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SCIENCE EDUCATION

Inquiry-Based Writing in the Laboratory Course

Writing lab reports in science classes can be more productive and engaging if the experience is structured well.

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Scientific writing is increasingly recognized as a key component of an undergraduate scientific education. As an integral part of scientific practice, scientific writing is best learned in the context of doing science (*1*, *2*). Because students "do" science (as opposed to "learn about" science) almost exclusively in laboratory courses (*3*, *4*), they need to learn the skills of scientific writing there.

The inadequacies of the traditional lab, in which students go through the motions of laboratory work in a series of "cookbook" activities, have been widely recognized. Inquiry-based approaches to lab instruction are transforming the undergraduate lab by having students undertake actual experiments designed to help them learn to think scientifically (*5*–*7*). However, educational reform has yet to overcome the inertia of the traditional school "lab report." Even in inquiry-based settings, such lab reports remain largely inauthentic and make-work affairs, involving little actual communication beyond the implicit argument for a good grade. Real scientific writing, on the other hand, involves a variety of rhetorical functions including persuading skeptical audiences, constructing interpretive frameworks, refuting the work of others, and so forth.

In short, the inquiry philosophy has not yet been extended to include what might be called "inquiry-based writing." In our view, successful inquiry-based writing requires three modifications to the inquiry lab. First, lab courses should give students practice in forms of writing actually used by scientists. Second, writing tasks must be aligned with the activity of the lab so that students have something meaningful to say. And third, student writing must have a real audience (see the chart).

Forms of Writing in the Lab Course

Broadly speaking, recent reforms to writing in the lab course can be classified as either "writing to learn" (WTL) or "writing as professionalization" (WAP). Much of this work has taken place in chemistry education (*8*). In the WTL approach, writing tasks are designed to help students engage with the scientific method and learn scientific ideas by reflecting on their experience. An exemplary version is the Science Writing Heuristic (SWH), which reframes the traditional school lab report as guided questions, providing opportunities for personal reflection about both the science and the scientific process (*9*). For example, in contrast with traditional lab reports—in which students insert content into boxes labeled "Methods," "Results," and so on—the SWH asks students to address thought-provoking questions such as "What can I claim?" and "How do I know?" (*10*).

In WTL, writing is primarily a tool to enhance scientific learning; it treats writing as a means rather than an end. When scientific writing is taught without regard to rhetorical function, expectations set for student reports are likely to be at odds with those of professional scientific discourse. SWH instructors, for example, are expected to check whether each student "lists all data" (*11*). Yet a key skill in communicating science is selecting which data to present.

The first step toward inquiry-based lab writing is to assign forms of writing that working scientists use. This step has been taken by the WAP approach (*12*). Students in WAP classes produce professional forms such as the conference poster; the research proposal; the review article; and, in the lab course especially, the experimental research report (*13*–*15*).

But because lab courses do not generally replicate the professional research settings that produce actual journal articles, assigning the experimental report brings its own pedagogical challenges. Consider what happens in the introductory sections of the typical research report: Researchers describe a knowledge gap in the literature and then explain how their current research fills that gap (*16*). But even in an inquiry-based lab, students have no research agenda and lack the breadth of knowledge needed to discuss their experiments in the context of the primary literature. Writing standard introductions for such labs can only be a sham. Students are not positioned to learn how to write such introductions until they have a scientific idea of their own to advance and at least a cursory knowledge of the related literature, probably late in their undergraduate studies.

The same problem exists with the teaching of the Methods (or Experimental) section. Because teaching the entire scientific paper at once is inherently problematic; one described strategy is to begin with the part that seems easiest on the surface: the Methods (*14*). Yet asking students to write Methods for experiments where the procedure is specified in detail in a lab manual, a common practice in WAP-style courses, requires that they engage in yet another kind of sham, because there is little for them to do but parrot back selected details from the manual. As students well know, those

DESIGNING EFFECTIVE INQUIRY-BASED WRITING ASSIGNMENTS

Give students practice in authentic forms of scientific writing

Consider a wide variety of professional genres, including experimental reports, methods papers, proposals, and peer reviews.

Consider only part of a genre as a whole assignment

Ensure that students have something meaningful to say

Design assignments for the curriculum rather than the individual course.

Assign only those parts of a genre that match the realities of the lab setting.

Abandon any part of an assignment that lacks an authentic communicative function.

Create a real communication scenario

Position students as apprentice scientists.

Position instructors as scientific readers.

Assign only as much writing as instructors can read and respond to thoughtfully.

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who will actually read these reports already know what was done. Devoid of an authentic communicative purpose, students have no basis for deciding which details should be included. Students should learn to write Methods in more advanced lab courses when they are designing their own experiments or at least substantially altering standard protocols.

Alignment and Audience

The second step toward inquiry-based lab writing is aligning student writing with lab activity. Short of the independent research project, no undergraduate course can replicate the total context of the research environment necessary to produce experimental reports in full. But if we relax the assumption that students must produce entire experimental reports for every lab or even in every course, we can design tasks that give students something to say: Introductions are written by advanced students undertaking original research; methods, by intermediate students who design experiments. In most lower-level labs, students have no research agenda nor do they design experiments. They do, however, generate and evaluate data; thus students at this stage can present and discuss results.

Yet to fully engage in laboratory writing, student authors need not only something to say, but also someone to say it to. Of the methods common approaches to laboratory writing considered here, WTL is not particularly concerned with the reader, and WAP assignments typically ask students to imagine that they are addressing, broadly, scientists in the field, an abstraction that means little, and provides little useful guidance to novices. Therefore, the third and final step toward inquiry-based writing is to provide students a tangible audience for their written work.

Picture the standard introductory-level titration lab. Now imagine that some students receive contaminated reagents, but they do not know who received which. Now, imagine that students are given, at random, either contaminated or uncontaminated reagents, but they do not know who received which. This inquiry-based version engages students in meaningful scientific inquiry, and yet the instructor still operates primarily as a grader. But if the instructors, too, are kept ignorant of the distribution of reagents, they cannot know what the results should be. Instead of grading a product in which claims match expected outcomes (*11*), they must read student writing as scientists, evaluating how clearly and convincingly each case is made. And once instructors shift from mere graders to readers, students cannot merely reproduce the form of scientific argument but must actually make scientific arguments (*17*).

What would inquiry-based writing in this lab look like? No longer compelled to have students write an introduction or describe methods, we might ask them to write only a single, well-designed page. This page would include a main claim supported by key results, appropriate visual displays, analysis of error, and so forth. Although considerably shorter than the typical lab report, this assignment makes authentic rhetorical demands, requiring students to argue for an interpretation of their data under constraints typically faced by the writing scientist. Similar to the body of a "letter" or "short communication," this highly condensed writing can help students learn to construct a representation of their data that is both selective and compelling (does not ignore results that challenge the hypotheses).

The Inquiry-Based Writing Lab

When writing tasks are integral to lab activity and when student writing has a real audience, students are more likely to find such tasks meaningful and engaging, and instructors can respond to such writing as the scientists they are, rather than as evaluators of standardized work or grammarians. Further, eliminating unproductive writing tasks allows both student and instructor to spend more time doing important work. Students can concentrate on a limited number of skills that are essential for writing science but rarely the subject of extended instruction: how to decide which data to present; how to use graphs, tables, and other visual displays effectively; and how to discuss those graphic supports in the accompanying prose. Instructors in turn can demand higher-quality work and provide more-useful feedback.

Some may worry that under our proposal students will not learn how to write a complete research report. Although undergraduate science majors should have the opportunity to design their own experiments and take on a scientific research project of their own (*5*), this is unlikely before the senior year. The senior-year research project therefore provides the proper occasion for learning to write the research report in its entirety.

Those who oversee undergraduate science labs may have pragmatic concerns about the cost of change: the time involved in redesigning assignments, the need to train teaching assistants differently, the need to rethink evaluation, and so forth. All serious pedagogical reform has costs, especially reform involving deep changes in mindset and practice. But there are long-term savings as well, when we consider the reductions in the amount of writing students produce.

Many institutions may find it impractical to implement all three proposed modifications at once. Thus, we suggest implementing change in the order we have described, as each modification is a precondition for the next. Finally, some instructors and students will find the transformation uncomfortable. But just as with inquiry-based labs, transitional discomfort is necessary to gain the advantages provided by a more realistic approach.

What is required of inquiry-based writing is precisely what is evaluated in day-to-day communication among scientists: care and integrity in handling data, clarity and persuasiveness of communication, relevant and compelling results. If we are serious about improving students' abilities as scientific communicators, we must take them seriously both as apprentice scientists and as apprentice writers of science.

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education system is a result of autocratic incompetent governance at all levels—including inefficient budget spending, staffing based on connections rather than merits, and increasing corruption—and the still-dominant Soviet mentality among the population, which places more value on a diploma than on substantive qualifications.

Reform of the post-Soviet education system should focus on the quality of education rather than the misleading quantity of graduates. This can be achieved by integrating independent evaluations of both faculty and graduates into the system, and by providing talented scholars with incentives to stay in the country and to cultivate quality research and teaching that live up to international standards.

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Lab Course Goals: Science or Writing?

AS A PHYSICS INSTRUCTOR, I READ WITH GREAT interest "Inquiry-based writing in the laboratory course" by C. Moskovitz and D. Kellogg (Education Forum, 20 May, p. 919). The authors present a clear argument for designing appropriate writing assignments throughout the science curriculum. I fear, however, that they have focused on teaching writing in the introductory science course at the expense of teaching science.

For example, their suggestion to deliberately hide information from the grader of a titration lab is misguided. Presumably, with less objective information, the grader will be more impartial when grading the students' writing. But to teach the science, the grader must be biased. The first priority should be ensuring that the students get the correct result; their ability to articulate that result is secondary.

Moskovitz and Kellogg also seem to conflate keeping a good lab notebook, a strictly scientific endeavor, with writing a good scientific article. They criticize the Science Writing Heuristic (SWH) because it requires students to list all data. It is true that scientists do not report all data in scientific articles, but they do record all data in lab notebooks. Given that students already tend to record too little data, the SWH instructions seem sound. After all, the lab notebook is the foundation upon which all scientific writing is built.

Improved science writing instruction begins by clarifying the pedagogical purpose of each assignment. In the introductory course, that purpose should be learning science.

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Response

WE AGREE WITH GOGGIN THAT STUDENTS IN introductory lab courses "should be learning science," but we disagree on what this means in practice. We believe that lecture courses offer undergraduates adequate opportunity to show whether they can get the right answer. Labs, on the other hand, offer an essential opportunity for students to learn about the practice of science, and this practice includes presenting one's work in a clear and compelling fashion.

The goal of the double-blind setup in our example titration lab is not greater impartiality in grading, but a lab experience that better captures the sensibilities of scientific discourse. Content mastery can be tested in other ways; we believe that too much emphasis on "the correct result" discourages students from engaging fully in the scientific experience labs are designed to offer.

Like Goggin, we believe that laboratory notebook writing is undervalued. However, our topic was teaching scientific communication, not documentation. Requiring students to construct cogent arguments from their data in the way we describe might give them a reason to take such documentation more seriously.

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Letters to the Editor

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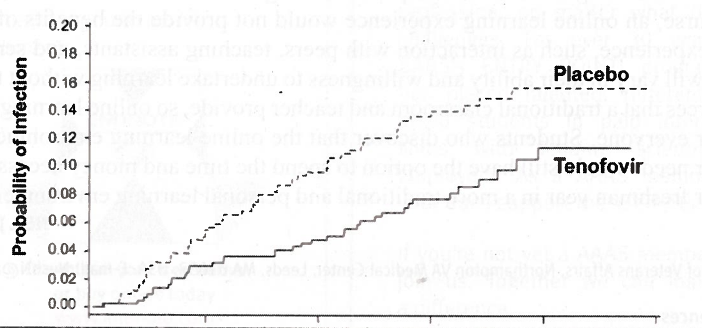
CORRECTIONS AND CLARIFICATIONS

Research Articles: "Effectiveness and safety of tenofovir gel, an antiretroviral microbicide, for the prevention of HIV infection in women" by Q. Abdool Karim *et al.* (3 September 2010, p. 1168). On page 1170, the first sentence of the first full paragraph should read, "Upon enrollment, a participant was assigned a sequential identification number, which corresponded to a unique envelope (accessible only to each study site pharmacist) that allocated her randomly, by using permuted block randomization of sizes 12 and 18, stratified by site, to one of six codes." In Fig. 2, the *P* value at the end of the Placebo and Tenofovir lines in the top chart should be deleted; the corrected figure is below. The Fig. 2 caption should include, "The lines showing the cumulative probability of HIV infection provide data on the first 28 months of follow-up only." In Table 2, an additional footnote should be cited at the end of the first-column entry "HIV endpoints plus HIV infection not meeting protocol definition" that reads, "This analysis is stipulated in the Trial's Statistical Analysis Plan as primary."



Months of follow-up	6	12	18	24	30
Cumulative HIV endpoints	37	65	88	97	98
Cumulative women-years	432	833	1143	1305	1341
HIV incidence rates (Tenofovir vs Placebo)	6.0 vs 11.2	5.2 vs 10.5	5.3 vs 10.2	5.6 vs 10.2	5.6 vs 9.1
Effectiveness (*P*-value)	47% (0.064)	50% (0.007)	47% (0.004)	40% (0.013)	39% (0.017)