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Using Rubrics as a Scientific Writing Instructional Method in Early Stage Undergraduate Neuroscience Study

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Scientific writing is an important communication and learning tool in neuroscience, yet it is a skill not adequately cultivated in introductory undergraduate science courses. Proficient, confident scientific writers are produced by providing specific knowledge about the writing process, combined with a clear student understanding about how to think about writing (also known as metacognition). We developed a rubric for evaluating scientific papers and assessed different methods of using the rubric in inquiry-based introductory biology classrooms. Students were either 1) given the rubric alone, 2) given the rubric, but also required to visit a biology subject tutor for paper assistance, or 3) asked to self-grade paper components using the rubric. Students who were required to use a peer tutor had more negative attitudes towards scientific writing, while students who used the rubric alone reported more confidence in their science writing skills by the conclusion of the semester. Overall, students rated the use of an example paper or grading rubric as the most effective ways of teaching scientific writing, while rating peer review as ineffective. Our paper describes a concrete, simple method of infusing scientific writing into inquiry-based science classes, and provides clear avenues to enhance communication and scientific writing skills in entry-level classes through the use of a rubric or example paper, with the goal of producing students capable of performing at a higher level in upper level neuroscience classes and independent research.

Key words: Undergraduate, scientific writing, inquiry-based learning, introductory neuroscience instruction, rubric, peer-tutoring, writing-to-learn

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Introductory biology courses frequently serve as the foundational course for undergraduates interested in pursuing neuroscience as a career. It is therefore important that neuroscience professors remain aware of the sweeping revisions to undergraduate biology education that continue to be implemented (Woodin et al., 2009; Labov et al., 2010; Goldey et al*.,* 2012). Recommendations for these changes are summarized in The American Association for the Advancement of Science's (AAAS) publication *Vision and Change in Undergraduate Biology Education: A Call to Action,* which provides a blueprint for massive change in the way that students are introduced to biology (AAAS, 2009). This new perspective encourages a focus on learning and applying the scientific method to a real and present problem that needs to be solved, whereas factual content is deemphasized.

Scientific writing competence is a crucial part of neuroscience education, and is a skill that is partly about process, partly about providing evidence, and lastly about constructing a careful argument. Requiring students to both catalog and reflect on their own work by constructing research papers allows students to experience yet another facet of a scientist's job description.

As our undergraduate biology classes move away from facts and towards process, we are left with the very real opportunity to teach future neuroscientists how to write up the experiments that they have constructed and run in our classes. As a result, introductory biology classrooms provide an ideal environment for science writing instruction that can serve as the foundation for the writing students will do in upper level neuroscience courses.

Writing as a Teaching Tool

Undergraduate neuroscience faculty should note that writing about science has more benefits than simply honing communication skills or reflecting on information. Previous research shows that the incorporation of writing elements into laboratory content enhances students' critical thinking abilities (Quitadamo and Kurtz, 2007). Obviously, learning-to-write strategies have been embraced by educators for many years, but writing-to-learn strategies are not as commonly used in the fields of math and science, primarily due to a lack of awareness by science, technology, engineering, and mathematics (STEM) educators about how writing can actually cause learning to occur. In particular, assignments that require the writer to articulate a reasoned argument are a particularly effective way to use writing-to-learn. Advocates of writing-to-learn strategies promote the merging of interpretative methods and rubrics (used so often in the humanities) with the hypothesis testing and experimental design that typically occurs in STEM fields to create a type of hybrid research paradigm (Reynolds et al., 2012), and a more holistic approach.

Making Scientific Writing Competence Part of the Introductory Biology Curriculum

The nature of scientific writing is different from traditional essay or persuasive writing, so providing specialized science writing instruction as early as possible in a young scientist's career is valuable even at institutions that mandate first year writing competence with a required core curriculum. If general undergraduate biology courses teach students the elements of good scientific writing and how to properly format a paper, future neuroscience students are much better prepared to tackle more difficult scientific content in upper-level courses, and are better able to communicate what they find in their own research. In addition, teaching science writing in a way that appeals to young scientists may help with attrition rates for majors.

Teaching students to proficiently write all sections of a scientific paper also teaches students about the different forms of communication that are essential to both scientists and to engaged citizens (Bennett, 2008). For example, the content of an abstract is similar to a news brief or could serve as a summary to inform a potential research student about what has been happening in the lab. The content of an introduction section justifies the scientific work, which is a key element in a successful grant proposal. Writing a thoughtful discussion shows that the researcher has selected the next logical experiment based on the results. Crafting a discussion that considers how the project fits into the global science community is particularly important for the introductory biology student who is taking the course just to fulfill their lab requirement, and may never sit in another science class again.

What is the Best Way to Teach Scientific Writing?

Given the importance of effective science communication (Brownell et al., 2013a), it is surprising that more resources and effort are not channeled toward teaching scientific writing to undergraduate students. There are multiple views on the most effective way to teach writing in a science classroom (Bennett, 2008; Reynolds and Thompson, 2011; Reynolds et al., 2012). Working in teams is a recommended strategy (Singh and Mayer, 2014) and many methods incorporate classmate peer review to evaluate student writing (Woodget, 2003; Prichard, 2005; Blair et al., 2007; Hartberg et al., 2008). Writing instructional methods that target scientific subjects have a history of success—for example, weaving elements of writing throughout a Neuroimmunology class (Brownell et al., 2013b), asking Neurobiology/Cell Biology students to write NSF-style grants (Itagaki, 2013) or using a calibrated peer-review writing-to-learn process in Neuroscience classes (Prichard, 2005).

Methods that emphasize understanding primary scientific literature typically focus on thesis writing (Reynolds and Thompson, 2011), the reading and discussion of landmark published peer-reviewed journal articles as an example of the correct way to write up scientific results (Hoskins et al., 2011; Segura-Totten and Dalman, 2013), or require students to actually write or submit their own articles to a peer-reviewed journal to experience the peer-review process first-hand (Jones et al., 2011). These methods typically work well to teach writing to upperclassmen, but may prove unwieldy for use in the general curriculum or for entry-level scientists. Use of a specific paper construction method can effectively help novice writers include required elements and get to a finished project (O'Connor and Holmquist, 2009), but more detailed expectations for content and style will be required for students in an introductory course.

Unfortunately for many undergraduate science writers, the first real attempt at scientific writing often happens during the undergraduate thesis, typically written as a senior, and students are commonly left to learn scientific writing on their own (O'Connor and Holmquist, 2009). It only seems reasonable that teachers should prepare their students to write an effective, culminating thesis well before the capstone coursework and research commences. Previous work showed that integrating science writing into an undergraduate psychology course over a year-long period resulted in improved student writing ability (Holstein et al., 2015). So how can underclassmen be taught scientific writing within a single semester?

Use of Rubrics to Teach Scientific Writing

The use of rubrics in STEM fields is not a new idea, and a grading rubric serves several simultaneously useful functions. First, it clearly communicates assignment requirements and sets uniform standards for student success, while eliminating unintentional bias in the faculty grading process. Next, it can be extremely useful in finding areas that the students still need help on and targeting future instruction accordingly. The rubric can also serve as a tool to create a more effective peer review process, if the instructor chooses to use it in this way. And lastly, the rubric sharpens the teacher's ideas about what he/she is looking for before the material is taught, possibly making for more effective instruction. A detailed outline can facilitate the writing process (Frey, 2003), and a detailed rubric may function in a similar manner, as it provides a scaffold to write the entire paper.

Previous research shows that rubrics can augment students' ability to use medical terminology correctly (Rawson et al., 2005) and can improve students' ability to critically evaluate scientific studies (Dawn et al., 2011). Use of a grading rubric has proven a reliable way to evaluate lab reports in large university settings using graduate teaching assistants across numerous sub-disciplines (Timmerman et al., 2010).

Informal assessment during previous semesters running a inquiry-based classroom revealed that some students with no previous active learning experiences can struggle with the lack of a textbook, the idea that process can be more important than content, and what they perceive as a lack of concrete items to memorize (personal observation, E. Clabough). In response to student feedback, rubrics were developed to provide very concrete methods of grading and assessment for items like oral presentations, lab notebooks, and writing assignments.

When presented with new material, the learning brain seeks out patterns as it processes information. Because a rubric provides structure and pattern to this process, it not only assists students with organizational strategies, but also reflects the way the brain actually learns (Willis, 2010). Use of carefully designed rubrics can increase executive functioning in students, including skills such as organizing, prioritizing, analyzing, comparing/contrasting, and goal setting (Carter, 2000). Requiring students to use the rubrics to make decisions about the material while self-grading may further tap into executive functions during the learning process.

Peer Tutoring to Enhance Science Writing Competence

Peer tutoring places a peer in the role of instructor in a one-on-one setting with a fellow student. The role of the peer tutor is to elucidate concepts, to provide individualized instruction, and to allow the tutee to practice manipulating the subject matter. Numerous studies have established the link between this form of tutoring and improved academic performance for tutees, which is measurable in a variety of subjects including reading, math, social studies and science (Utley and Monweet, 1997; Greenwood et al., 1992; Bowman-Perrott et al., 2013). The effectiveness of using peer tutoring to teach science writing to undergraduates has been under-examined, and to our knowledge, this is the first study to combine this approach with the use of a grading rubric.

The current experiment explored different ways to teach scientific writing to undergraduate students by incorporating a detailed grading rubric into established inquiry-based undergraduate biology classrooms over the course of a semester. All students were provided with scientific writing rubrics, though some students received additional peer tutoring. We did not directly measure instructional success, but the quality of scientific papers was assessed as a routine part of the course and compared against the attitudes that students had towards science writing in general. Student attitudes about the effectiveness of different ways to teach writing were also measured.

MATERIALS AND METHODS

Course Design

Randolph-Macon College (R-MC) is a small liberal arts college that converted their introductory biology classes into an inquiry-based learning format in 2010. Two semesters of the module-based Integrative Biology are offered and students may take them in any order. The current experiment was performed in these Integrative Biology (BIOL122) classrooms, which were run as a combination lecture/lab course broken into three separate instructional modules over the course of a semester. Short 20-30 minute lectures were interspersed with experiment brainstorming, experiment execution, hands-on class activities, statistics, and paper writing exercises. The three-hour courses met twice weekly throughout the semester, and were taught by the same professor (E. Clabough). Undergraduate students were primarily freshman and sophomores and the course was open to both biology majors and non-majors.

Students were expected to design, perform, and analyze their own experiments in groups using the provided module organisms. Students were broken into small groups of 3-4 students to work as lab teams. Individual papers were written at the conclusion of each of the three modules. Module 1 explored the molecular biology of energy in mouse mitochondrial isolates. Students assessed if a redox dye could substitute for the enzymes within the mitochondrial membrane, and used a colorimeter to assess whether or not an electron was successfully passed to cytochrome C in the preparations. Module 2 centered on genetics using commercially available alcohol dehydrogenase *Drosophila* mutants. Students used an inebriometer to measure the susceptibility of an AHD mutant/wild type flies to ethanol vapors. Module 3 looked at vertebrate development using a zebrafish fetal alcohol paradigm. Students exposed developing embryos to various ethanol concentrations and measured response variables of their own choosing, including body size, heartbeat and behavioral measures.

Scientific Writing Experimental Conditions

Scientific writing was taught in chunks to the students as the course progressed (Table 1). Each student was expected to individually write a lab paper at the conclusion of each module in order to communicate that module's experiments. The Module 1 paper consisted of the title page, methods, results, and references. The Module 2 paper consisted of the title page, introduction, methods and results, discussion, and references. The Module 3 paper was formatted as an entire article, complete with title page, abstract, introduction, methods, results, discussion, and references. Some paper elements, particularly at the beginning of the semester, went through several rough drafts before the final module paper was due.

Sections were randomized to one of three experimental conditions—Rubric Only, Rubric + Tutor or Self-Grade Rubric—using a random number generator. Each condition centered on a different use of the same grading rubric for scientific writing. Since it is not practical to withhold a rubric from one section of a multi-section course, all sections had access to the exact same rubric. The first group (n=16) served as a Rubric Only control group. Individual paper element rubrics were handed out to students when each element was introduced during class, and the instructor went over each rubric in detail for all classes. Students were told to consult the rubrics before turning in their drafts or final papers. In addition, a rubric summarizing the upcoming paper requirements (see Supplementary Material) was handed out approximately a week before each module paper was due.

The second group, Rubric + Tutor (n=14), received the rubrics and peer tutoring. This group was given rubrics, but was also required to use tutoring services at least one time for each module paper (three times over the course of the semester). Due to the specific formatting and content requirements of a scientific paper, participants were tutored by biology subject tutors rather than the writing center tutors. The three biology tutors were upper-class biology majors, nominated by faculty, and employed by the academic center at R-MC. These tutors demonstrated outstanding competence in their courses of study and had undergone a tutoring training program that is nationally certified by the College Reading and Learning Association (CRLA). In addition, the biology subject tutors had all taken Integrative Biology at R-MC.

Biology subject tutors (2 female and 1 male) had designated weekly hours for drop-ins or appointments, generally in the evenings. At the beginning of the semester, the instructor met with the biology subject tutors and informed them of the experiment, provided them with

Week of Semester	Paper Element Taught	Rubric Given to Students	Assignments Due
Week 1 (Module 1: Metabolism)	Title Page; Materials and Methods	1. Title Page 2. Materials and Methods	Draft of Title Page
Week 2 (M1)	Results (Figures with captions)	3. Results	Draft of Materials & Methods and Results (Figures with captions only)
Week 3 (M1)	Results (Statistics and Text); Discussion; References	4. Discussion 5. References 6. Overall Paper Writing	Draft of Discussion and References
Week 4 (M1)			Final Module 1 Paper Due-Title Page, Materials & Methods, Results, and References
Week 5 (Module 2: Genetics)			
Week 6 (M2)			Draft of Results
Week 7 (M2)			Draft of References
Week 8 (M2)	Introduction	7. Introduction	Draft of Title page, Materials & Methods, & Results
Week 9 (Module 3: Development)			Final Module 2 Paper Due–Title page, Introduction, Methods & Materials, Results, Discussion, Literature Cited
Week 10 (M3)			
Week 11 (M3)	Abstract	8. Abstract	
Week 12 (M3)			Final Module 3 Paper Due-Title Page, Abstract, Introduction, Materials & Methods, Results, Discussion, and References

Table 1. Timetable for teaching scientific writing. Scientific writing content, format, rubrics, and assignments were introduced using a specific timeline throughout the module-based Integrative Biology course. Three separate scientific papers were assigned based on class experimental results. The rubric had eight distinct components that were utilized as needed throughout the semester. Each rubric component was handed out at the time the students were assigned that particular element of the paper. A summary rubric was also handed out before each final paper.

the grading rubrics and paper due dates, and asked for a log of upcoming student sessions. Ongoing contact was kept between the instructor and the subject tutors throughout the semester.

The third group, Self-Grade rubric (n=14), received the same grading rubrics, but used them in a different way. They were given the relevant rubrics, but instead of having the instructor go over the rubrics, this group was asked to make decisions about whether or not their own assignments fell in line with the rubric requirements during class. Students were asked to grade their own drafts, as well as other students' drafts throughout the semester. For this peer-review, each student used the rubric to grade two other students' drafts during class and immediately communicated the grading results one-on-one with the writer.

Many students in this study had previously taken the first semester of Integrative Biology (86% of the students in the Rubric Only section, 92% of the Rubric + Tutor group, and 40% of the Self-Grade Rubric section). These students had exposure to and practice with scientific writing, since students in both semesters are required to write scientific papers, so this difference may alter interpretation of between groups differences. Students enrolled in the Rubric Only section reported an average self-reported estimated GPA of 2.69 and the class was composed of 84% freshman. Students in the Rubric + Tutoring section were also mostly freshman (92%), who reported an average GPA of 2.83, while the Self-Grade rubric section contained more upperclassmen (60% freshman), and self-reported an average GPA of 2.46. GPA was not statistically different between groups.

Scientific Writing Evaluation Rubrics and Tutors

Rubrics were designed using a point system for each required paper element (to total approximately 70% of the overall score), and overall paper writing style/format was weighted as approximately 30% of the overall paper grade (see Supplementary Material). All students were encouraged to use the biology subject tutors as a valuable college resource, although it was only compulsory for students in the Rubric + Tutor group to visit the tutors.

Scientific Writing Attitudes and Perceived Competence Assessment

At the beginning of the semester, all students completed a Likert-based questionnaire (Likert, 1932) which explored their attitudes towards writing in science, as well as how relevant they felt effective writing is to good science. The questionnaire also collected information about how students personally assessed their own competence in writing overall, as well as in science writing, and their perceptions about the effectiveness of different ways to teach scientific writing. The same questionnaires were given again to students during the final week of classes (see Supplementary Material).

Data Analysis

The writing attitude and perceived competence questionnaire was examined for meaningful change between and within groups to look for differences in the assessment of scientific writing importance or in writer confidence. The mean and SEM were calculated for each Likert style question. After ensuring that the data met the requirements to use a parametric statistic (data were normally distributed, groups had equal variance, there were at least five levels to the ordinal scale, and there were no extreme scores), data were analyzed using ANOVA, followed by t-tests for pairwise comparisons. One pre-assessment question had high variance as measured by standard error, so the Kruskal-Wallis test was used in that instance. The responses were anonymous within each group, so it was not possible to track changes within individual students, but t-tests were also performed to detect differences in each group between the first and last weeks of class.

Although writing performance was not the primary objective of the study, the rubric was used to grade the scientific reports to determine a paper score for each of the three module papers as a part of the course. Papers for all experimental groups were mixed together for grading by the class instructor, though the instructor was not blind to their identity. Because each module paper required that students demonstrate competency writing new parts of a scientific paper, overall paper scores were calculated across the semester. Papers were worth more points as the semester progressed and more paper sections were added (Paper 1: 50 points, Paper 2: 60 points, Paper 3: 100 points). Differences between groups in overall paper scores were collected (total points accumulated over the three papers) and analyzed using an ANOVA.

RESULTS

Biology Subject Tutor Use

In the Rubric + Tutor group, 78.6% of the students visited the tutors an average of 2.3 times per student. Tutoring hours and services were advertised to the students as a valuable paper writing resource, but just 20% of the Self–Grade Rubric class and none of the Rubric Only class visited the tutors at some point during the semester. During the current study semester, a total of 19 students visited the biology subject tutors a total of 44 times campus-wide. This reflects an increase from the semester prior to the current study, when just 10 students utilized the tutors a total of 23 times.

Scientific Writing Rubric Use

Reliability between raters was calculated based on a randomly sampling of student papers scored by two independent raters with disparate education backgrounds (one rater had earned a Ph.D. in science and the other rater had an English Ph.D.). Reliability for overall paper scores was found to be high (r = 0.8644, ICC; Table 2).

Paper Element	Intraclass Correlation Coefficient (ICC)	Agreement
Title Page	0.5511	Moderate
Abstract	0.6341	Moderate
Introduction	0.3852	Fair
Materials and Methods	0.9104	Near Perfect
Results	0.135	Poor
Discussion	0.8583	Near Perfect
References	0.1176	Poor
Writing Style and Formatting	0.7712	Strong
Overall Paper Score	**0.8644**	**Near Perfect**

Table 2. Rubric Reliability. The intraclass correlation coefficient (ICC) was calculated to determine rubric reliability. Seven final papers were randomly selected to be scored by two independent raters. The ICC provides a measure of agreement or concordance between the raters, where the value 1 represents perfect agreement, whereas 0 represents no agreement. ICC values were calculated for the individual paper elements, as well as for the overall paper. ICC was interpreted as follows: 0-0.2 indicates *poor* agreement, 0.3-0.4 indicates *fair* agreement, 0.5-0.6 indicates *moderate* agreement 0.7-0.8 indicates *strong* agreement, and 0.8-1.0 indicates *near perfect* agreement.

The rubrics worked very well as a grading tool for the instructor, consuming about 10-15 minutes to grade an individual paper. One student paper was inadvertently shuffled to the bottom of the pile and unknowingly re-graded. Remarkably, he received the same 87.5% score on the second grading attempt as he did during the first grading session. Use of the rubric made it easier to have conversations with individual students about their papers if there was a grade inquiry, and eliminated the need to write large amounts of comments on each paper. Biology subject tutors reported that they used the rubrics during the tutoring sessions, but felt that they concentrated primarily on grammar and sentence structure with students.

Student Writing Performance

Although writing performance was not the primary focus of this study, no significant difference was found between the Rubric Only group, the Rubric + Tutor group and the Self-Grade Rubric group in overall paper writing scores, calculated as all by adding all the scientific writing points over the semester (by ANOVA; p = 0.096), nor was there a difference in the final paper scores (by ANOVA; p = 0.068).

Attitude Change within Groups

No changes were seen in each group between pre and

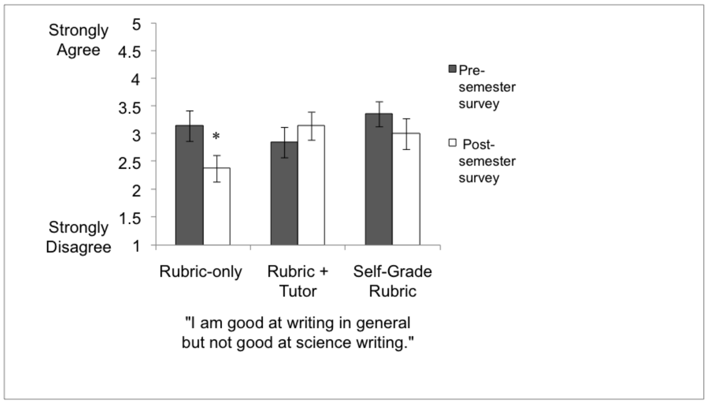

Figure 1. Significantly more students in the Rubric Only group disagreed with the statement "I am good at writing in general but not good at science writing" at the end of the semester compared to the beginning (by t-test; p = 0.0431; pre-mean = 3.14 ± 0.275 and post-mean= 2.375 ± 0.24). No other group displayed a significant difference pre-course vs. post-course. Data depicts student responses on the Likert questionnaire, where 1 is strongly disagree and 5 is strongly agree.

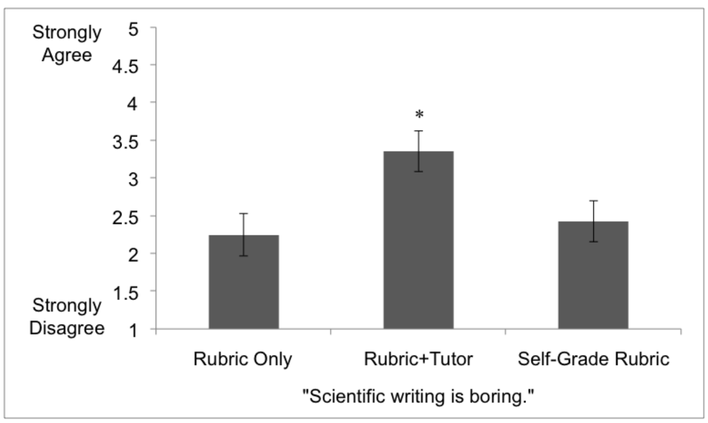

Figure 2. More students in the Rubric + Tutor group agreed with the post-statement "Scientific writing is boring." Data depicts student responses on the Likert questionnaire administered at the conclusion of the semester, where 1 is strongly disagree and 5 is strongly agree (by ANOVA; p = 0.016; mean of Rubric Only group 2.25 ± SEM 0.28; mean of Rubric + Tutor group 3.36 ± 0.27; mean of Self-Grade rubric group 2.43 ± 0.27).

post assessment answers on the Scientific Writing Attitudes questionnaire, except one significant difference was found for the statement "I am good at writing in general but not good at science writing." Significantly more students in the Rubric Only group disagreed with this statement at the end of the semester compared to the beginning of the semester (by t-test; p = 0.0431; pre-mean = 3.14 ± 0.275 and post-mean= 2.375 ± 0.24, where 1 is strongly disagree and 5 is strongly agree) (Figure 1).

Attitude Differences between Rubric Groups

Significant differences between the groups were detected in the post-questionnaire answers for several of the writing attitude and perceived competence questions. The Rubric + Tutor group held significantly more negative attitudes towards scientific writing on several questions. On

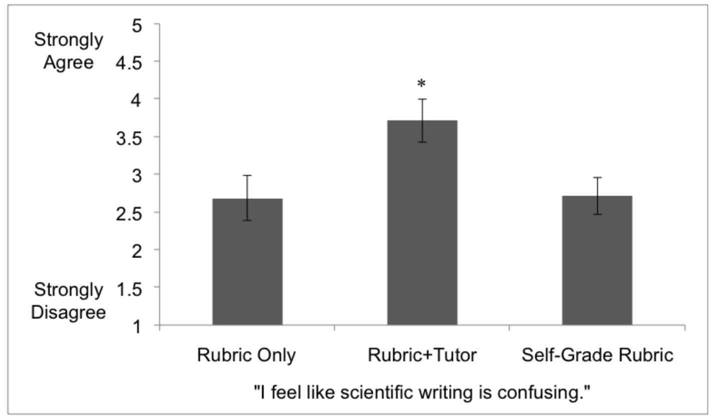

Figure 3. More students in the Rubric + Tutor group agreed with the post-statement "I feel like scientific writing is confusing." Data depicts student responses on the Likert questionnaire administered at the conclusion of the semester, where 1 is strongly disagree and 5 is strongly agree (by ANOVA; p=0.021; mean of Rubric Only group 2.69 ± SEM 0.30; mean of Rubric + Tutoring group 3.71 ± 0.29; mean of Self-Grade rubric 2.71 ± 0.24).

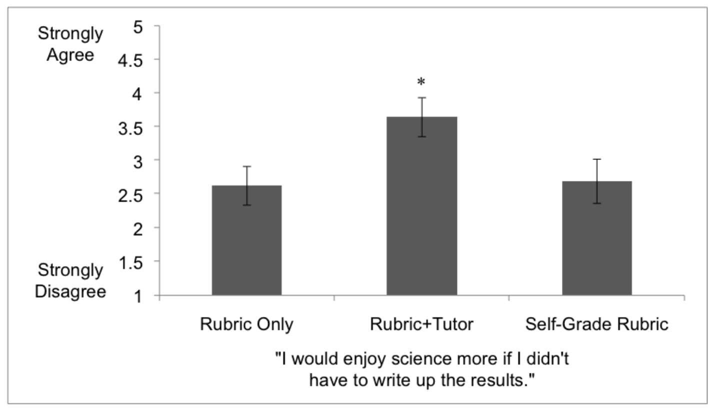

Figure 4. More students in the Rubric + Tutor group agreed with the post-statement "I would enjoy science more if I didn't have to write up the results." Data depicts student responses on the Likert questionnaire administered at the conclusion of the semester, where 1 is strongly disagree and 5 is strongly agree (by ANOVA; p=0.037; mean of the Rubric Only group 2.63 ± 0.29; mean of Rubric + Tutor group 3.6 ±.029; mean of Self-Grade Rubric group 2.69 ± 0.33).

average, more students in the Rubric + Tutor group agreed with the post-statement "Scientific writing is boring" (by ANOVA; p = 0.016; mean of Rubric-Only group 2.25 ± 0.28; mean of Rubric + Tutor group 3.36 ± 0.27; mean of Self-Grade Rubric group 2.43 ± 0.27) (Figure 2). This difference was not detected during the pre-assessment (by ANOVA, p = 0.46).

On average, more students in the Rubric + Tutor group agreed with the post-statement "I feel like scientific writing is confusing" (by ANOVA; p=0.021; mean of Rubric-Only group 2.69 ± 0.30; mean of Rubric + Tutor group 3.71 ± 0.29; mean of Self-Grade Rubric 2.71 ± 0.24) (Figure 3). This difference was not detected during the pre-assessment (by ANOVA, p = 0.96).

Significantly more students in the Rubric + Tutor group also agreed with the post-statement "I would enjoy science more if I didn't have to write up the results" (by ANOVA; p=0.037; mean of the Rubric Only group 2.63, ± 0.29; mean of Rubric + Tutor group 3.6, SEM .29; mean of Self-Grade Rubric group 2.69, SEM 0.33) (Figure 4). This difference was not detected during the pre-assessment (by ANOVA, p = 0.79).

Student Perception of Teaching Tools

The questionnaire also assessed how biology students judged the effectiveness of teaching tools to write more effectively. Students agreed or disagreed with the effectiveness of six methods commonly used to teach writing: working on drafts one-on-one with someone, modeling a paper after an example paper, watching someone else construct a paper from scratch, looking at a detailed grading rubric, participating in small group writing workshops, and listening about to how to place the experimental elements into the paper during a lecture. No significant differences were found in each group's pre- vs. post- semester assessment responses.

When the post-semester assessment responses from all classes were pooled together (n= 44), we found that students perceived the effectiveness of scientific writing teaching methods very differently (by ANOVA; p <0.0001; using an example paper 4.17 ± 0.12; using a detailed rubric 3.98 ± 0.16; listening to a lecture about constructing science papers 3.8 ± 0.99; one-on-one assistance 3.78 ± 0.4; participating in small group workshops 3.63 ± 0.2; or watching someone else construct a paper from scratch 3.24 ± 0.17; data shown are means ± SEM, where 1 is strongly disagree with effectiveness and 5 is strongly agree) (Figure 5).

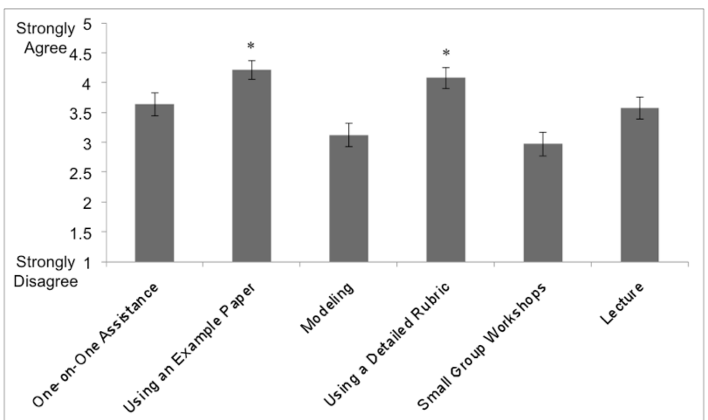

Figure 5. Post-semester assessment showed that students thought the most effective ways to teach scientific writing were 1) using an example paper or 2) using a detailed rubric. Students though that 1) watching someone else construct a paper from scratch or 2) participating in small group writing workshops were the least effective ways to teach scientific writing (by ANOVA; p <0.0001; using an example paper 4.17 ± 0.12; using a detailed rubric 3.98 ± 0.16; listening to a lecture about constructing science papers 3.8 ± 0.99; one-on-one assistance 3.78 ± 0.4; participating in small group workshops 3.63 ± 0.2; or watching someone else construct a paper from scratch 3.24 ± 0.17; n = 44). Data depicts the means ± SEM of student responses on the Likert questionnaire administered at the conclusion of the semester, where 1 is strongly disagree and 5 is strongly agree.

Students rated using an example paper as significantly more effective than listening to a lecture about how to place experimental design elements into a paper (by t-test; p < 0.01), more effective than one-on-one assistance on paper drafts (by t-test, p = 0.02), more effective than participating in small group workshops (by t-test, p < 0.0001), and more effective than watching someone construct a paper from scratch (by t-test, p < 0.0001).

Students rated the use of a rubric as significantly more effective than watching someone construct a paper from scratch (p < 0.001), and more effective than participating in small group workshops (p < 0.0001).

Students also rated participating in small group workshops as less effective than one-on-one assistance on paper drafts (p = 0.02), and less effective than listening to a lecture about paper construction (p = 0.05). In fact, students rated participating in small group workshops as significantly less effective than nearly every other method.

Mean final course grades were not significantly different between the classes, nor were course or instructor evaluations scores different. The mean class grade for the Rubric Only section was 85.9%, the mean evaluation score for course structure was 4.0 (out of 5), and the mean instructor effectiveness evaluation score was 4.43 (out of 5). The mean class grade for the Rubric + Tutor section was 83.7%, the mean evaluation score for course structure scores was 4.25 (out of 5), and the mean instructor effectiveness evaluation score was 4.33 (out of 5). The mean class grade for the Self-Grade rubric section was 77.9%, the mean evaluation score for course structure scores was 4.07 (out of 5), and the mean instructor effectiveness evaluation score was 4.27 (out of 5).

DISCUSSION

Scientific writing falls underneath the umbrella of "Ability to Communicate and Collaborate with Other Disciplines," as one of six core competencies in undergraduate biology education (AAAS, 2009). Scientific writing is a skill that can be applied to the discipline of biological practice, and is also a key measure of biological literacy. AAAS focus groups involving 231 undergraduates reported that students request more opportunities to develop communication skills, such as writing assignments in class or specific seminars on scientific writing (AAAS, 2009). In 2004, approximately 51% of undergraduate educators that attended past American Society for Microbiology Conferences for Undergraduate Educators (ASMCUE) reported that they introduced more group learning and writing components after attending an ASMCUE conference targeting biology education reform (AAAS, 2009).

Additionally, as we noted in the introduction, scientific writing is an important part of undergraduate neuroscience education because it provides students with an opportunity to utilize writing-to-learn strategies to promote the merging of interpretative methods and rubrics with the hypothesis testing and experimental design that typically occurs in STEM fields to create a type of hybrid research paradigm (Reynolds et al., 2012) and a more holistic approach.

As a growing number of schools embrace CURE curriculums, instructors will increasingly need to deal with the problem of how to have their students effectively communicate the results of the experiments they do. Scientific writing is the natural extension of a complete scientific project, and requires students to think clearly about process, argument, and making evidence-based conclusions. These competencies are linked to life-long skills, including critical thinking, and perhaps executive functioning.

Undergraduate students in our biology classes believe that the most effective ways to teach scientific writing are by providing an example paper, a rubric, or by effective lectures. Interestingly, these are all very “hands-off” approaches to learning, indicating that either the students crave more structure in this type of inquiry-based learning course, or that the students’ past experiences with one-on-one tutoring or small group based writing workshops were not ideal. It would be interesting to see if these types of attitudes persist in a more traditional lecture classroom format.

Peer Tutoring

Despite boosted confidence, the group of students who were required to use a peer tutor felt that scientific writing was boring and less enjoyable than students who were not required to visit a tutor. Peer tutoring, particularly in writing, has a long history of improved paper performance, with mostly positive subjective feedback from students. Certainly a student’s experience with a peer tutor may revolve around both the tutor’s willingness to help and competency in the subject matter, but even with a willing and competent tutor, students may be unhappy with what they perceive as an extra assignment (visiting the tutor). Previous studies show an added benefit of self-reported enhanced writing ability in the tutors (Topping, 1996; Roscoe and Chi, 2007), a finding that was also reflected in the current study in informal post-experiment feedback from our tutors.

Tutoring services are a staple offering of most colleges and universities, but the training can be relatively general in nature. Tutoring centers can consider developing working relationships between individual science departments and their own subject tutors. Departmental faculty members can take a more active role in the tutoring by offering tutor training sessions, instruct the tutors about specific desirable ways to support students, and possibly follow up with their own assessments to track tutor outcomes.

Rubrics, Example Papers, and Effective Lectures

We find that undergraduate students in our inquiry-based biology classrooms believe that rubric use is a very effective way to teach science writing. As such, we propose that undergraduate neuroscience faculty consider that the use of rubrics may better fit the needs of beginning science students (and future students interested in upper level neuroscience courses) better than more commonly used peer review instructional methods. In particular, rubrics are a logical fit for use in inquiry-based writing instruction, since they provide needed structure, they clearly communicate standards for success in the classroom, and students think they are effective teaching tools. Yet rubrics remain an important tool for all disciplines at all college levels.

Most professors have rubrics that they use to assist with their own grading, but many do not share these rubrics with their students during the writing process. This is similar to withholding the driver’s manual from a Driver’s Ed student as they learn to drive by observation or by practicing driving around the parking lot. Use of the rubric may give the students an element of control otherwise missing from an assignment. Prior research shows that learners who are not in a power position demonstrate poor task performance, but do better when they are in control over their own learning (Dickinson, 1995; Smith et al., 2008). Although we did not directly compare the use of a rubric with non-rubric use, perhaps the perception of control during learning is valuable, as more rigorous use of the rubric allows the student to essentially pre-determine what grade he or she will receive on each paper.

Nothing is wrong with teaching students the way they want to be taught. However, more research needs to be done to compare teaching methods. Students stated that a preference for “effective lectures” to teach scientific writing, but characteristics of these “effective lectures” need to be further elucidated. Exposing groups of students to various types of lecture styles and then administering a subsequent writing assessment would allow evaluation of both writing performance and allow students weigh in with their perceptions of what makes an “effective lecture.” Studies comparing use of example papers, very specific rubrics, and effective lectures would be helpful, as well as combinations of the three elements. It would also be helpful to track the specific responses of those students who go to focus their studies on neuroscience to see whether their views deviate from or adhere to the findings for the group as a whole.

Despite the frequent use of peer review or tutoring that is commonly used in writing workshops and with classroom paper rough drafts, we did not find that peer review boosted student perception of writing competence. Students prefer to hold the keys to classroom success in their hands—a printed out rubric or model paper is, in their eyes, more valuable than listening to or talking about writing.

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