begin with; they may have written better lab reports in any case, and may well already be more invested in the idea that writing is important to science. The improvement in student writing is likely due to a combination of factors, but faculty believe it is related both to the peer-review workshops (including students who attended the workshops potentially helping others who did not attend) and to the faculty doing a better job of emphasizing what constitutes good writing in the discipline (Cell biology faculty). It is also important to note that other factors play into the success of the workshops since they began in 2007. The workshops are not the only component of the courses focused on writing. As noted above, since 2009, students have written their reports with their lab partners; such collaboration builds in the possibility of revision and peer review. Progressing slowly through the lab report sections may help students feel more comfortable with science writing; in their first assignment, students begin by writing the title, results, and responses to a few discussion questions, adding the introduction and literature cited, submitting a complete lab report only at the end of the semester.

In addition, students are now given detailed grading rubrics with instructions about writing, tables, figures, etc. Finally, the quality of students admitted to the college is gradually improving and more students have had previous research experience (Cell biology faculty).

Generalizability of these findings is limited by the fact that it was conducted on two introductory courses at a single institution. However, we believe that this model—using trained peer writing tutors to facilitate peer review workshops about writing assignments in large introductory science courses—might prove useful in other contexts. Our approach brings into large undergraduate courses two strategies—writing and peer review—that have been demonstrated to promote student learning and critical thinking in STEM disciplines, and it does so in a way that enables students to learn about writing in a specific discipline. Moreover, this model uses relatively minimal resources, essential in this time of shrinking budgets and cost-cutting, as it does not increase faculty workload, add additional material to the syllabus, or demand much additional investment from the STEM department or the writing program.

Notes

[1]This and all subsequent references to interviews are from in-person interviews undertaken, and email responses collected, by Brieger in January and February 2011. All interviewees participated in some capacity in the creation, implementation, and/or reformulation of the workshops. We thank André Calvalcanti, Kris Cheney, and Len Seligman (Genetics faculty); Karl Johnson, Karen Parfitt, and Bruce Telzer (Cell biology faculty); Carolyn Bacon, Hannah Doll (née Salim), and Erik Lykken (Writing fellows); and Dara Rossman Regaignon (Writing program director).

[2]Complete information about our data collection procedures is available at http://research.pomona.edu/pam-bromley/research/science/methods-supplement/

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