Peer Assessment of Writing and Critical Thinking in STEM: Insights into Student and Faculty Perceptions and Practices

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Introduction

In recent years, the National Academies Board on Science Education has placed a heavy emphasis on improving pedagogy in STEM disciplines in order to recruit and retain students in STEM fields. A key component to success in STEM education is experiential learning through scientific research projects and internships (Fairweather, 2008). A vital element of experiential learning is discourse with peers. Students must be able to communicate their ideas in a logical and formal manner (for grants and publications), to analyze current scientific reports to identify key findings and limitations, and to effectively discuss scientific ideas.

When revising the curriculum in 2012, the University of Saint Joseph biology department formalized specific goals to facilitate the development of critical thinking and writing in the sciences. As a way to introduce scientific writing to students, a new, two-credit, once-a-week course, Biol 232: Scientific Writing, was designed for second-semester freshmen. The class aims to familiarize students with how the components of a scientific report function and work in relation to one another to clarify ideas. It also initiates students into the process of acquiring scientific information through online databases, journals, and other relevant media outlets, and it teaches them how to analyze that information so that they are able to recognize its validity (or lack thereof), formulate hypotheses based on that information, and question that information to further inquiry.

Thus, there were two significant reasons for developing this course. The first reason was that because each biology course incorporates, in varying degrees, experimentation in the laboratory, the ability of the student to think critically about the processes and outcomes of that lab work, and then to communicate that thinking with a high degree of clarity and concision, is important for the advancement of science itself. The second reason was that faculty in the biology department found that the content requirement of the major was such that there was not enough time available in any one lab-work oriented course to dedicate to teaching the necessary foundations for writing scientific reports.

Consequently, and for their own value, this course aims to lay the foundation for critical thinking and writing skills, such as analyzing primary literature and discussing experimental design, learning how to paraphrase effectively, reviewing sources for reliable information, and incorporating rough drafts throughout the course to reinforce the editing and revision processes, that science students will need to be successful throughout their undergraduate careers. Since almost all of the biology courses include a laboratory element, being able to use lab reports to develop discourse and critical thinking abilities only strengthens the students' advancement in the discipline.

The presence of critical thinking in the Spring 2013 course, which was taught by two of the authors, integrated the University's "CORE" rubric—an evolving instrument being developed as a hybrid domain-independent/domain-relevant tool (Goldin, 2011) that serves heuristic, pedagogical, and assessment functions for engaging writing and critical thinking. The CORE explains and defines critical thinking as a pandisciplinary act that places increasing value on increasing intellectual work, with strong evaluation as the pinnacle act. The CORE teaches

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students to move from lower-order acts, such as reporting and summarizing, through the higher-order act of finding a focus worth reasoning about, to the highest-order act of evaluating evidence, assumptions, and implications in the defense of a conclusion. Note that the CORE makes no assertion that summarizing involves no intellectual work. It does, however, assert a crucial intellectual hierarchy. At the bottom of the hierarchy is the ability to quasi-randomly list a variety of things from source materials. To reach the next level, the student must be able to find a focus worthy of discourse. To reach the final level, students must be able to defend/support their conclusion.

The CORE's conception of critical thinking is consistent with "abilities, skills, and dispositions" identified by Washburn (2010) and is also consistent with attributes described by Faccione (2010), both of whom value evaluative skills among higher-order characteristics of critical thinkers. However, the CORE equally places value on self-awareness and meta-cognition, such as that advocated by Jones and Ratcliff (1993). Thus, the CORE articulates, in student-friendly terminology, the more general value of making, and gaining the metacognitive awareness of, evaluative moves from which conclusions emerge.

Although the CORE does define critical thinking in pandisciplinary terms so that faculty across the curriculum can reference thinking through a similar lexicon and value system, the CORE equally embraces contentions (Jones, 2007; Moore, 2004) that critical thinking occurs within disciplinary constructs. While the CORE therefore asks students to consider the value of evidence, it equally recognizes that "evidence" will take differing forms in literary criticism and biological experimentation, and it relies on faculty members to help students contextualize CORE ideas within disciplinary constructs. For that reason, the CORE was developed (and is still developing) with qualitative input from faculty and students so that the language crafted functions specifically enough to provide students a consistent message, while it is pliable enough to apply to the spectrum of disciplines at the university. It serves as a pedagogical tool for faculty members, allowing them to introduce more critical thinking into their teaching by referring to the CORE's language and method during the classes. It also serves as an assessment tool for rating discourse, written or oral, from a critical-thinking-centered stance.

Of particular importance to the course is the use of the CORE for peer assessment. Other theorists have advocated for peer assessment as part of undergraduate and graduate STEM work. Peer assessment helps build a classroom simulacrum for the dynamic environment of the real world in which STEM students will find themselves (Heylings & Stefani, 1997; Towns et al., 2001; Venables & Summit, 2003). Namely, STEM work typically involves a culture in which peers must be able to offer their contemporaries meaningful discourse on scientific work, and where those in the discipline must also become adept at employing peer feedback into the evolution of their practice. Such contentions find support in other studies (Lin, Liu, & Yuan, 2001; Topping, 1998) demonstrating that peer assessment does indeed foster the kind of student interaction on which STEM depends, namely, inter-peer discourse, observational skill sets, professional critique, and related skills that build critical thinking. Such advocacy for peer assessment centers on the "convergence of raters on a 'single truth'" about which "multiple perspectives … do not necessarily have to agree" (Miller, 2003, p. 390), thus requiring peer assessors to engage in discourse about the subject matter and the writing, and, in this case, to reason their way to a consensus grade.

Much of the research on peer assessment has addressed questions of reliability and validity (Cho et al., 2006; Falchikov & Goldfinch, 2000; Magin, 2001; Sadler & Good, 2006), as well as the conditions that facilitate stronger peer assessment outcomes (Van den Berg et al., 2006),

norming for assessment methods and standards (Falchikov, 2005; Smith et al., 2002), and the practice afforded to students (Wen & Tsai, 2006). Yet less research has been conducted on students' perceptions of peer assessment, particularly with respect to critical thinking. Perhaps Nicol, Thomson, and Breslin (2014) provided some of the strongest insight into peer assessment's connection to critical thinking, finding that the unique kind of "reflective comparison" it requires also "engages students in active critical thinking" (p. 115, 116). Furthermore, data from Nicol et al. (2014) suggest that "through reviewing the work of peers, students can learn to take control over their own learning, to generate their own feedback and to be more critical about their own work" (p.113).

Other studies speak more generally to students' engagement. Hanrahan and Isaacs' (2001) study of 233 students defined eight "general dimensions" of student perception of peer assessment, which ranged from higher-order concerns, such as "better understanding of marking" and "difficulty," to lower-order concerns around "implementation" (p. 58). But the authors of the study recognized that they did not address the scope of the responses, only the categories. Other research, by Wen, Tsai, and Chang (2006), of pre-service and in-service teachers found that both groups "had positive attitudes towards [in-person] peer assessment and online peer assessment" (p. 87). And Llado et al. (2014) found increased motivation and engagement among students engaging in peer assessment.

This report from the field offers insight into STEM students' perceptions of peer assessment that used the CORE for a central and criteria-driven scoring system. This report, furthermore, articulates the relationship between peer assessment and STEM goals, as well as provides the faculty members' reflections on the use of the same.

Course Overview

As previously mentioned, the course lays the foundations for strong critical thinking and writing by focusing on the processes that contribute to the production of scientific reports. Moreover, the authors contend that an important part of this process is developing the students' sense that they are members of a peer review community. As such, focus on process is as important as product.

To that end, every section of the scientific reports produced by students went through three revisions and was assessed through peer critiquing and then peer grading. The authors intended this process to elevate the students' understanding of the content and function of the specific components of the scientific report format, and to enhance their understanding of their own writing skills. The instructors, however, recognized several challenges with this model, including accurate monitoring and evaluation of student feedback to their peers. In a classroom of many students, one instructor cannot monitor all conversations simultaneously. Therefore, a formal mechanism for evaluating feedback was implemented. Students wrote formal justifications of the grades they assigned to peers and identified the components of the writing that needed improvement based on the specific elements of the rubric. To maximize the value of feedback to their peers, students were encouraged to offer solutions to shortcomings in the texts they reviewed.

Course Design

Student Outcomes

The primary outcomes of this course, as stated in the syllabus, are that students will be able to

- learn the components of a scientific report,

- analyze peer reviewed scientific reports to determine their benefit for their own reports,
- identify reliable sources of scientific information,
- reflect on their writing qualities and how to improve this skill,
- develop writing skills through writing and revising components of a scientific paper of their own development,
- understand and reflect on the value of group work, and
- become skilled in peer assessing.

Course Work and Schedule

Weeks 1 – 3: Read, discuss, and analyze the components of a scientific report in informal groups and whole class activities.

The first three weeks of the course were dedicated to introducing students to the components of scientific literature. Activities included comparative analysis of scientific literature, concept mapping, and component identification and analysis of scientific reports in detail through concept mapping. Students analyzed differences between the information in daily news articles and primary literature that the news articles were based upon to see what was missing from the news article that could clarify the point being made. Another activity employed in this period was the detailed analysis of "classic" articles, that is, articles that the scientific community regard as foundational, or that represent the starting point for the expression of foundational ideas, to make sure students gained an understanding of how each component of a scientific report functions to make meaning. Identification of the authors and their associated institutions, hypotheses, and the significance and implications of the results were also reviewed with students in depth.

Weeks 4 – 12: Write an original scientific report based on a student-derived question and hypothesis. Peer critiquing and graded assessment will take place within predetermined groups of three students.

The most unique feature of this course was that peer assessment was heavily integrated into the day-to-day activities and conversations. The students were introduced to the practice of peer assessment through the following means: in-depth discussion of the importance of peer review in the sciences, training on how to use the CORE to gauge critical thinking in writing, and instructor-led workshops using sample papers from previous biology classes. After the initial introduction to reading and analyzing scientific literature, led by the instructors, students critiqued and assessed each other's work in an organized setting. Once a student completed a specific section of her report (e.g. an introduction, a methods section, etc.), that student's work was evaluated by two different groups from two different perspectives. The first perspective was that of the writer's "peer group." Once completed, a draft was formatively critiqued by the two other members of the peer group, made up of two other students who were designing experiments similar to the writer's experiment, or closely related to the writer's topic. By organizing peer groups based on similarities in research, the authors ensured that peer reviewers had foundational knowledge of the writer's work.

The second perspective was that of the "outside reader." After the student received comments from her peer group, she would have the opportunity to revise the piece and submit it for a graded assessment by a "sister" group of three students acting as outside readers. While sister groups had knowledge of how to read and respond to a scientific report, including knowledge of the necessary content and function of each component of a scientific report, they had no specific

knowledge of the writer's project. Submitting work for graded assessment to a group of readers who could critically read and respond to scientific reports, but who required the author to clarify concepts, articulate logic, and make explicit connections, implications, conclusions, etc., helped to cultivate in student writers a more comprehensive awareness of what constitutes a strong argument, clear writing, and well-formed ideas. The peer groups and sister groups remained consistent throughout the semester.

Both groups used the CORE rubric to assess the work of their peers. One of the reasons for using the CORE for peer assessment is that it provides students with common and specific language with which to identify and describe moments in a piece of writing that require stronger clarity, additional support, or further intellectual development (e.g. stronger discussion of the relationship between evidence and ideas, the development and discussion of the implications of an experiment, hypothesis, or conclusion). By giving students, especially those just beginning to understand the requirements and necessities of a specific genre of writing, a common language for critiquing, developing, and ultimately grading each other's work, the authors were able to foster a more consistent and productive dialogue regarding the level of critical thinking in student writing.

This common language was especially useful as each student was then required to write a justification of a particular grade on one of the scientific reports they all had reviewed. Each justification was then assessed by the authors. These justifications addressed the rubric components and included not only what was lacking but also how the writer could improve the report by providing clear resolutions.

<u>Weeks 13 – 15: Draft and revise the final scientific report.</u>

The same peer formative critique and final graded assessment continued with the rough draft of the complete report and then with the final graded report. At the end of the course, each student had completed a scientific report focusing on an original question (developed by the student) that had its parts critiqued and revised several times throughout the semester. Students were highly encouraged to submit this work for their writing portfolio (a requirement of graduation).

Management of Groups

Attendance was critical, especially during the grading sessions. Extra make-up work needed to be completed before the next class meeting in order for the student to keep on track with the group. It was also critical for students to come to class with their own work prepared and with copies available for their peer/sister group, depending upon the week.

Evaluation of the Course

The course was evaluated using student self-assessments, course performance, and reflections. The self-assessment process was composed of a series of questions that addressed the change over the semester in their understanding of scientific literature, the components of a scientific report, knowledge of designing experiments, developing a report, and evaluating other students' work. The authors used a Likert Scale of 1-5, with 1 being "no knowledge" and 5 being "expert," to measure students' self-analysis. The university also administers an online course evaluation tool through which students may provide feedback about the course and instructor in general.

Course performance was composed of their graded assessments, which included the parts of the scientific report, the final product, and the written justifications graded by the instructors. Each graded assignment was also reviewed by the instructor to maintain reliability. Additionally, student reflection was utilized throughout the course to help students develop and monitor their own thinking processes. Students were asked to reflect on numerous aspects of their work,

including their approach to reading sources, peer group work, how and why they critiqued an article with the rubric, and how their approach to writing changed over the course of the semester.

Results and Discussion

This report provides insights into students' perceptions about the influence of peer evaluation and assessment on their own writing process. Previous research suggests that peer evaluation improves the quality of students' own writing, potentially by engaging problem-solving skills and offering solutions for improvement (Cho & MacArthur, 2011; Nicol et al., 2014). Student feedback and performance in the course suggest a positive learning experience. Students recognized the value of peer evaluation through their perceptions of their own learning. This perceived improvement was also reflected in the course grades as measured by the CORE standard. The authors implemented both peer evaluation (critiquing) and peer assessment in the course; therefore, the reported results cannot determine if student perceptions are a result of one act over the other. However, including peer assessment as part of the course engaged the students in the justification of their evaluations of peer writing. As part of the justification process, students were required to engage the material, evaluate the material, and provide specific suggestions for improving the writing. The authors perceive these acts as fostering critical thinking in a hierarchical manner.

Student Perceptions of Their Learning Through Peer Assessment

Student feedback was collected using self-assessments and periodic student reflections. Self-reported data indicated that students felt they gained significant knowledge in key skills and content areas, including writing the sections of a scientific report, reading and analyzing scientific literature, using a standardized rubric, and employing peer assessment (Figure 1). On average, students reported that they had "little knowledge" (= 2.8) in these areas at the start of the course, and by the end of the course reported that they were "very knowledgeable" (= 4.1) (Figure 1).

From the Likert scale surveys and student feedback, it was determined that the structure of the course had a positive effect on the students' perceptions of their own learning. At the start of the course, several student perceptions were presented to the instructors. First, students were concerned that they would not be graded fairly. Second, students were skeptical about the quality of feedback they would receive from their peers. Finally, there was some student resistance to working in groups for the entire semester, particularly the same group week to week. However, after we analyzed the feedback, it was clear to us that students felt peer evaluation and assessment had several positive outcomes. Students commented that working in a group facilitated multiple perspectives, helped develop strategies for solving conflicts, aided in identifying weaknesses within their own writing, and increased confidence in public speaking and justification of arguments.

Students working with their peer and sister groups also fostered different approaches to reading and synthesizing information. Students commented that "it was helpful to be critiqued by one group of peers and assessed by a different group of peers, because it was easier to provide constructive criticism to an outside group." Also, the "good cop/bad cop" approach was utilized to encourage both positive feedback and constructive criticism since it was difficult for students to adopt a negative tone with their peers. One student commented that "good cop/bad cop led to a more in-depth discussion of the paper, since we had to identify both positive and negative aspects of the report." Student reflections also provided insight into the influence of peer critiquing and grading on their own writing. Several students commented that peer group work, particularly writing grade justifications, "helped them identify weaknesses in their own writing."

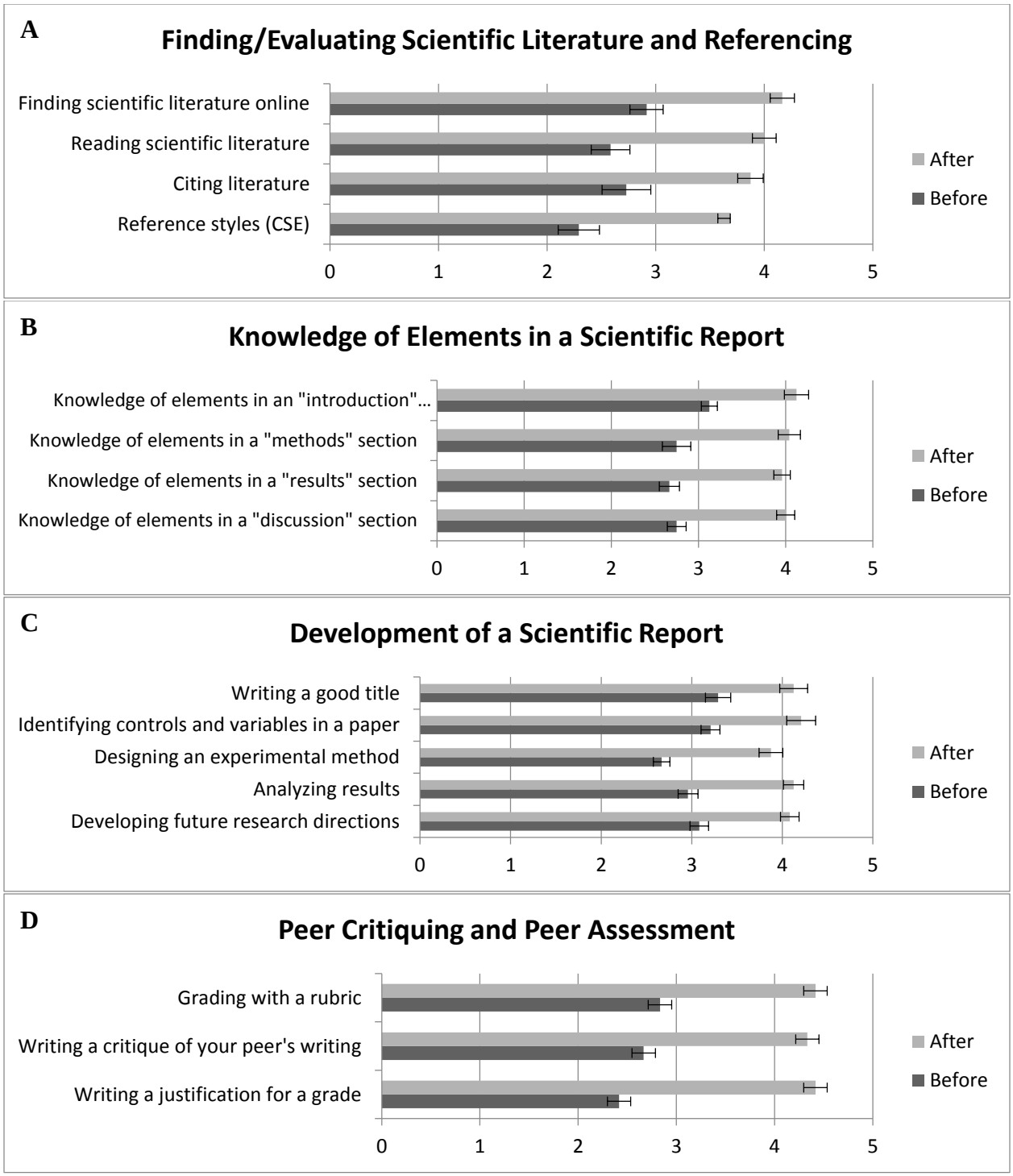


Figure 1. Student self-assessment (n = 24). Surveys were administered to students in order to identify their knowledge level of (A) finding and evaluating scientific literature and referencing practices, (B) elements in a scientific report, (C) development of a scientific report, and (D) peer critiquing and peer assessment. *Scale: 1 = no knowledge, 2 = little knowledge, 3 = some knowledge, 4 = very knowledgeable, 5 = expert.*

Improved Performance as an Indicator of Student Perceptions

Students reported in course surveys and reflective narratives that they perceived improvements in

their own writing as a result of peer evaluation and assessment, particularly as a result of writing justifications for the assigned grades. These reports were mirrored by an upward trend in writing quality as indicated by grade analysis and average assessment grades. Analysis of the grade distributions for each major assessment (introduction, methods, results and discussion, and final paper) demonstrated a range of grades, indicating that students were comfortable with assessing work displaying various levels of intellectual achievement (Figure 2A). Furthermore, average assessment grades improved by a full letter from the start of the course to the end of the course (from C+ to B+ average) (Figure 2B). One concern at the start of the course was whether students would grade each other fairly and effectively using the CORE rubric that was introduced early in the course. To ensure fairness in assessment, the instructors reviewed all grades, and grades where changed in the event of a disagreement between the instructor and the student sister group. Surprisingly, inter-rater reliability was high, with only eight assessment grades modified out of a total of ninety-six assessments (Figure 2C). It should be noted that in all cases where instructors changed grades, it was only by a half of a grade step (e.g. from a B to a B-). Out of the eight total grade changes, six of the grades were raised by the instructors, and two of the grades were lowered (Figure 2C). It is possible that these outcomes are a result of the writing and revision process and not a direct effect of peer evaluation; however, the authors feel that peer evaluation heavily influenced the revision process since this was the only feedback received by the students (instructor feedback was not provided). As Nicol et al. (2014) suggested, the improvement in writing performance may be attributed to the reviewing process itself, which is intrinsic to the peer review exercise. Therefore, the act of peer evaluation and assessment likely directly influenced the quality of the writing and revision process.

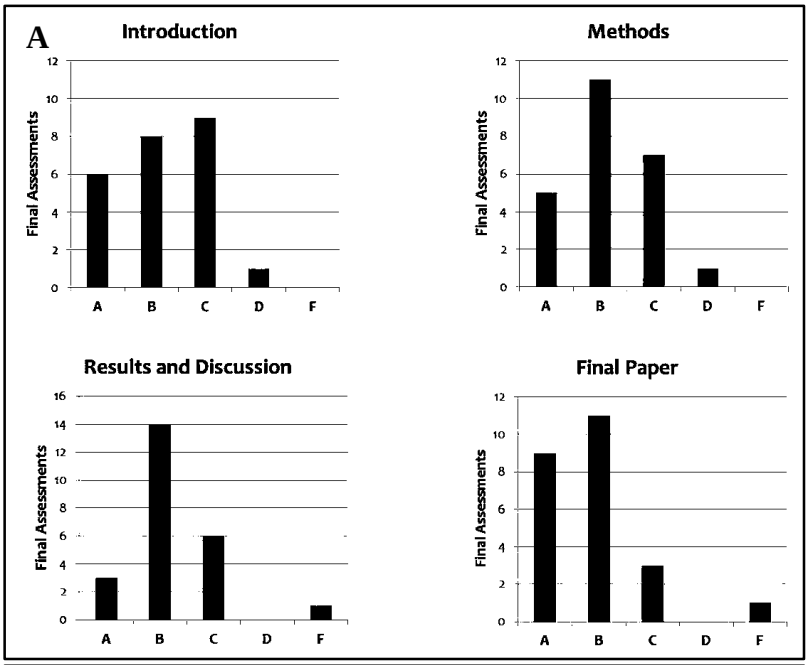
Logistical Improvements

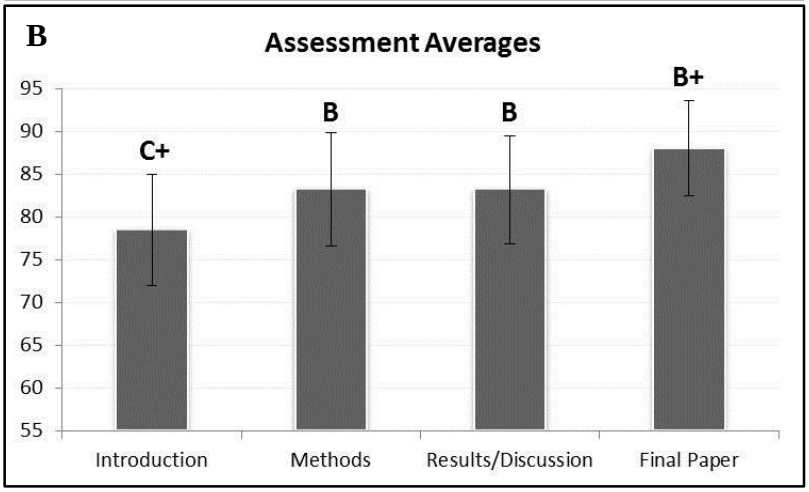
Overall, the students commented that this course was extremely helpful and effective in teaching them to write scientifically; however, several challenges arose as a result of this course design. In the future, the course will be modified to shorten the initial reading and analysis of scientific literature (allowing students to begin writing their original work earlier), and additional examples of primary literature will be integrated for analysis. Another logistical issue involved the accessibility of written work. Absences, printer issues, and a lack of student preparedness impeded the ability of students to assess work in a timely manner. One solution would be to require students to submit all work to an online forum, such as a discussion board on Blackboard or turnitin.com, so that all written works are available electronically.

Pedagogical Improvements

The success of peer critiquing and peer assessment is dependent on a clear and consistent assessment tool (CORE rubric) that measures key components to scientific writing, including critical thinking, organization, appropriate tone, style, and citations. Though students agreed that the rubric was effective, improvements in the clarity of the wording would better assist students in writing assessment justifications. Currently, an improved version of the rubric is being developed for use in future courses. Major changes include a simplified method for evaluating critical thinking, and refined descriptions of supporting categories, such as evaluation, limitations, and difference between just summarizing and providing a clear thesis.

This course integrated exposure to experimental design in the students' academic career, which was challenging. Students commented that it would be helpful to include a session focused on method development. In future iterations of the course, a methods workshop will be





C

Total Number of Assessments	Number of Assessment Grades Modified by Instructor	Grade Raised	Grade Lowered
96	8	6	2*

Figure 2. Grade analysis**.** (A) Grade distributions for each assignment. It should be noted that the "F" assigned was due to the failure of a student to withdraw from the class after excessive absences. (B) Assessment averages were tracked throughout the semester for each assignment. Error bars represent the standard deviation (n = 24). (C) Inter-rater reliability was measured by tracking the total number of grades changed by the instructors out of the total number of assessments. *Grade changed from A to A-.

incorporated to provide students with results from experiments that will be utilized to reverse engineer methods for the sample data. This exercise will aid students in developing their own methods to obtain results that are relevant to their hypotheses. It would also be helpful to introduce the students to strategies for analyzing raw data and presenting it in a professional manner. Finally, more time will be spent at the beginning of the course discussing the fundamental differences between the results and discussion sections, since many students felt the elements of these sections overlapped.

Long-Term Study

To validate the effectiveness of peer evaluation and assessment using the CORE-defined standards for critical thinking, we believe subsequent studies of this course design should be conducted. Specifically, a control group (no peer evaluation, writing assessed by the instructor using the CORE rubric) and an experimental group (peer evaluation implemented using the CORE rubric) should be established. Critical thinking should be measured using an independent, validated tool at the beginning and end of the course. Furthermore, additional data on student perceptions should be collected by utilizing focus groups.

In the context of the current biology curriculum, this course was designed to introduce scientific writing (finding, reading, and analyzing primary literature), experimental design, and composition of an original scientific report at the freshman level. In addition to better preparing students in their approach to scientific writing, this course serves as an introduction to an upper-level course (Biol 250: Introduction to Research Methods), in which students author a research proposal and present their proposal at Symposium Day (annual student research day at the university). We predict that students who have taken Biol 232: Scientific Writing will be better prepared for their upper level writing-intensive biology courses, as well as their senior research projects. To assess long-term progress of students who matriculate in the biology program as freshmen, we will collect sample papers from students who have completed Biol 232, Biol 250, and Biol 495 (senior research thesis). Each of these courses requires the submission of a final scientific paper. Each of these papers will be assessed using the CORE rubric. Students should show progressive development of critical thinking at each level. Student-generated feedback could also be collected by administering similar surveys at the end of Biol 232, and at the beginning and end of Biol 250. Survey questions would focus on the students' knowledge level of finding, reading, and analyzing scientific literature, and writing a scientific report. Not only is it pertinent to assess students' work as they advance through the biology program, it is also important for the students to be aware of their progression in the area of scientific writing.

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