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CourseSource

Essay

Strategies for developing a science communicator through authentic science writing assignments

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Abstract

To prepare biology undergraduates to be able to read and evaluate the primary literature, it is beneficial to teach students how to write documents in the style of professional science style manuscripts. By breaking manuscripts into individual section assignments, we can distribute instruction across a four-year undergraduate curriculum to scaffold writing practice mastery. These skills are aided by peer review, writing tutor instruction, and assignment repetition. Students gain not only competency in writing about the discipline, but can better understand and critically evaluate the written work of others. The science writing and communication skills gathered over the course of this curricular framework provide all students with expertise in accessing science themselves and disseminating science to others.

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Introduction

One of the primary skills developed during undergraduate science courses is how to access and understand material directly from the primary literature. In scientific disciplines, especially in biological fields, the fast pace at which new information is discovered and disseminated often outpaces textbooks. Primary peer reviewed journals and comprehensive literature reviews provide current and detailed sources for student learning about biological discoveries and concepts. The intended audience for primary and secondary sources is wide ranging, depending on intended audience of the journal where it is published. Readers of a journal article may be experts in the overall topic, may be looking for insight into one specific protocol being used, or may be investigating a single facet of the research design. Therefore, the level of analysis each reader will apply to each article will depend on the end goal of the reader.

Primary journal articles are distinct in their writing style from textbook material, where a reader is typically guided through a topic. However, to provide students with the most current information available in biology courses, an instructor may shift from using a static textbook to more dynamic and changeable communication mediums, such as online or primary sources (1). For students to fully engage with the content in these professional sources, students must be able to access the material in a thorough way. This can be accomplished by clear writing and presentation by manuscript authors. However, a more universal strategy focuses on providing students with the appropriate tools to interpret the content represented or assumed in primary manuscripts.

Whether or not it is a primary document, the overall impact that a piece of writing can have on the audience depends on how clearly the document communicates the science and results (2). There are many strategies and resources that support novice readers on how to approach scientific papers and how to teach students to gain insight from the findings presented in different resources (Table 1). Along with practice in reading

Table 1. Scientific manuscript reading resources.

Institution	Source Name	Website Address
Columbia University	Efficient Reading of Papers in Science and Technology	http://www.cs.columbia.edu/~hgs/netbib/efficientReading.pdf
UNC Chapel Hill	Reading to Write	http://writingcenter.unc.edu/handouts/reading-to-write/
Stanford University	Reading Scientific Papers	http://web.stanford.edu/~siegelr/readingsci.htm
Rice University	How to Read a Scientific Paper	http://www.owlnet.rice.edu/~cainproj/courses/HowToReadSciArticle.pdf

primary literature, the process of learning by doing, or writing to learn (WTL), can be an effective way to instruct students (3). In courses, students can produce authentic scientific writing, learn to use peer review procedures to edit and critique work (4-6), and have a chance to repeat similar writing assignments both within a course, as well as over a curriculum. Through these experiences, students gain expertise in effectively writing about their own work, but also learn how to successfully navigate and interpret the writing of others. These skills are gained over time, and can be reinforced by repeated practicing and providing clear feedback.

Previous reports have examined the benefits of using the primary literature in a STEM classroom (7,8), as well as using WTL in the STEM classroom (3). Various textbooks and websites cataloging college writing centers, with their accessible science writing tools and techniques, are widely available and useful resources for courses (9,10), as listed in Table 2. Moreover, in studies assessing students' skills for evaluating primary literature over the arc of an STEM curriculum, researchers observed some gains made by all students, as well as clear distinctions in the ways that introductory and advanced students approach the task of reading and analyzing papers (7). Similarly, studies demonstrate that learning to write scientific-style manuscripts has long term positive effects post-graduation, including improving career trajectories for the involved students, both in their writing and overall science communication (11-13)

Table 2. Scientific manuscript writing resources.

Institution	Source Name	Website Address
Duke Graduate School	Scientific Writing	https://cgi.duke.edu/web/sciwriting/
Bates College	Introduction to Journal Style Biological Writing	http://abacus.bates.edu/~ganderso/biology/resources/writing/HTWgeneral.html
Colorado State	Writing the Scientific Paper	http://writing.colostate.edu/guides/guide.cfm?guideid=83
Nature/Scitable	Writing Scientific Papers	http://www.nature.com/scitable/ebooks/english-communication-for-scientists-14053993/writing-scientific-papers-14239285

Examples have been published using authentic scientific writing in in STEM courses, specifically focusing on using individual courses and assignments to teach various aspects of scientific writing. Assignments in these courses are designed to include parts of a final manuscript, such as the results and discussion section (14), a full manuscript (15), a review paper (16), as well as an NSF style grant proposal (17,18) . In contrast, the strategy presented here uses the timeframe of a four-year biology sequence of core and elective courses in a general biology curriculum, to provide instruction and repetitive practice for students in how to write in the style of professional scientific manuscripts. This goal is accomplished by breaking down the portions of the manuscripts into small writing goals with level-appropriate assignments, and using peer review and repetition to practice and refine techniques over the course of semester, and over the entire 4-year undergraduate degree. The resulting science writing skills provide students with a better foundation for preparing future writing assignments, in addition to associated skills for critically reading and understanding the writings of others.

Science Writing Througout the Liberal Arts Curriculum

This work was conducted in a small liberal arts college in the Northeast, where students major in programs from one of 4 divisions (Languages and Literature, Social Sciences, Arts, and Science, Mathematics and Computing). The college's curriculum is firmly seated within the liberal arts tradition, requiring students to fulfill courses in nine general education distribution categories for graduation, in addition to the courses required for their major. Additionally, in their first year of study, all students have three unique, mandatory, educational course experiences (Language and Thinking, First Year Seminar, and Citizen Science) that focus on the development of student writing and critical thinking skills (19). Students select to focus their studies on a discipline or program (e.g. biology), and complete the curricular requirements established by the faculty of that program. Finally, to complete graduation requirements, all students are also required to complete a two semester (eight-credit) senior project thesis. Biology senior thesis projects must include data that address a novel hypothesis and analysis of these data in relationship to the greater field of this research topic. Senior project theses include an introduction section resembling a literature review, in addition to an abstract, materials and methods, results, discussion, figures and legends, and citations modeled after a discipline-relevant primary journal manuscript. Students are also required to present a printed research poster based on their work at a public, campus-wide presentation, as well as defend their work during a final board meeting with three faculty members. Thus, oral communication skills are also a large part senior project, and require the students to be able to discuss the project with a wide variety of audiences. The scale and intensity of the senior project can be managed by teaching to students how to master specific science writing and communication skills as part of the curriculum leading up to the senior year. Such an approach enables students to practice these skills prior to the senior year and the senior project experience. Student feedback on the senior writing experience specifically note that, "the senior project is a culmination of all of the writing techniques we learn in our earlier classes."

The biology curriculum followed (Table 3) requires students to complete many courses within the program, at all course levels (100-400) (Figure 1). A variety of topics and scientific content are taught in all levels, and in all courses, students are required to read and evaluate primary literature, as well as develop specific science writing skills. Although not all

Table 3. Scientific writing assignments across biology curriculum*.

Course	Writing Assignment	Hoffman** Book Chapters Assigned	Assignment Repeated During Semester?
100 level; Introductory Example Courses: - Environmental Microbiology (4 credits) - Microbiology Techniques workshop (2 credits)	Figures/tables and from primary journal style manuscript (data collected from laboratories completed); Scientific Poster	1-5, 13	Yes
200 level; core course for majors Example Course: - Genetics and Evolution (4 credits)	Results and Discussion from journal style manuscript (data collected from laboratories completed)	1-5, 6.8-6.10	Yes
300 Level; majors level laboratory electives Example Courses: - Microbiology (4 credits) - Virology (4 credits)	Full journal style manuscript (data collected from laboratories completed) Focus: Introduction; materials and methods	1-6	Scaffolded assignments; Introduction section/review assignment repeated
400 Level; seminar majors level elective (2 credits) Example courses: Cholera: Pandemics, Pathology and Molecular Mechanisms (2 credits) Topics in virology: Ebola (2 credits)	Mock NSF style grant proposal (focus on literature review for background and significance section)	1-4, 10, 14	Scaffolded assignments for grant
Senior Project; Mandatory for all students of the college (8 credits)	Hypothesis driven data collection Written document consisting of extended literature review for introduction, and style of primary peer reviewed research manuscript	1-10, 13	Scaffolded assignments

* All assignments are peer reviewed.

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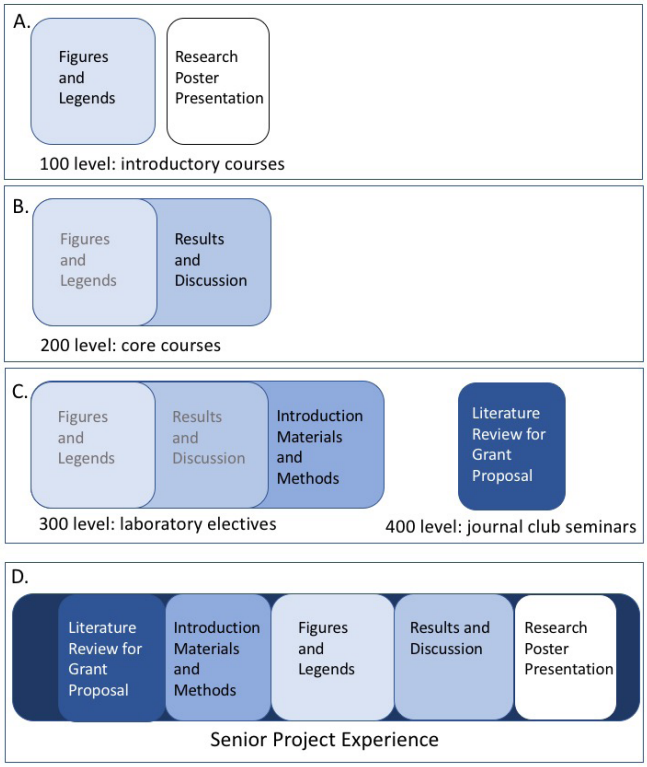

Figure 1. Scientific writing and communication assignments. Science writing and presentation skills are scaffolded throughout the four-year biology curriculum. **(A)** Representation of the initial skills learned during the introductory 100 level laboratory based courses. **(B)** Additional skills learned and practiced during the 200 level core courses, typically taken in the second year of study. **(C)** Variety of writing skills that are learned in the upper college courses, 300 and 400 level, taken in the third and fourth year. **(D)** Representation of the culmination of all skills in the final senior project experience.

students will take courses with the same topical focus, the set of reading, writing and communication skills are considered outside the scope of the subject content. To provide consistency in writing instruction to students throughout the curriculum, we use a singular biology writing textbook as a reference for students, which focuses on the specific features of science writing, while teaching who to write distinct manuscript sections as discrete learning goals (10). The craft of science writing is both encouraged and expected from the first semester of study, and its practice becomes more of a habit for students as they progress through the curriculum. To further the continuity of these courses, many faculty assign similar writing assignments within the various courses throughout the curriculum. Therefore, students throughout the entire biology program optimally receive the same skill development, regardless of the course topics and senior theses projects selected.

To provide faculty concrete ways to focus on writing within the biology curriculum, writing training workshops are offered through the college's Center for Faculty and Curricular Development (CFCD). These workshops are followed up with individual course support by paid student peer writing tutors who have completed pedagogical training in peer review and editing. Use of writing tutors in courses is helpful for establishing an open peer review process early in the academic career (20). Writing tutors meet with the faculty member at the beginning of every semester to discuss the writing assignments, assignment goals, and course schedule. The students are required to meet with each student in the class at least two times per semester to discuss assignment drafts for construction, clarity, and development of writing skills. Often, writing tutors are assigned to tutor courses that they have taken previously, and are therefore familiar with the assignments, as well as how they relate to future coursework. Collected student feedback related to the role of writing tutors in the classroom is positive, reflecting on the value of peer review and learning how to simplify and clarify statements. Specifically, "writing tutors allow students to collaborate with other students. This has helped me learn how to communicate my thoughts on scientific literature to others in a way that is clear and concise," and "meeting with a writing tutor is an excellent way to get a non-biased, informative opinion on your scientific writing. . . guide you to more clearly state your claims/better understand your own writing." The class-associated peer review process, both in the classroom and outside of the classroom in writing tutor appointments, is analogous to that used in the academic world, and gives insight into this crucial process at an early stage of skill development (21).

First Year Course Writing Skills - Figures/Legends and Poster

In their first year of study, biology students begin their major course work with two laboratory-based introductory courses in some field of biology (e.g. Environmental Microbiology- four credits; Microbial Techniques Workshop- two credits). These courses focus on development of skills in reading primary literature, as well as laboratory skills in experimental design and data collection and analysis, using a specific topic (such as microbiology, genetics, plant biology, neurobiology) as the focal lens for the content. For each individual laboratory exercise, students must collect the data from an experiment and present it in a way that most clearly represents the results. Prior to each week's laboratory, students complete a pre-laboratory assignment that requires them to find a primary research article that uses the same technique they will use in that day's laboratory (Supporting File S1). This assignment gives the students practice in searching through the primary literature using tools such as PubMed and Google Scholar, as well as provides them with concrete ways that data gathered from these assignments can be presented to a reader. Using examples from the primary literature as comparison, students learn how to present the data in a clear and professional manner. The primary writing assignments for these introductory courses develop students' skills by teaching students to present data as formal figures/tables and legends, as well to construct a research poster to communicate results to others (Table 3, Figure 1). To practice this assignment, and gain expertise in writing, written work is routinely peer reviewed during class sessions using a rubric developed from the learning goals of the writing text (Supporting File S2). Students are also provided with access to a college-trained, peer writing tutor who can assist in the peer reviewing and editing the mechanics and clarity of the writing. This assignment structure is repeated throughout the semester, following the completion of six or seven distinct laboratory experiences. At the end of the two-credit laboratory course, the experimental results are summarized as a printed scientific poster. Students present their work to others orally. Each of these communication skills are required in subsequent classes and assignments; thus, the first year of study help build a foundation for mastering these skills.

Student feedback surrounding the role of dealing with reading and writing primarily literature at this early stage uniformly mention how this is the first exposure to this type of assignment, "practicing the critical thinking and analytical skills necessary to understand papers at the lower level [courses],"and "We are challenged to begin to write elements of research papers related to our laboratory work." These introductory courses highlight the need for clear scientific communication using primary sources, while simultaneously providing methods to gain these skills.

200 Level Course Writing Skills - Results and Discussion

Immediately following the completion of two 100 level introductory courses, students who major in biology enroll in additional research-based laboratory courses (e.g. Genetics and Evolution- four credits, Ecology and Evolution- four credits). In these courses, particularly due to the rapid expansion and development of these fields, textbooks provide supporting background information, while the majority of course readings are derived from the primary literature. In the laboratories, students design experiments and collect data to address specific class developed hypotheses. This information is reported in the format of a results and discussion section of scientific manuscript (Table 3, Figure 1). It is expected that students will also prepare figures/tables and legends to accompany the results and discussion writing, practicing a skill from their introductory courses. During class instruction time, assignments are designed to teach students to recognize the features of these types of writing. These assignments also help students to decipher and master the language cues that are crucial to distinguishing a results section from a discussion

section of a paper. Drafts of writing assignments are peer reviewed using a rubric developed from the instructional writing textbook (Supporting File S3). In this course, meetings with peer writing tutors are required as part of the final course grade, to emphasize the mechanics of writing these paper sections, and highlight the importance of careful editing and peer review. These results and discussion assignments are repeated at least three to four times over the course of the semester. The repetitive aspect of these assignments, both over the semester and over the 100 and 200 level courses provide students time to practice and gain expertise in these type of scientific technical writing, while reading primary research papers throughout the semester. In their feedback, students specifically mention the role of linking the reading of primary work with the production of science writing, stating, "the emphasis on close readings and analysis [of primary manuscripts] helps to reinforce and connect the writing techniques we learned in each class." As these core courses are required for all biology majors, the skills specifically taught in the 200 level courses are universally available for extension in upper college work.

300 Level Laboratory Electives - Writing Full Length Scientific Manuscripts

As a part of the upper college curriculum, 300 level laboratory courses (e.g. Microbiology- four credits; Virology- four credits) help students to gain experience with more independent and inquiry-based and research based laboratory techniques. In many ways, we consider these courses crucial to building a set of skills needed to successfully complete a senior project thesis. In these courses, students have already become well practiced with reading and understanding the primary literature. In this level of course, students are also given opportunities to practice how to utilize materials and methods sections of manuscripts to construct specific laboratory protocols, in tandem to learning how to convert laboratory protocols into the format of a materials and methods writing style prose. The typical final assignment for this course is to produce a manuscript in the style of a peer-reviewed, primary journal article, including abstract, introduction, methods, results, discussion, and figures/tables and legends (Table 3, Figure 1), based on the data collected throughout the course of the semester. In-class discussions and practice focus on methods for writing a literature review. Peer reviews occur for outlines of the introduction section, for sample method sections, as well as a peer review of a full manuscript draft (Supporting File S4). Optional support from assigned science writing tutors is available, as is open access to the general tutors at the college writing center. These courses serve, in many ways, as a trial run for students to design and execute projects that mimic the style of their eventual senior project thesis. Students self-report that these assignments allow them to "critique the methods and approach used in research projects and suggest further questions. . . we begin to learn to craft our own introductions. . . building on the writing skills we established as underclassmen." The skills students build in this course, both in the laboratory, and in writing, allow for a more prepared entry into the senior project capstone experience.

400 Level Seminar Course - NSF-Style Grant Proposals

In our upper college curriculum, in addition to laboratory electives, we also require students to learn how to investigate specific scientific topics in-depth, relying only on primary literature for scientific content. These courses are often run in a style much like a graduate school journal club, and focus on specific topics of interest (e.g. Cholera: Pandemics, Pathology and Molecular Mechanisms- two credits; Topics in Virology: Ebola- two credits). These courses are primarily student managed, relying on student presentations of primary papers, reading review articles for background information, and sophisticated and nuanced evaluation of results, through examination of figures and tables. Students are evaluated on their presentation of figures (Supporting File S5). Over the course of the semester, using the in-depth knowledge they gain from the primary literature, students are required to write a shortened NSF-style grant proposal, selecting a hypothesis that is literature based, and will move the field forward. Students are required to write a shortened aim section, as the focus of this assignment is more directed at the Background and Significance section. The Background and Significance writing is viewed as a proxy for a literature review that is required in the introduction of the senior thesis. Throughout the course of the semester, the assignments for the grant proposal are scaffolded, with peer review occurring for the outline of the Background and Significance section, as well as a full peer review of the proposal draft (Supporting File S6). As in 300 level laboratory courses, there is optional support from assigned science writing tutors, in addition to access to the tutors at the college writing center. This course incorporates written and oral presentations, identifying and analyzing the literature, and synthesis of unique hypothesis-based research questions. Student reflection on this assignment reveals connections made between the process of reading papers and writing them, specifically that "this research based paper allowed me to formulate a relevant question that had not yet been researched and write about why the topic was important. . . .This required me to read countless primary literature articles to learn what kinds of discoveries were being made and how they were related to my question."

Senior Project Experience - Full Length Literature Review and Full Length Research Manuscript

An important aspect of the undergraduate curriculum at Bard College is the requirement that all students complete a two-semester, research-based senior project, under the mentorship of a faculty member. In the biology program, we require that all senior projects be framed by a novel hypothesis and include data analysis. Students report their findings in a senior project thesis format that has a literature review length introduction section of approximately 20-25 pages, in addition to an abstract, methods, results, discussion, and figures/tables and legends sections. To facilitate the writing aspect of the senior project, groups of students under the mentorship of one or two faculty members meet weekly to discuss writing goals and to peer review sections of their papers (using Supporting Files S4 and S7). This approach is student-centered and student-driven, but the process of writing is informed by our four-year curriculum. Through this engaged process, students become comfortable with peer review and breaking down scientific writing into manageable assignments. Students mention this comfort level when describing the senior project process, stating, "these assignments have helped me to build skills in written communication that are being directly tested

and utilized for the writing of my senior project manuscript."

Observation of Effectiveness

While teaching our students how to be effective communicators of science, faculty have a secondary goal of supporting student majors in the completion of the two semester senior theses projects. Senior projects are mandatory for all graduates. When students reach the point when they begin this experience, they have not likely encountered an assignment of this magnitude in their academic history. Student issues including consistent time spent on the writing, careful editing, and clear communication of results are all pitfalls that senior project advisors deal with on a weekly basis throughout the senior project experience. The strategy described here promotes an open conversation about the senior project writing that begins in the first year of study, rather than waiting until senior year to learn how to complete the task. The sections of the senior project are literally broken down and taught repeatedly throughout all stages of the biology curriculum. This repetition provides students with opportunities to practice writing tasks, as well as provides transparency to students about the criteria on which they will be evaluated for all assignments.

Formal assessments have not been conducted to determine if writing has improved for senior projects following implementation of these writing goal driven course assignments. However, the overall anxiety expressed by students has been reduced. Most students have anecdotally revealed worries concerning the size and scope of this writing assignment and how to define the steps to complete the project. As the curriculum has evolved, students are more clearly instructed in all courses as to how individual assignment writing goals specifically relate and map on to the senior project experience. We much more frequently observe that students are more prepared to tackle this writing challenge. As the various writing assignments and rubrics/grading criteria have been developed, faculty within the program have routinely discussed strategies for teaching these assignments during weekly program meetings and annual curriculum retreats. Assignments, rubrics and syllabi are routinely shared among faculty to provide a more uniform instruction for all students. In this way, new faculty are equipped with frameworks of what current faculty are using to help improve student success.

Conclusion

All courses in the curriculum contain explicit content goals for students to achieve throughout the semester. However, the development of writing and communication skills are equally crucial to master, especially in STEM fields that have a unique style for their writing and literature (22,23). This scaffolded writing curriculum teaches students early on and repeatedly how to both read and write formal, professional style documents. Following this training, students enter the workforce better prepared to be clear communicators of their knowledge, and have skills for both accessing information, and producing writing for others. The required senior project thesis experience is one that will likely have a large impact on the postgraduate career decisions made by the student (24-26). Completion of any of these courses provide students with not only science content, but with writing and communication skills. Students who complete only one of these courses, for example a non-biology major taking a class for interest or to complete a college wide distribution requirement, will gain insight into the authentic nature of the scientific process, and become "a competent outsider" (as defined by Feinstein in 27). The completion of multiple courses over the undergraduate biology curriculum allows for practice, refinement, and elevation of these skills to a that of a mature scientist.

Supporting Materials

- S1-ScienceWriting-Assignment for 100 level pre-lab
- S2-ScienceWriting-Rubric for assessing figure and legend assignments
- S3-ScienceWriting-Rubric for assessing results and discussion assignments
- S4-ScienceWriting-Rubric for assessing full manuscript style paper
- S5-ScienceWriting-Rubric for assessing journal club style contributions
- S6-ScienceWriting-Rubric for assessing grant proposal assignments
- S7-ScienceWriting-Rubric for assessing review paper

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