CHAPTER 8

Final Papers

> Our [final papers] were far from the traditional lab report. I liked how we had the freedom to write and not be confined to strict guidelines of how a certain format had to be. . . . The written assignments were quite enjoyable because I was able to go over all the notes I had taken, and decide which, what, or how I was going to create the paper. —Johnny

> Sometimes it's hard to talk about it with people who are not in the class because they don't have the group background we've built together. —Ariana

In other chapters, we describe the ways in which scientists use texts that often are not considered "academic writing," and advocate for their place in the science classroom: lab notebooks, whiteboards, graphical representations, peer reviews, annotations of readings, and the joint construction of definitions. Here we turn toward texts that usually *are* what faculty think of when they think of "writing" assignments: the more lengthy expository paper, submitted to the instructor for a grade at the end of a unit, that ties together experimental evidence and scientific models.

Parallels between these assignments and scientific practices are obvious: The culmination of a productive line of inquiry, for a scientist, is usually the scientific paper. In these papers, findings are introduced that fill a gap in our understanding, answer an open question, launch a new line of inquiry, describe a novel technique, and so forth. In many writing assignments for science courses, students are asked to generate similar writing, often employing the structure of a journal paper (with introduction, methods, data, and analysis) to inform their own writing. A common school-equivalent of a journal-like composition is the lab report. (A brief Google search of "college science lab report" leads to numerous campus help pages and advice for students; the lab report is clearly alive and well in the university.)

However, an emphasis on the structure of the lab report can ignore a more significant feature of the scientific paper. As mathematician Halmos (1973) notes, in an essay on writing,

> It might seem unnecessary to insist that in order to say something well you must have something to say, but it's no joke. Much bad writing, mathematical and

> otherwise, is caused by a violation of that first principle. . . . To have something to say is by far the most important ingredient of good exposition—so much so that if the idea is important enough, the work has a chance to be immortal even if it is confusingly misorganized and awkwardly expressed. (pp. 20–21)

While it can be hard to have "something to say" in reference to scientific phenomena, it is harder still to organize and write a meaningful paper when you have nothing you really want to say. The structures designed to help with the exposition of an idea—a five-paragraph essay or the headings of the typical lab report—become a MadLibs of science writing as students, without a clear idea to share, seek the "right" words to fill in the template. Rhetorical structures, which may be useful in organizing ideas and helping us find the holes in our arguments, can do only so much in helping us have an argument to make in the first place. If students "cannot" write a topic sentence, it is likely that they have no topic sentence. If they do well on all but the "analysis" section of a lab report—and why report on a lab if not for the analysis?—then it is likely that they have no real analysis to share. These structures can help highlight that, but all the writing instruction, rubrics, and templates cannot give students something to say.

It is, therefore, critical that students *have something to say*—a hard-won idea that they are proud of, a unique insight that they have developed, a representation or a piece of evidence or a way of phrasing an idea, or even a question that their investigations have helped them articulate. One aim of our course is to help students have scientific ideas they want to share. That, in a nutshell, can be considered the underlying goal of lab notebooks, whiteboards, class discussions, definitions, and reading annotations. And the purpose of the final writing assignments is to give students a place where they can say it.

Of course, traditional courses and lab reports do provide this for some students, some of the time: We certainly recall high school and undergraduate courses where we felt as though there was something significant that we had figured out and wanted to write about, and we can remember assignments that provided that opportunity (some 25 years after the fact). One author distinctly remembers writing a paper regarding what was meant by "equal and opposite," and even a seemingly routine proof for the field inside a spherical shell was a source of great pride when rederived from scratch. And, of course, scientists employ routine structures in their writing, with many journals providing style guides to authors. But for many students, particularly nonmajors, writing assignments fail to provide a space where they share their own ideas, and the structures we provide are distractions from that fact (Wiley, 2000). We advocate, therefore, for careful attention to developing students' ideas and generating writing assignments that value those ideas. In this way, the assignments function like scientists' journal papers, although they frequently lack the structures that journal papers have.

In addition, students not only need to have something to say, but *they should have someone to say it to*. Halmos, in the essay referenced above, notes: "The second principle of good writing is to write for someone" (p. 22). In many cases, the literature review that starts a scientific paper is as much about defining the "someone" as it is about situating the work in a particular tradition or set of questions. The two go so hand-in-hand that "having a scientific idea" practically requires that one is engaged in a scientific conversation—that is, scientific ideas are socially constructed and will have a particular scientific audience in mind. Although scientists (and many others) create popularized accounts for nonscientists, the science itself is generated in dialogue with other scientists, building on open questions, challenging settled questions, or providing a unique analysis, a new technique for a defined field, or data to use in selecting between competing ideas. The intertextuality of scientific writing is, in large part, what makes it so hard to read: These texts hardly stand on their own, but require a knowledge of the field, the open questions, the competing ideas, the peculiar definitions and mathematical constructs, in order to understand their claims (Sharma & Anderson, 2009).

Moreover, there has been a lot of attention to the value of a "real" audience for writing assignments (Ede & Lunsford, 1984; Weiser, Fehler, & González, 2009). This often is construed to mean "someone outside of the classroom," as a way of ensuring (to the degree possible) that the writing is not a school-based performance, but is situated in a genuine rhetorical situation. But students cannot, in general, address open questions in scientific fields in one semester (citizen science and other data collection projects notwithstanding). The point of a dissertation—years in the making—is to show that you have something to say and a community of scientists to say it to (some of whom must agree that the thing you said was worth saying). We certainly are not advocating that undergraduate students generate new science for a scientific audience.

And so our course must create this community among ourselves. In our courses, the audience, although wholly within the classroom, is nonetheless "real": Students read one another's work because they are interested in it, want to find out about it, and want to weigh in with their own thoughts. Again, this is not because our students are inherently interested in color, light, or any of the other topics—this interest, both in the topic and in their peers' ideas, is cultivated in the classroom. Through our construction of ideas, the feedback, and iterative work that we do, students are vested in one another's ideas, findings, and claims. The arguments they make are designed, over time, for one another. And much of the peer review work outlined in earlier chapters is how this community develops.

TAKEN UP

Before proceeding, let us quickly describe what we mean by "something scientific to say." What does this look like in the context of nonscience majors in an undergraduate course? There is a concern when you move away from the textbook, clear laboratory procedures, and defined content outcomes, that student ideas will not be aligned with disciplinary knowledge in any meaningful sense, and research on "open inquiry" bears this out (Kirschner, Sweller, & Clark, 2006). To be clear: These classes are not purely "open" inquiry, but instead highly structured in the ways outlined in earlier chapters. Below are two examples of the kinds of things students "have to say" in our courses. Some things to note are that they strike us as deeply scientific and insightful: The ideas are tied to arguments, questions, and data. But they are not, in general, wholesale theories, nor do they necessarily represent weeks of development.

1. In one class, students were puzzled by the "fuzzy edge" of shadows as they shone a light down a long, black tube. One student proposed that this edge was due to rays being reflected from the tube; another articulated that they were "fuzzy" in appearance because some of the light was absorbed when it was reflected. In a later conversation, someone questioned whether light reflecting off a mirror should be considered a "fuzzy" ray (rays they called "seconds"). Another student suggested that mirrors reflect all the light, so these are not "seconds." We suggested that this could easily be measured, but another student suggested this wasn't necessary: "Mirrors must absorb light. Metal slides get hot."
2. As we studied the eye, this question came up: Why do you have to look right at a word to read it? You don't have to "direct" your ears to hear a word. Two possible answers were generated: (1) images are truly in focus only at that point directly behind our lens—the rest is blurry, and (2) we have better resolution in the center of our vision—perhaps the receptors in our eye are closer together there—so reading with our peripheral vision is like trying to write in 12-point font with a crayon. In discussing whether we could even tell (with our own eyes) the difference between blurry and low resolution, a student noted: "Well, you have to look directly at the sun for it to hurt. So the sun must be out of focus in your peripheral vision."

We could recount similar insights from almost every day of the course: The student who decided that the eye must have receptors that mimic the colors on a cellphone screen, and that her color-blind lab mate must be missing one of those colors. The student who challenged our model of diffuse reflection by asking why objects don't appear to "glow." A disconnect between our theory that a more rounded lens should focus light, and the sense that our eyes strain to focus, suggesting the muscles are pulling the lens taut to focus on nearby objects. When we say that students are authors of their own scientific ideas, and that they are, indeed, disciplinary, these are the kinds of ideas we are talking about. Students are engaged in developing models of phenomena and coordinating those models with evidence, both "scientific" evidence and everyday observations. They are collaborative, building on or challenging other students' questions and models. It is these ideas that we want to honor with our writing assignments, giving students a place to share those insights.

Each 5-week unit ends with a formal writing assignment. These are lengthy papers (5–10 pages, in general) that tie together major ideas from the unit. We have used two types of final writing assignments in our courses: (1) assignments, which we write a day or two before they are handed out, that are tailored to each lab group's specific observations, data, and explanations, and (2) a common assignment, determined in advance, based on students' ideas. Both are described below, with examples of how they are connected to students' own ideas.

Assignments Tailored to Students' Ideas

Below are three of the assignments from the first unit of the semester. The topic was color (beginning with the question, Is every color in the rainbow?), and students had developed questions around lights, paints, pigment, and screen displays. In particular, students had a model wherein the primary colors of paint were cyan, magenta, and yellow—all other painted colors were assumed to be a blend of these—and red, green, and blue were the primary colors of light, because of their relationship to those primary paint colors (namely, that cyan absorbs red, and so on).

One group had developed a technique for investigating the appearance of printed colors under colored lights. Students printed a "rainbow" spectrum, placed it in a box, and used colored bulbs to illuminate the paper, which they then photographed with their cellphones and shared on our course website. This experiment was designed to examine the notion that red paint reflects red light, but not other colors. Their data complicate this somewhat, in that cyan paint seems to reflect more blue light than blue paint reflects (the cyan shines brightly under blue light, while the blue paint looks quite dim), but they have not attended to that yet.

For their assignment, we asked them to explain why. In doing so, they would need to articulate the models they (and the rest of the class) had developed and use those to explain this observation. As the models fall short, we anticipated that they would need to reconsider their model for either blue light (this bulb is not likely a primary shade of blue) or cyan pigment.

> ***Assignment 1:*** Explain why, under blue light, the cyan stripe practically blends in with the white background but the blue stripe does not. Shouldn't blue light on blue ink appear to be the same color as blue light on white paper (at least, that's what Estefan's group argues)?

Another group used the above technique to examine paints, which seemed to behave differently from printer inks. (Paints are not always made by mixing primary colors. That is, green might be made from green pigment and not from a mixture of yellow and blue pigments. Students do not know this.) They painted stripes of color on paper: blue, green, yellow, orange, and red. To generate yellow light, they used red and green bulbs. When they shone the yellow light on the colored stripes, the yellow paint, as expected, practically blended in with the white paper since both reflected all of the yellow light. More surprising was that the green paint appeared orange and the blue paint appeared to be almost the same shade as the red paint. Again, to explain this they needed to draw on the existing theories and consider implications for what this evidence told them about the nature of the blue, green, yellow, orange, and red paint. The assignment included a photo from their investigation, and a range of data was available on the spectrum of the red and green bulbs that students might draw from to justify their responses.

> ***Assignment 2:*** You tried to shine both red *and* green light in your box at the same time. Explain at least two of the colors and why they appear this color under red + green light. This is a tough question, and your job is not to get the "right" explanation, but to clearly explain your own ideas.

We knew that a third group's observations on fluorescent lights and incandescent lights had not been considered in terms of the implications for seeing particular colors. That is, we had discussed blue light and the way it interacts, say, with red pigment. But we had treated all "white" light the same, as if the white fluorescent light, with its distinct bands of color, was equivalent to the incandescent bulb with its complete spectrum of colors. We hoped students might recognize that a pigment (say, something between cyan and green) that did not have an equivalent wavelength present in the fluorescent spectrum would be much dimmer when viewed under the fluorescent light. To justify this idea, they would need to use theories we had developed and build on those to consider the particular shades that are not present in fluorescent light.

Assignment 3: We know that a green pigment under red light looks black. Are there any pigments that would look different under fluorescent light than they do under sunlight? Below are pictures you took of sunlight (left) and a fluorescent light (right). This is a tough question, and your job is not to get the "right" answer, but to clearly explain your own ideas.

Common Assignments

We don't always write assignments that are specific to a particular lab group, or even for a particular semester. For example, we assign an "eye paper" at the end of our unit on the eye that simply asks students to "explain how the eye works." This may seem like a vague and easily "Google-able" assignment. However, the sequence of homework leading up to this final assignment, together with our work in class on constructing ideas and definitions, leads to a highly personal account of each student's understanding of how the eye works.

In particular, our homework assignment at the start of the unit on the eye always includes a question along the lines of, "Why do we need an eye at all—what would happen if we had a retina on our skin?" In this way, students begin the unit by recognizing some of the problems that the structures of the eye must solve. Having articulated these problems themselves—that is, clearly defined them, so that "blurriness" and "too bright" are not just vague ideas, but carefully constructed terms and models—they are better positioned to describe the functions of the iris and lens. Later, we ask a version of the question, "What happens when the retina gets an iris?" Here students, who are familiar with pinhole cameras, begin to consider the scale of the eye and the degree of blurriness that is present even with a small pupil. The arguments they make become more sophisticated as they draw on experiments and observations they have made, along with models they have constructed. And finally, we ask about what happens when a lens is placed behind the pupil. Models of focus and how the lens achieves focus at a range of distances must be addressed.

By the time students are writing about the eye, then, they are not rewriting a set of lecture notes or a book report that describes their interpretation of text. Nor are they filling out a lab report of hypothesis, methods, data, and interpretation. Instead, they are highlighting problems that others generated ("the periphery, however, is not likely to be in focus . . ."), with vocabulary the class has constructed (the Seurat spot reunification point), referring to experiments they have done ("because we saw that the lens inverts the image . . ."), answering questions that were relevant to their class ("these rays are made up of smaller rays of light"), and drawing on readings that they have critiqued ("Berkeley describes this as 'confused vision' . . ."). Every semester, these ideas are tackled in different ways, with students attending to slightly different questions and building on slightly different models. Some semesters, students are vexed by the question of how the eye changes focus; other semesters, as noted above, they work to understand why we see more detail in the center of our vision. That is, even though these assignments are not tailored to student ideas, they are embedded in a class that is, and the expectation is that these assignments will give students an opportunity to share their ideas.

These papers, then, lack some of the conventions of "academic writing" that many have come to expect in courses that introduce students to science writing. For example, we do not insist on a particular structure or require a particular format for citations. It is not essential that students embed figures and title them in a particular way. We sacrifice this fidelity to scientific writing in support of writing that offers students an opportunity to share their own ideas. We do not think the two are mutually exclusive; we can imagine a course such as ours in which, after developing these ideas, we would work to establish style and formatting conventions for our writing. However, given our student population and the time constraints, this is not our focus.

CHALLENGES

When students begin to write, they often fall back on idiosyncratic conventions and expectations about what a "paper" should look like. For example, they may start by saying something like: "The eye is a very important organ in our body . . ." or, "Many people wonder how the eye works. This paper will explain in three steps how the eye works." These rhetorical moves are not necessarily problematic, but they do suggest that students are framing this paper as a more formulaic essay or lab report, rather than an extension of the kinds of writing we have been doing all along.

When we notice students doing this, we usually ask them why. Is it a familiar structure and they find it helpful, or, instead, do they think that this is the approach we were expecting? When students find the structures useful, then we encourage them to use those structures. More often than not, however, they find it difficult to use these structures to explain their ideas. So much of our work is not a progression from hypothesis to test and analysis, and recasting it as such (while common in the sciences) is not necessarily the most meaningful approach for students to take. Those trying to write "five-paragraph essays" generally find that their claims do not have three supporting paragraphs. And so we ask them to map out their own questions that they resolved, and the explanations and justifications they generated, and then use those to construct their paper. Or we may suggest they look back over the readings we have used in class and use those as models to start or structure a paper.

Of course, often it is only after this paper has been submitted that we notice that students have framed it as a “lab report” or essay. In those cases, we grade, as noted below, on the content of the paper.

Finally, as noted in the Introduction, this is not a book that emphasizes grammar and other conventions for writing. And we also noted earlier that “as the ideas become clear, the writing becomes clear.” But that is not to say that our students all write beautifully constructed, clear sentences and well-organized papers. We read our students’ final papers knowing that they are newcomers to our field; they are trying out the ideas in science, and as they try out challenging ideas, the sentence structures may not be tidy (Bartholomae, 1985; Lunsford & Lunsford, 2008). We attend to errors on final drafts, but only when an error is competing with an understanding of the ideas the writer is trying to convey.

We’re often asked whether students ever “Google” an answer. There is no shortage of explanations online for vision, for example. However, by the time we have reached the end of a unit, as we hope the earlier chapters illustrate, students have a rich set of ideas, representations, and experiments to draw from so that a “Googled” answer would stand out—both to their peers, who will review their writing, and to the instructors as we read the assignment. More important, incorporating “Googled” answers with their ideas, representations, and experiments is not trivial; those who could do this effectively would, essentially, not be copying ideas from an authority, but would have to interpret those in light of their own ideas. That is to say, using external resources has not been an issue for our final papers.

FEEDBACK AND GRADING

By the end of a unit, students should have received feedback on their ideas for 5 weeks: in lab groups, in whole-class discussions, via whiteboards, in gallery walks, in silent science, on homework—almost all of our interactions are structured to provide feedback from their peers and from faculty. Because our exams explicitly draw on these ideas, there have been numerous opportunities for feedback on students’ ideas over the past weeks.

We generally provide some brief class time to garner additional peer review. For example, we might ask students to bring in one paragraph, one diagram, or other short excerpt they have been working on to share with their lab group and receive feedback. We also ask them to establish routines for getting feedback on drafts outside of class, such as setting up a time to meet with their lab group, or ways to share documents online with timelines and guidelines for that feedback. We often ask student writers to write memos to their readers. A memo gives the reader some context for the goals the writer has for the draft, shares what the writer likes about the draft, and asks for specific feedback the writer would like from the reviewer (see Jaxon, 2006, for more on setting up productive peer feedback). The reviewer uses this memo and considers the writer's ideas and requests as part of the feedback.

As with homework, when we approach grading we first read through the assignments and write a brief letter to each student that comments on what students are doing well and what we appreciate about their writing, and also includes any questions we have about their claims and inferences. We hold them accountable to the ideas generated in class: common terminology, models, data, and evidence.

After reading and responding to the writing, we cluster the papers of similar quality together. Generally, a few stand out as thorough and detailed, with thoughtful use of diagrams, clear references to evidence, and careful engagement with our established ideas as the students develop responses to new questions. Others will have similar strengths, but perhaps the diagrams are a bit imprecise, or the question that we asked the students to consider is addressed but without careful attention to the range of ideas and evidence available to them. Still others will offer more cursory explanations, not draw on our established ideas correctly, or have representations that are vague and confusing. As we sort through the papers and group them, we assign grades, on a 10-point scale. In general, although this varies, we may have two to three papers to which we assign a 10, and we'll have two to three that are a 6, with the rest falling in between.

Take-Home Messages

- To write well, students must have something to say. Prior to being given a summative, high-stakes writing assignment, students should have ample opportunity to develop their own ideas about the topic.
- An emphasis on students' own ideas is not equivalent to students producing opinion pieces or naive, "science fair" accounts: Allowing students to have their own ideas does not mean we abandon rigor. The prior chapters, in which students develop these ideas, provide examples of how we structure assignments and feedback so that this is not "anything goes."
- To write well, students need to write to someone. In our courses, this "someone" is (usually) their classmates and faculty. Prior to the summative, high-stakes writing assignment, students should have ample opportunity to develop a classroom community, with ongoing negotiations and debates to which they can speak, shared observations they might reference, and common terminology they all understand similarly.
- If you opt to have students write to a different audience (e.g., 5th-graders in the Flame Challenge, an editorial, a practitioner journal), then they should have ample opportunity to understand those communities.
- Assess ideas first: If you—as a fellow member of this course, with the knowledge you have—can clearly understand the idea(s) the student is writing about, the writing has done its first and most important job. Honor that in your feedback and in your grading.
- Assess consistency with classroom ideas: If an idea is consistent with the discussions you've had as a class, also honor that in your feedback and grading.