Learning to Communicate in Science and Engineering

Case Studies from MIT

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foreword by James Paradis

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1 First Steps in Writing a Scientific Identity

Throughout this book, the writing and speaking tasks that science and engineering students engage in are largely modeled on professional tasks and genres, including research articles, poster presentations, and grant proposals. The use of professional-like tasks calls for students to assume identities as scientists or engineers as they engage in these apprenticeship activities. The development of this professional identity guides the case studies in this chapter as we explore the following questions:

- What are students' challenges and opportunities as they face the dominant writing task of scientists: the scientific research article?
- How do students' identities as science students and neophyte scientists shape teaching and learning in a molecular biology laboratory class?

As we noted in the Introduction as we reviewed the social theories of learning that inform this book, identity is a key concept for students as they learn to write and speak in science and engineering classes. Literacy theorist James Gee makes the connection between identity and learning as follows:

> Knowledge and intelligence reside not solely in heads, but, rather, are distributed across the social practices (including language practices) and the various tools, technologies and semiotic systems that a given "community of practice" uses in order to carry out its characteristic activities. . . . Knowing is a matter of being able to participate centrally in practice, and learning is a matter of changing patterns of participation (with concomitant changes in identity). (2000, p. 181)

In terms of students learning to write science, participation in the communities of practice of scientists represents changing patterns of participation, which in turn potentially alters students' sense of who they are or will be as scientists. This notion of students as novice professionals learning to write and speak successfully in their chosen fields leads to the need for instruction from professionals in those fields, a strong feature of the courses and students profiled in this book. Learning in these settings is thus a form of apprenticeship, another key term for social theories of learning and one explored in this chapter.

Nevertheless, while the work of professional scientists and engineers is shaping teaching and learning, communication activities are still occurring within the aegis of the classroom or school-based laboratory. In many of these rhetorical situations, the classroom teacher is the ultimate reader and evaluator of students' texts, and the strongest identities that students assert are their identities as students. Dannels (2000) found that for student groups engaging in real-world tasks in mechanical engineering, the context of the classroom itself, rather than the professional goal, strongly determined their actions. As was true in Dannels's study, for many of the students profiled in this chapter and in this book overall, the powerful influences of schooling were consistent factors, and it would be naive to ignore them (see also Freedman, Adam, and Smart 1994; Freedman and Adam 1996).

For many MIT students, outside-of-class experiences have provided strong technical backgrounds in experimental science. Often these are highly valued experiences: working in research laboratories as interns or during summer projects and competing for science prizes and competitions, for example. However, within those activities, students' roles rarely include writing up that research for publication or communicating what they have learned. In a sense, students' ''discursive identities'' (Brown, Reveles, and Kelly 2005) or their sense of themselves as scientists (or science students, for that matter) as expressed through their writing and speaking about science are barely formed. As the case studies that follow show, most students are only beginning to assert identities as scientists. Those identities are in flux as they sample majors, have their first significant laboratory experiences, and balance the intellectual work required in that context with the time they decide to make available as busy students.

The development of a scientific identity belies notions of learning to write as simply a matter of following a protocol. Instead, students strive to convey often messy scientific results and distill meaning from those results, while at the same time working within the IMRD (introduction, methods, results, discussion) form valued by scientific professionals. As shown by the Biology Department students profiled in this chapter, writing tasks in biology are also fraught with the complications that always accompany writing tasks: lack of clarity on the tasks themselves, the influence of previous experiences, allocation of time and attention, the mixed messages they might receive for the goals of the assignment, or the varied audiences for whom they are writing. Thus, in addition to the usual rhetorical complexity of scientific writing tasks, the rhetorical situation for school-based laboratory reports or other writing tasks is affected by elements inherent to schooling and students' identities *as students*, particularly the final evaluation or grade that will be assigned to the report. For better or worse (and usually for worse), MIT students can be strongly driven by grades, both as motivators and as indicators of how much time to allocate to any task. These optimizing behaviors add a constraint that is yet another element among a host of social forces that shape the teaching and learning taking place.

Learning to Write in Introduction to Experimental Biology and Communication

The biology class profiled in this chapter is particularly apt for studying the development of students' identities in apprentice-like settings. Biology is a well-established field and major at MIT (though the laboratory class itself has students exploring relatively new technologies), and instruction in its communication-intensive (CI) courses is geared to teaching students to write up their laboratory work as professional biologists would. This assertion of identity, however, is complicated in the class presented here, Introduction to Experimental Biology and Communication (hereafter referred to as Experimental Biology), as few students are headed toward research careers in which they will need to write research articles. Because Experimental Biology fulfills a premed requirement and an MIT laboratory requirement and has relatively large numbers, the enrolled students have fairly diverse majors. During the semester studied, of the ninety-one students enrolled at the start, slightly more than a third, or thirty-two, were listed as biology majors, while twenty-eight were chemical engineering majors, with additional multiple representatives from chemistry, physics, aeronautic/astronautic engineering, brain and cognitive science, nuclear engineering, mathematics, and mechanical engineering. For some of these students, future careers might encompass bench research and the need to write up scientific findings, but many more students will engage in the myriad writing tasks of the various science, medical, and engineering professions they will pursue. Thus, engaging in authentic tasks to develop an identity that maps to students' professional pursuits is a relatively difficult target.

Nevertheless, the writing that students do in Experimental Biology has been identified by the Biology Department as a key component of the course, and particular resources have been focused as a result. For example, when MIT adopted a CI course requirement, Experimental Biology was a natural fit as a CI course, given that students had been writing up their experimental work for many years. However, under the new requirement, the class went from a twelve-credit class to an eighteen-credit class to accommodate and acknowledge the additional work students would be doing. More important, rather than fold writing instruction into the existing course routines, a series of writing workshops was created in conjunction with the Experimental Biology laboratory instructor at the time and two writing instructors from the Writing Across the Curriculum Program, one of whom, Marilee Ogren, is the instructor of the writing section described here. These writing workshops are in addition to the two hours per week of lecture, eight to ten hours per week of lab, and one to two hours per week of recitation students are expected to attend in Experimental Biology.

Students are assigned to these instructional workshops, known as Scientific Communication, or SciComm, in groups ranging in size from six to twenty, and these whole groups meet for two hours five times over the course of a semester. Students also meet an additional three to five times for one-to-one or small group meetings with their SciComm instructor to workshop writing in progress. SciComm is 25 percent of students' overall Experimental Biology grade.

In terms of the learning objectives of SciComm and their relationship to the development of a scientific identity, students were presented with the following goals during the semester under study (spring 2008):

At the conclusion of this class, students will be able to:

1. Understand the seven components (title, abstract, introduction, methods, results, discussion/conclusion, tables/figures) of a laboratory research paper.
2. Understand the writing process and its application to scientific writing.
3. Understand the importance of communicating in writing as a scientist.
4. Apply an understanding of scientific writing to their subsequent independent research. (SciComm Syllabus 2008)

Thus, in this genre-based and process-oriented instruction (as indicated by the first two goals), student outcomes are geared toward professional roles or identities (goal 3), learning the writing behaviors of professional scientists (goal 2), and mastering scientific writing that would then be applied to new authentic contexts (goal 4).

Instruction during the five whole-group SciComm meetings is focused on learning a professional genre—the IMRD structure of the research article: introduction, materials and methods, results and figures, discussion and conclusions, titles and abstracts. The focus on this particular genre is a rhetorical one; in other words, rather than having students learn what material goes in each section, SciComm offers them the opportunity to learn why each section of a research article has a particular shape and how professional scientists make deliberate discursive choices based on findings, interpretation of those findings, intended publication venue, and potential readers' reception of the overall ideas and approach. Few SciComm students have previous experience writing in this way, though most are quite familiar—and dissatisfied—with "plug-and-chug" laboratory reports as often taught in high school science. SciComm instructor Ogren says that SciComm students "have no appreciation for what are the components of a scientific paper. That's all new. And no one has taken the time to make that explicit, even if they've been involved in a publication before. And so they come with a huge dearth of knowledge about the mechanics and the principles of writing a peer-reviewed research article. But that's not really a weakness, I mean, that's why they're here, to be educated about those things."

Students' lack of experience with writing scientific research articles also results in a lack of knowledge about the importance of writing and revision to the discursive practices of scientists; thus, drafting and revision are central activities in SciComm in the hope that students' development of scientific discursive identities will include not merely knowledge of form, but knowledge of the rhetorical requirements of that form and of the writing behaviors common to professional scientists.

In terms of the content of students' SciComm research articles, for the semester presented here (spring 2008), students wrote up the laboratory work they did during the recombinant DNA and biochemistry module of Experimental Biology and were expected to offer that report in the form that mirrored the authentic task of a publishable research article. Students were investigating how mutations to the archaeabacterium *Pyrococcus furiosus* (*Pfu*) would affect the performance of this DNA polymerase as compared to the nonmutated or *wildtype Pfu*. DNA polymerase is a vital enzyme in the process of DNA replication as it both enables the replication process to occur and ensures the accuracy of that process. Thermostable polymerases such as *Pfu* are key components in the lab-based process by which DNA is rapidly multiplied, polymerase chain reaction (PCR), which occurs at high temperatures and thus requires DNA polymerases that can withstand such conditions (*Pfu* and other such polymerases were originally discovered in undersea heat vents). Nevertheless, a great deal is unknown about the relationship between the structure of DNA polymerase and its function, and this line of experimentation has the goal of shedding more light on this relationship as well as improving PCR performance with a mutant version of *Pfu*. In addition to investigating this problem, students were learning molecular biology techniques such as site-directed mutagenesis, DNA purification and restriction digestion, recombinant protein expression and purification, a PCR assay, and a forward genetic screen (*7.02 Manual*, Fall 2007).

As far as SciComm students' emerging sense of their identities as biologists or scientists, the results from this study were decidedly mixed. Based on whole-class surveys administered at the beginning and end of the semester, students' overall sense of what it means to write like a biologist was primarily focused on matters of format and structure rather than on rhetorical knowledge or meaning making. In a sense, the instructional activity and focus on the parts of the research paper resulted in students' focus on those parts (understanding the elements of the research article—goal 1 from the course syllabus) rather than on the relationship among those parts, the process involved in creating them, and the larger meaning making that scientists engage in (goals 2 and 3). For the four case study participants, however, these results are more nuanced, and certainly learning to write like a scientist did occur in different measures. For several students uncertain about just what they would do beyond Experimental Biology and beyond MIT, this uncertainty over professional outcomes made for uncertainty over the lessons learned by writing in Experimental Biology. Overall, for many of these students, the specific requirements of the research article (and, more specifically, the research article being assigned and graded in this class) were what was learned—not necessarily a bad outcome, but possibly a limited one.

Learning from SciComm: Survey-Based Results

To understand students' development of discursive identities in SciComm, one data collection technique was to survey students at the beginning and end of the semester in terms of their previous experiences with scientific writing, their knowledge of the components of a research article, and what they felt to be the purposes for scientific writing (see appendix B for these surveys). These questions followed the work of Ellis and colleagues on undergraduate learning of science (Ellis 2004; Ellis, Taylor, and Drury 2006) in which it was found that students with more sophisticated notions of the purpose of writing science (e.g., to learn the science itself, to engage in rhetorical practices) had higher achievement overall in their first-year biology course than students whose conceptions of what they learned by writing in their science courses was focused on mastering a specific form or process. In other words, a more professional scientific identity as seen in a more nuanced understanding of the role of scientific writing and of the relationship between writing science and learning science had a strong relationship with students' overall achievement.

Thus, in the initial SciComm survey, students were asked to list their experiences with scientific-technical writing and then were asked, ''When you wrote these scientific documents (e.g., research articles, lab reports, technical reports), what did you feel you were learning?'' In the end-of-term survey students were asked, ''What do you feel was the most important thing you learned in SciComm?'' and ''When you wrote your SciComm Writing Project, what did you feel you were learning (e.g., format of a research article, science of Pfu, experimental methodology)?'' The assumption was that students' conception of learning through writing about science would become

Table 1.1
Forms of scientific writing students reported writing before SciComm

Lab reports	Research articles and technical papers	Scientific posters	No experiences
80% (55)	35% (24)	3% (2)	12% (8)

Note: Sixty-nine students responded.

Table 1.2
Students' start- and end-of-semester survey responses to what they feel they learned by writing science

When you were writing up your science, what did you feel you were learning?	Learned clear and concise communication/Learned the format of the research article	Learned about the science
Start of semester (62 total responses)	68% (42)	21% (13)
End of semester (41 total responses)	88% (36)	24% (10)

more sophisticated—or more professional—by the end of the term; in other words, their identities as biologists would be more developed.

In response to the initial question about experiences with scientific writing, 80 percent of the total students surveyed indicated limited experiences, citing "lab reports" as most common and often describing these tasks as "high school lab reports" or "just lab reports." As shown in table 1.1 far fewer engaged in more authentic scientific writing tasks such as research articles, technical papers, or posters. In addition, 12 percent reported no previous experiences with scientific writing.

In terms of what students felt they had learned from engaging in these tasks (see table 1.2), a majority (68 percent) described an understanding of scientific writing as "clear and concise" communication as their learning outcome or described what they were learning in terms such as "learning how to communicate effectively, more concisely," or "I felt I was learning the basic methods of how to write a logical report with all the main components," or "how to present data and analysis clearly." A much smaller percentage of students, 21 percent, described learning about the science as an outcome with answers such as, "I used it as a way to pull together everything that we did in the lab. It was a good way to look back at the experiment as a whole," or "I felt I was mostly learning about the content of the material (i.e., gaining a deeper understanding of the scientific research material) and how to put my findings into words." And several students saw very little learning as a result of their previous scientific writing experiences, remarking, ''I didn't feel like I was learning. I felt like I was regurgitating old information—my writing did not reflect my own ideas as much,'' or ''Honestly, nothing—I was more focused on transmitting/communicating than in engaging in any sort of introspective process.'' Thus, most students—as expected given their limited experiences—described scientific writing as a process of translation rather than a method of learning science or engaging in persuasive or rhetorical activities. In other words, they saw themselves taking some technical finding or problem and using clear and concise language and specific formatting to describe it.

Given the large majority of students who initially saw scientific writing as mostly conveying scientific findings in clear and concise language rather than a rhetorical practice and given the goals of SciComm to reveal the deeply rhetorical nature of writing science as part of students' development of scientific identities, we would have expected students' end-of-term surveys to reflect this developing sophistication. However, end-of-term results do not support this conclusion. When asked in the final survey, ''What do you feel was the most important thing you learned in SciComm?'' 88 percent of the forty-two students who responded reported a learning outcome that was usually expressed as ''how to write a scientific report'' or ''the correct format for a biological paper.'' Only 12 percent of the total reported learning something about their writing or revision processes, such as the response, ''Learning some of the weaknesses in my writing and how to improve on them (with the rewrite).''

When asked at the end of the semester, ''When you wrote your SciComm Writing Project, what did you feel you were learning (e.g., format of a research article, science of Pfu, experimental methodology)?'' students' responses as shown in table 1.2 were quite similar to the start-of-semester survey: the vast majority of students (88 percent) described outcomes closely matching the first question, such as ''format of a research article'' or ''format—what's included and how that's stated/organized.'' Still, some students did express an outcome that indicated a more sophisticated discursive scientific identity, even if that outcome was paired with learning structural components. Nearly a quarter of the total thought that they primarily learned about the science, indicating that the writing ''not only made me think/reconsider the experiment and the ideas involved but also made me check the organization and style of my writing'' or ''forced me to go back and make sure I understood the experiment well enough to write about it, so I also learned about the science.''

Still, if most students' take-home message from SciComm was primarily about translation of scientific knowledge from specialized content to clear and concise language, the lessons for developing discursive identities of scientists are muted. Surveys, of course, are often relatively blunt instruments for exploring the processes of student learning. Interviews with and analysis of writing produced by four SciComm students described next provide more nuanced findings.

The four case studies that follow feature students in SciComm sections taught by Marilee Ogren, who by this semester had been teaching SciComm for twelve consecutive semesters. With a Ph.D. in neurobiology and extensive experience as a scientific writer and teacher, Ogren sought to convey her professional values for scientific writing, particularly the idea that scientists value writing that is "clear and concise." In large measure, she embodied a professional writer's identity that she hoped would provide a model for her SciComm students. In an interview, she told of a two-year stint with the *New England Journal of Medicine* when her task was, in her words, "to take the published research articles and condense them and simplify them so that people could read them, people who were not M.D.s or even Ph.D.s." This experience translates to the specific professional goals she now holds for her students: "I learned how to write concisely in those two years. I learned how to make every word count. It was the most powerful writing experience of my life. And I think it's why that's what I drive home to these students more than anything else." The utility of this message for students' development of discursive identities of scientists is in question, however, particularly for less experienced students who strongly believe that the goal of scientific writing is mainly to clearly convey scientific findings, not to engage in a rhetorical process. The case studies that follow show that as students grapple with their shifting student identities, developing sophisticated scientific identities is a challenge.

Case Study 1: Nira—Learning to Write for a Specific Reader

A sophomore biology major at the start of this study, Nira intended to pursue a career in research and had already had several experiences working in biological research labs. Still, she felt she had few opportunities to learn to write scientifically beyond formulaic high school lab reports and that as "a technical writer, I'd say I'm pretty mediocre." In her initial survey, Nira described the communication skills needed by biologists in rhetorical terms or that biologists needed to know "how to convince an audience of the importance of their research and how to present their research in an accurate fashion." By the conclusion of the term, Nira felt she had learned a great deal, particularly about making her writing more concise, and she had a solid "foundation" for future writing, but at the same time she was not sure if what she had learned was particular to SciComm or, more specifically, to the extensive feedback she received from her SciComm instructor. Would these lessons apply to other scientific readers and other writing tasks? Had Nira started to form a discursive identity that could be applied to future scientific writing? Nira hoped so, but she was not certain.

In her start-of-term interview, Nira described successful scientific writing as that which reached a broad audience, perhaps reflective of her few experiences with such writing. "I would characterize [successful scientific writing]," she said, "as structured in that it starts off in a general sense, but specific enough to the topic so that any field can understand the idea of the project to begin with, and then as it gets more specific, it's specialized to that field." This response mirrors her more notable experience in writing for her high school science teacher, one in which the teacher's lack of familiarity with the topic meant that Nira needed to write for a more general audience and add "a lot of background in my paper, which ended up being more of, like, I do not know, not quite a scientific paper, but just like a lot of review and background." Nira was quite aware that this writing was a school-based rhetorical situation (i.e., written for her teacher) rather than mirroring the authentic task of professional scientists. At the end of the term, when she was reflecting on what she had learned in SciComm, she noted that her previous scientific writing was "more oriented on extraneous details that do not really matter too much" and that the reason for this approach was "because that's what gave me the A in high school, basically."

Doing away with these "extraneous details" seemed to be Nira's primary take-home message from her SciComm experience, and as noted previously, this lesson was the goal of her instructor. On her end-of-term survey, Nira identified "conciseness" as the most useful thing she learned in SciComm, and in her end-of-term interview, she expanded on this response, noting that she had learned to edit out "extraneous sentences or words and, like, trying to condense as much as possible and focusing on topic sentences, mainly; really like it kind of changed my whole style of writing."

In the first draft of her SciComm introduction with instructor comments in box 1.1, Nira presents a fairly long (742 words) and fairly general overview of the topic of DNA polymerases, their function and structure, and a somewhat slight idea of the specifics of her research project (though it is important to note that she wrote this draft before engaging in most of the experimental work itself). She described her process for this draft: "I didn't expect it to be a good draft. When I was reading it, I knew that it was disjointed, and it wasn't really what I wanted to say, but I didn't know how to fix it at the time, so I did the best I could, and then I knew it was a rough draft, so I handed it in and waited for the feedback."

The feedback Nira received from Ogren focused primarily on tightening her language, forecasting more clearly to the reader why she moved in particular directions within the text through the use of strong topic sentences, and tying the explanation more strongly to the actual work in the lab. Based on this feedback, Nira wrote another

Box 1.1
Nira's SciComm introduction, first and revised drafts

First draft with instructor's comments

DNA polymerases are perhaps the most important and the most well characterized *cellular* enzymes within a cell. They are responsible for the accurate and efficient replication of a cell's DNA, allowing ~~for~~ [*unnecessary*] regulated cell proliferation (Kuroita, 2005). This makes polymerases not only essential for the cell but also incredibly useful in research. [*reorder the "not only" . . . "but" device—is it really needed or effective here?*]

DNA polymerases are widely used in molecular biology applications ~~today.~~ largely because of Polymerase chain reaction (PCR). [*Make your topic sentence more substantial and make it reflect the actual topic of the paragraph.*] *PCR* is a key tool for obtaining amplified target sequences in order [*see tips*] to further study these sequences in greater detail, and analyze the proteins we wish to study [*too vague*]. ~~Since~~ [*Because*] PCR is a chain reaction, ~~this indicates that~~ the replication of DNA is exponential. ~~It's therefore necessary to use a~~ ~~p~~*P*olymerase*s* with ~~a~~ high fidelity ~~in order to~~ [*wordy*] minimize the mutations that get perpetuated with every cycle of amplication. ~~Thus, it is important to~~ *This study focuses on* find*ing* ways to increase the fidelity and stability of such useful enzymes.

All polymerases contain three basic domains, the Thumb, the Palm, and the Fingers, and each domain is responsible for a different aspect of replication. The palm domain is conserved throughout three ~~different~~ families of polymerase, and

Final draft

DNA Polymerases are responsible for the accurate and efficient replication of a cell's DNA, allowing regulated cell proliferation (Kuroita, 2005). The enzyme's intrinsic physical properties determine its accuracy and efficiency, and its ability to replicate DNA makes it very useful for molecular biology. As a result, polymerases are perhaps the best characterized cellular enzymes known, and are essential for research.

DNA polymerases are widely used in molecular biology applications, largely because of polymerase chain reaction (PCR). Polymerases are characterized by their fidelity, which refers to the enzyme's accuracy of base pairing, and processivity, which refers to the length of template it is able to replicate before falling off. PCR is a key tool for obtaining amplified target sequences to further study the sequences and the products associated with the sequences. PCR is a chain reaction, because the replication is exponential. Polymerases with high fidelity minimize the mutations that get perpetuated with every cycle of the amplification. This study focuses on increasing the fidelity and processivity of these useful enzymes.

Polymerases are capable of polymerization and proofreading. Polymerization extends the primer 5′ to 3′ down the single template strand, creating a duplex DNA strand. Proofreading is the exonuclease activity of the enzyme, carried out 3′ to 5′, to repair mismatches that occur during polymerization. Polymerases that can exhibit both of these functions have

Box 1.1
(continued)

~~has been observed to be~~ [*wordy passive voice*] *is* [*strong verb*] responsible for catalyzing the phosphoryl transfer reaction. The structure of the thumb and finger domains vary ~~between different~~ *with* families of enzymes. The finger domain is responsible for positioning the dinuceotide triphosphates (dNTP), and the thumb is responsible for correctly position the duplex strand of DNA (Steitz, 1999).

~~There are~~ [*always reconsider—usually unnecessary*] ~~t~~*T*wo functions that can be carried out within a polymerase enzyme *are polymerization and proofreading*. ~~The first function is~~ ~~p~~*P*olymerization~~, extension of~~ *extends* the primer using the template strand. This occurs 5′ to 3′, down the single template strand, creating a duplex DNA strand. ~~The other function is~~ ~~p~~*P*roofreading~~, or~~ *is* the exonuclease activity of the enzyme*, and* ~~. This~~ is carried out 3′ to 5′, in order [*see tips*] to repair mistmatches that occur during polymerization. Polymerases that can exhibit both of these functions have an increased fidelity, as compared to polymerases with just replication activity. [*Make sure you define fidelity and processivity correctly*.] The two subunits, the polymerization unit and the exonuclease unit, make up what is called the Klenow fragment, and comprise the active sites of the enzyme (Steitz, 1999).

Two families of polymerases have been studied extensively [*why?*]: ~~these are~~ pol 1 and pol alpha polymerases. ~~The first family,~~ [*unnecessary*] pol 1, or DNA polymerase A, includes polymerases isolated from *Escherichia coli*, a *Bacillus* polymerase, and a bacteria called *Thermus aquaticus*. ~~The~~ an increased fidelity, as compared to polymerases with just replication activity. The two subunits, the polymerization unit and the exonuclease unit, make up what is called the Klenow fragment, and comprise the active sites of the enzyme (Steitz, 1999).

All polymerases contain three basic domains, the thumb, the palm, and the fingers, and each domain is responsible for a different aspect of replication. The palm domain is conserved throughout different families of polymerases, and is responsible for catalyzing the phosphoryl transfer reaction; it also contains the exonuclease domain. The structure of the thumb and finger domains vary with families of enzymes. The finger domain is responsible for positioning the dinucleotide triphosphates (dNTP), and the thumb is responsible for correctly positioning the duplex strand of DNA for polymerization (Steitz, 1999).

KOD DNA polymerase, a pol α archaeic polymerase, is used in laboratories because of its processivity and fidelity. It is derived from the bacteria *Thermococcus kodakarainsis* (as reviewed in Kuroita et al., 2005). Kuroita et al. (2005) discovered a mutation in the H147 residue of this protein that affected the 3′-5′ exonuclease activity of the enzyme while keeping the PCR and fidelity of a wild type polymerase. This residue lies on the tip of the thumb portion of the enzyme, as shown in Figure 5. In further studies, Hashimoto (2001, as reviewed in *Pfu* module, 2008) was able to engineer a KOD polymerase with a H147K mutation that actually

Box 1.1
(continued)

~~second family,~~ pol alpha, or DNA polymerase B, include all eukaryotic replicating DNA polymerases as well as polymerases from phage T4 and phages RB69 (Steitz, 1999). Pol alpha polymerase also include ~~what are termed~~ [*needless words*] as archaeal DNA polymerases, and have been increasingly studied for use in laboratory applications [*Why?*] (Uemori et al. 1997, Takagi et al. 1997, Braithwaite et al. 1993, Bult et al. 1996, as ~~referenced~~ *reviewed* in Kuroita et al., 2005).
Among this second class of polymerases is the polymerase from *Thermococcus kodakarainsis* (KOD DNA polymerase), highly used in laboratories because of its high efficiency and extension rate [*Can you reconstruct this sentence to make it more direct?*] (Takagi et al., 1997, as ~~referenced~~ *reviewed* in Kuroita et al., 2005). Kuroita et al. (2005) discovered a mutation in the H147 residue of this protein that affected the 3′-5′ exonuclease activity of the enzyme while keeping the PCR and fidelity of a wild type polymerase. This indicates that the mutation in this residue affected the exonuclease active site (termed the E-cleft). Hashimoto (2001, as ~~referenced~~ *reviewed* in *Pfu* module, 2008) was able to engineer a KOD polymerase with a K147K mutation that actually resulted in ~~an~~ improved exonuclease activity compared with the wild type protein. It is not known if a mutation in this site in relative [*what's this? Related?*] proteins causes a similar effect.

The KOD polymerase is closely related to Pfu polymerase, isolated from the archaeabacterium *Pyrococcus furiosus* [*Please* resulted in improved exonuclease activity compared with the wild type protein.

We believe that the H147 residue is an important site in a closely related enzyme, *Pfu* polymerase. *Pfu* was isolated from the archaeabacterium *Pyrococcus furiosus* (as reviewed in *Pfu* module). This polymerase is useful for DNA amplification in sequences up to 25 kb, with an error rate up to 10 fold lower than the bacterial-derived *Taq* polymerase (Debyser et al., 1994, as reviewed in Cline et al., 1996). This study is an effort to produce a mutation in the H147 residue that will increase the fidelity and processivity of the enzyme function. We've inserted a H147A mutation and we've tested the mutation by analyzing the processivity and fidelity of the mutant enzyme. The fidelity assay was inconclusive, while the processivity assay displayed a phenotype similar to wild type. The compilation of class data revealed possible mutants that displayed an increase in processivity.

Box 1.1
(continued)

write a better topic sentence.] (Hashimoto, 2001, as referenced in *Pfu* module). *Pfu* DNA polymerase has, specifically, been useful in high-fidelity amplification of DNA sequences up to 25 kb in size, and the error rate of *Pfu* has been found to be up to 10 fold lower than the bacterial-derived *Taq* polymerase (Debyser et al., 1994, as referenced in Cline et al., 1996). [*Break up*]

We believe that the H147 residue is an important site in the *Pfu* polymerase's structure and function [*good focus*]. ~~In order to determine this,~~ [*see tips*] ~~w~~*W*e have mutated the H147 residue into a random amino acid*, and* ~~. We've~~ tested four of these mutations by analyzing the activity of the enzyme produced by each of the plasmids above. ~~, and we are presenting our methods and our results from these assays.~~ [*Forecast our results once you get some*.]

Good start [Nira]. The content is pretty much on target. Background is ok and focus, too, but where is the justification? Please work on using fewer words to say more. This requires careful word choice. I've provided several examples. Also be sure your paragraphs focus on a single topic that is made explicit in the topic sentence.

draft, which received another round of comments (not shown), and then produced her final draft. This final draft was shorter than the first by 17 percent (613 words compared to 742), and it was much more focused on the intent of the experiment, the context for that intent, and the potential payoffs—in Swale's (1990) terms, the elements of focus, context, and justification essential to professional scientific introductions. It also offered a brief idea of the results that Nira obtained in lab. In many ways, then, Nira responded to the specific feedback she received and improved her introduction (and the rest of her paper, which underwent a similar process) as a result of that feedback.

In her end-of-semester interview, Nira looked back on her SciComm experience as a positive one, but she also identified her writing for a specific reader—and an inability to extend from that reader to other rhetorical situations—as a potential problem. In a sense, she wondered if she had developed a discursive identity as a scientist applicable beyond her SciComm instructor. As she described the writing she would do "on her own," she noted that

> while I was doing the SciCom paper, there were a lot of things I didn't like about it, particularly that I didn't know what to include and what not to include, and it seemed like even the decisions that I made, like, they were either correct or not correct, not tailored to my own choices. So I think that in the future when I write my own, it's going to be different because I'll have to decide what is important and what's not important. I will not have, you know, grades docked if I have something in there that I think is important, but they do not think is important.

In a sense, Nira expected these new rhetorical situations to be free of the trappings of school, in which her identity as a student and her grades play a key role, and thus her revision was tailored to what she felt would earn the highest grade, a prominent theme in this research. However, Nira also speculated about these new rhetorical situations and seemed to look forward to them, while knowing that she was not quite ready to face them yet:

> I think my problem at the beginning of the term was I was writing too much for a wide audience and not enough for a specialized audience. That will come with more study of the science, I think. I tried to do that as much as possible this term, but again with the requirements that we were supposed to have in our paper, I wasn't sure what was considered specialized and what was considered, like, wide. So, I'm realizing now that it's not a matter of writing style, it's more a matter of knowing the field and knowing the science.

This statement seems a particularly important moment in Nira's emerging identity as a scientific writer. As she learns the field and the science and not merely the content but the context and rhetorical demands of those contexts—as the tasks become more authentic in her view—she hopes to take forward what she learned from SciComm.

Case Study 2: Carla—Searching for a Professional Identity

Like Nira, Carla was a sophomore biology major at the start of this study and similarly imagined she would pursue graduate work in science, specifically biological engineering, following her MIT degree, though she also was considering becoming a high school biology teacher. Carla also had little experience as a scientific writer, declaring in her initial survey that what she learned from her previous scientific writing experiences was "nothing really. I felt that it was more of a teaching exercise." However, unlike Nira, Carla considered her writing background strong with a fairly developed identity as a writer, largely through her minor in and love of history, particularly ancient history, and that her writing did not have the excess verbiage that Nira felt was a problem. Instead, Carla said her writing "tends to be concise and easily understood." If anything, this concision was a problem, as Carla felt "I tend to write in a manner where the reader has to fill in the gaps."

Another similarity between Nira and Carla is that Carla also saw her SciComm experience as providing a strong "foundation" on which she would build her future scientific writing experiences. However, her commitment to biology as a career or to her future identity as a biologist seemed to play a role in her performance over the semester. Her effort and low final grade in SciComm was reflective of this uncertainty, and by the end of the term, she was ready to move on to different challenges.

In terms of Carla's identity and future as a science student, her circuitous route to biology at the start of her sophomore year was perhaps indicative of the fleeting nature of that decision:

> What I really wanted to when I came here was [biological engineering], and then I took [a biological engineering class] last semester, and I didn't really actually just have a good time in that class. I felt like the department was very new. Like I wasn't really standing on solid ground with a lot of the TA's, a lot of the professors, and then I knew I wanted to do grad school anyway, so then I just made a decision to switch from [biological engineering] to [biology]. On top of that, I took a [humanities] class last semester, which really made me want to major in history as well, so now I can double major in biology and history and still do grad school for biological engineering.

She added in her start-of-term interview that biology had always been "the subject I'm just best at, too," which factored heavily in her decision. A powerful factor in Carla's learning in SciComm, then, was her shifting identity as a student and her search for a disciplinary comfort zone—whether that comfort would come from academic success or congruence with her future plans.

In terms of Carla's conception of successful scientific writing at the start of the term, she offered a rhetorical situation in which conciseness and clarity were in the service of reaching a fairly general audience: "You always have to, like, state everything you did, state why you did it and, then, like, be clear and concise so anyone from any field can understand what you're saying.'' Carla followed this belief closely when she revised the draft of her SciComm introduction, reporting that she solicited opinions from one friend who had some knowledge of biology and from another who was unfamiliar with the field to make sure that ''the intro was as perfect as possible.''

The issue with the writing task for SciComm, however, was that it was quite particular to the discourse community of Experimental Biology, given the specific content about DNA polymerase and the knowledge of the research in the field that one needed to know, as well as the particular demands of her SciComm instructor. In her end-of-term interview, Carla expressed some dismay with the practice in SciComm to critique poor models of scientific introductions and not to offer many ideal models: ''The intro I felt was very, very difficult just because what I usually base my writing on . . . professors will usually give, like, this is a good example of what somebody did, and I felt like the examples that we had were just poor examples, especially because we discussed in class how they were poor examples, and I just found it very difficult.'' In other words, Carla's quest for ''perfection'' in her introduction was frustrated by her seeking out preliminary readers who could not represent what Ogren would value as a scientific professional and a writing teacher and by Carla's lack of experience with this kind of scientific writing task.

Carla's first draft for the introduction in box 1.2 can be characterized as in accord with a feature she described in her writing: it is lacking in the specific detail required of this task. Nevertheless, her final version does not show much change, only the incorporation of most of her instructor's recommended edits and the addition of one sentence of background on thermostable polyermases. Such minimal reworking in this and subsequent components resulted in Carla's receiving one of the lowest grades among students in her SciComm section .

Also like Nira, Carla seemed to feel that she was writing to one specific reader, her SciComm instructor, rather than to a more general scientific audience and that her lack of experience with this task resulted in a great deal of uneasiness. She summarized her experience as follows: ''SciComm was a little excruciating because I had never written like that before, so I was just, like, I do not really know what I'm doing, especially the discussion section. The discussion section I felt like I turned in one and I was like, yeah, and I got like a check minus on it and I'm like, what?''

Despite her grade, by the end of the semester, Carla reported a great deal more comfort with the genre of the research article and that concise, hypothesis-driven writing had filtered over into the work she was doing in a political science course. But the end of the semester also brought a change for Carla: she had decided to change her major

Box 1.2

Carla's SciComm introduction, first and revised drafts

Introduction First draft with instructor's comments (added words in italics; comments in bracketed italics)

DNA polymerization is part of [*needs article*] mechanism by which DNA replicates itself [*needed?*]. Specifically, it is the act of adding additional nucleotides to the replicating string of DNA by the assistance of enzymes known as DNA polymerases. A DNA polymerase's general exonuclease activity can be described by its processivity, ~~or~~ the speed of assembly and fidelity, ~~or~~ the accuracy of assembly. ~~Currently, the scientific community seeks to~~ [*empty words—get right to the point*] ~~i~~*I*ncreas~~e~~*ing* the processivity and fidelity of the commonly used DNA polymerases ~~because~~ *would benefit* many standard laboratory procedures, such as Polymerase Chain Reaction (PCR)*, which* demand fast and accurate DNA replication (Kuroita et al., 2005).

~~In a recent study,~~ [*Avoid long lead—bogs down the reading—get right to the point*] Kuroita et al. (2005) *recently mutated* the DNA polymerase Thermococcus kodakaraensis [*ital*] (KOD1) ~~was mutated~~ by substituting the 147 amino acid position Histidine with a Lysine. This mutation resulted in an increase in ~~exonuclease activity by higher~~ processivity and fidelity than the wild type. ~~This~~ *The present* study focuses on mutating the *Pyrococcus furiousus* (*Pfu*) DNA polymerase to increase its processivity and fidelity ~~from wild type in a manner similar to that has already been accomplished with KOD1 DNA polymerase~~ [*adds no new info*].

Introduction final draft

DNA polymerization is part of the mechanism by which DNA replicates. Specifically, DNA polymerization is the act of adding additional nucleotides to the non-template strand of DNA. This is done with the assistance of enzymes known as DNA polymerases. DNA polymerases are defined by two qualities: processivity—the speed of assembly, and fidelity—the accuracy of assembly. Increasing the processivity and fidelity of the commonly used DNA polymerases would benefit many standard laboratory procedures, such as Polymerase Chain Reaction (PCR), which demands fast and accurate DNA replication (Kuroita et al., 2005). Typical PCR requires a thermostable DNA polymerase, a DNA polymerase that can function at 100 degrees Celsius for several minutes (7.02 Lab Manual, 2008).

Kuroita et al. (2005) mutated the thermostable DNA polymerase, Thermococcus Kodakaraensis (KOD1) by substituting the 147 amino acid position Histidine with a Lysine. This mutation resulted in an increase in processivity and fidelity compared to the wild type. This study focuses on mutating the thermostable *Pyrococcus furiosus (Pfu)* DNA polymerase in an effort to improve its processivity and fidelity.

The DNA polymerase *Pfu* is strikingly similar in structure to KOD1. The two DNA polymerases are approximately 90% identical in amino acid sequence. KOD1 and *Pfu* also have similar half lives and proofreading capability. However, they differ in extension rate and accuracy. *Pfu*

Box 1.2
(continued)

The DNA polymerase *Pfu* is strikingly similar in structure to KOD1. The two archael DNA polymerases are approximately 90% identical when comparing amino acid sequences. ~~In many respects~~ [*needless words*] KOD1 and *Pfu also* have similar properties. Both DNA polymerases for example have the same half life and proofreading capabilities. Where they differ is in extension rate and accuracy. *Pfu* has an extension rate 1/3 the rate of KOD1, but has a accuracy 1.75 times that of KOD1. ~~This study seeks~~ *We hypothesize* [. . .] to keep the high accuracy of wild type *Pfu* polymerase while increasing its exonuclease activity. [*Please <u>briefly</u> describe your approach (a sentence or two). When you get your results, add a line or two to forecast them.*] *Good start [Carla]—Please focus on word choice and sentence structure to make your writing more compact. Also be aware of needless phrases and sentences. You could include some background on thermostable polyermases. Use your lab manual as a source of background as well—you can cite it.*	has an extension rate 1/3 the rate of KOD1, but has a accuracy 1.75 times that of KOD1. We aim to keep the high accuracy of wild type *Pfu* polymerase, while increasing exonuclease activity. Using site-directed mutagenesis, we substituted the *Pfu* 147 position Histidine with a Tryptophan. Our study is consistent with the published literature in that the H147W mutant has a greater processivity than wild type.

to materials engineering with biology as her minor. As she described this decision, ‘‘I’ve pretty much taken what I’ve wanted, I guess, out of biology, and I’m like, I do not know, I’m very fickle so, like, I just was like, all right, I got biology. I got a sense of it, saw what it’s about. I want to do something new now.’’

Although Carla did see the SciComm writing tasks as ultimately useful, the shifting nature of her future plans and of her identity as a science and engineering student makes the lasting impact relatively unresolved. Carla’s case also raises questions about developing a discursive identity when one’s future professional identity itself in is flux. How can students’ scientific discursive identities be flexible enough to serve them in a variety of classes in a variety of disciplines? How much is learning indexed to specific tasks and contexts? In SciComm, the writing task was relatively specific to molecular biology and to the science of DNA polymerase. For students such as Carla with only a weak commitment to that field and uncertainty over her future, distilling larger lessons from this specific task was difficult.

Case Study 3: April—Facing New Learning Challenges

Carla was not the only SciComm participant with a future in relative flux. April, a sophomore chemical engineering major, was only starting to develop a sense of her future paths and of scientific writing as a rhetorical act. When asked about her plans for her career after MIT, she speculated about possibilities in the pharmaceutical industry or in biotech, but largely confined her vision to a summer internship possibility. When asked about her conception of what scientific writing entails, her response focused on the notion of experimental results supported by evidence: "I do not know if you need to be, like, highly persuasive, like it's not a debate, but I think just having to convince your readers that you actually know what you're talking [about], I guess providing enough backup in your analysis or something, just so you're not, like, you're not just pulling your analysis out of anywhere. You are saying why you think that result happened, that kind of thing."

April's uncertainty with a scientific discursive identity extended to the writing she might encounter as a chemical engineer or the types of skills she might need. When asked to imagine that future, her answer indicated a fairly limited idea of those possibilities, marked, as she acknowledged, by her lack of direct experience: "It's a good skill to have, in general, to be able to perform an experiment and get the results and be able to tell it to someone else. I guess that's definitely something good to know how to do. I'm sure I'll have to write papers. I do not know how many. I'm sure it would probably be less than, like, a bio major would have to or something, but I do not really know that yet."

In terms of her introduction to her SciComm paper, April's first draft with instructor's comments in box 1.3 is not appreciably different from Carla's with the exception of her confusion over amino acids, rather than nucleotides, as the basic elements of DNA. In her rewrite, she incorporates the suggestions of her SciComm instructor without going beyond those suggestions to tighten her wording and add a bit more background literature. Overall, it is a solid middle-of-the-pack effort, one that led April to offer in her final interview that "I feel pretty confident about being able to write a good paper now" (see box 1.3).

While April might have felt "pretty confident" as a scientific writer at the end of term, her discursive identity or her conception of what she learned from SciComm

Box 1.3

April's SciComm introduction, first and revised drafts

Introduction first draft with instructor's comments

All life forms store genetic information-including information on behavior- in DNA. DNA is formed by double-stranded chains of amino acids, and a small change, or mutation, in the sequence of those amino acids can create profound changes in the behavior of an organism. Each cell needs DNA to direct its growth and function. DNA replication, which occurs just before cell division, ~~is necessary so that~~ [*wordy*] *provides* each new cell ~~can have~~ *with* an identical copy of the parent DNA strand. This replication is performed by enzymes called DNA polymerases. During replication, the DNA splits into single strands, and the DNA polymerase "reads" these strands and adds amino acids to the 3′ end of the complementary strand forming along the parental DNA strand to create identical copies of the parental strand. Different types of DNA polymerase ~~exist from different organisms, and a polymerase is defined by its~~ [*wordy*] *are characterized by their* processivity (speed at which it adds new nucleotides to the new strand) and fidelity (accuracy of ~~the process~~ *replication*, and error correction). [*good context*]

~~To perform~~ ~~e~~*E*xperiments using DNA~~,~~ ~~we must have~~ *require* multiple copies of the DNA available. [*Try writing direct sentences that are right to the point.*] ~~We can use the~~ [*needless* words] ~~p~~Polymerase chain reaction [*strong subject*] ~~, or~~ (PCR)~~,~~ ~~process to~~ creates [*strong verb*] multiple copies of DNA ~~to use for study~~. This

Introduction final draft

All life forms store genetic information—including information on behavior—in DNA. DNA is formed by double-stranded chains of nucleotides, and a small change, or mutation, in the sequence of those nucleotides can create profound changes in the behavior of an organism. DNA replication, which occurs just before cell division, provides each new cell with an identical copy of the parent DNA strand or gene. This replication is requires enzymes called DNA polymerases. During replication, the DNA splits into single strands, and the DNA polymerase "reads" these strands and adds nucleotides to the 3′ end of the complementary strand forming along the parental DNA strand to create identical copies of the parental strand. Different types of DNA polymerase are defined by processivity (speed at which it adds new nucleotides) and fidelity (accuracy of replication, and error correction).

Experiments using DNA require multiple copies of that DNA. Polymerase chain reaction (PCR) rapidly creates multiple copies of DNA. This process occurs at high temperatures, requiring a polymerase that does not denature at high temperatures. The DNA polymerase of Thermococcus kodakarensis (KOD), an archaeal strain of bacteria, can operate at the high temperatures required for PCR. Researchers discovered that a single KOD mutation can cause dramatic improvements in the processivity and fidelity of this polymerase. When histidine, amino acid 147, was substituted with other amino acids, the

Box 1.3
(continued)

process occurs at high temperatures, and ~~we need~~ *requires* a polymerase that ~~will~~ *does* not denature at high temperatures. ~~One such polymerase has been found, in~~ [*needless words*] Thermococcus kodakarensis (KOD) *is a … [describe].* Researchers discovered that a single *KOD* mutation *can* cause~~d~~ dramatic improvement*s* in the processivity and fidelity of ~~the~~ *this* polymerase [*This sentence could be more specific*]. When histidine, amino acid 147, was substituted with other amino acids, the effects were varied (Kuroita et al., 2005).

We mutated a similar polymerase~~,~~ from the archeabacterium *Pyrococcus furiosus* (*Pfu*)~~,~~ to determine the effects of the mutation on ~~the~~ *this* enzyme. ~~Our~~ *We* hypothesi~~s~~*zed* ~~is~~ that mutation of the H147 gene ~~will~~ *could* create a change in the processivity ~~and~~ *or* fidelity of the *Pfu* DNA polymerase. We ~~want to study if those~~ [*This is process-oriented langauge—avoid.*] *examined whether such* changes increase or decrease the function of the enzyme.

Good start, [April]. The content is pretty much on target but your sentences tend to contain several needless words & phrases as indicated. You might include the study by Hashimoto (KOD) in your background info.

effects were varied (Kuroita et al., 2005). Lysine substitution caused the greatest improvements in polymerase and exonuclease activity, and a lower mutation frequency.

We mutated a similar polymerase, from the archeabacterium *Pyrococcus furiosus* (*Pfu*), in an effort to improve the function the enzyme. We hypothesized that mutation of the H147 gene could create a change in the processivity or fidelity of the *Pfu* DNA polymerase. We examined whether such changes increase or decrease the function of the enzyme.

was focused on the rudiments of structure and format. In her end-of-term survey, April identified the most useful thing she learned in SciComm as "how to format a typical scientific paper" and that while she was writing her SciComm paper, she felt that she was learning "more of the format of a research article than anything else." April's relatively narrow conception of what one learns by writing about science also meant relatively low performance in SciComm and in Experimental Biology as a whole. Her final SciComm grade was fifteen points below class average, and her final Experimental Biology grade was close to the bottom of the class.

Although April ultimately felt that the task of the SciComm paper was useful, her lack of clear vision about a professional future complicates the relationship between the task itself and her emerging identity as a scientist. As her overall grade in Experimental Biology showed, April was struggling with the science itself. Ogren identified this uncertainty and relative timidity in her end-of-term reflections: "[April] seemed to struggle with the content, and she struggled with the writing. She was just desperate to do what was right. . . . She was just desperate to figure out what she was supposed to do and get it, get it right." April presents a challenge to notions of students developing discursive identities when they are struggling to grasp the content of the science they are writing about. Is there a developmental threshold for students in order for them to derive maximum benefit from authentic tasks such as research articles? Or are the benefits not necessarily apparent by the end of a single semester? April's case raises these questions and complications in the relationship between writing science and developing discursive identity.

Case Study 4: Jake—Stepping Stones to Success

Jake, the lone senior among the SciComm research participants, had the most extensive experience with scientific research and with scientific writing, and, perhaps as a result, the most sophisticated understanding of what it means to write as a professional. Overall, Jake's academic accomplishments were impressive. At the start of the semester under study, he was a senior physics major with an original intention of pursuing a Ph.D. in high-energy physics. He was enrolled in Experimental Biology because during the fall semester of his junior year, he had decided to shift his future identity from "physicist to physician," in his words, and complete the course work needed for premedical training. He completed this course work in three semesters, a remarkably short period of time, took the MCAT, and scored high. By the end of his senior year, he learned he had been accepted to a prestigious MD/PhD program. In a sense, then, Jake's identity as a physician scientist was a powerful motivating device for his success in pursuit of this goal, but he also learned that he could succeed in a new field. "What

I've learned," he told us, "is that, from this shift [in career goals], is that personally and perhaps in general, . . . I feel I'm able to go from one area to another, and I can learn a very different field if I have the motive, the desire."

In terms of his conception of what it meant to write like a scientist, Jake took a view in accord with his desire to do good in the world:

> There's a logical process involved in the scientific writing. And . . . especially to be able to communicate. I see that as the goal of the writing. It's not just to capture your thoughts, like a brain dump . . . , but it is to communicate the message that you have with an intention of educating those that you're writing to in your audience—and hopefully inspiring them in some way so that they can be the better for it.

For Jake, a key concept in scientific writing was the difference between presentation and communication—in a sense, the difference between understanding scientific writing as mostly a matter of correct formatting and concise style versus scientific writing as a form of persuasion. In Jake's words, the purpose of scientific writing is "being able to articulate in a coherent way, intelligible way, both to the general public and to your colleagues. I mean, that's the whole point. We're not just trying to find something out just for ourselves. If we're trying to find some sort of truth or if we're trying to make a discovery, what real good is that unless it's shared and that message is communicated, not just presented?"

Jake also shared a great deal in his interviews about the differences that he saw between the extensive writing he had done as a physics students and the new kind of writing he was encountering in SciComm. By the end of the semester, some of what he had learned about scientific writing in SciComm was in contrast to the important skills he had taken away from the writing-intensive experiences of Physics Junior Year Lab: "I'm taking away how to present the scientific method in written form. That's definitely what I'm taking away, more than my Junior Lab papers. I feel that through SciComm, I've been able to develop that structure, that hypothesis driven, data-driven type analysis then relating it back to my hypothesis. I see more of the vision of how to structure these papers."

In terms of other outcomes he felt he derived from SciComm, Jake described a deeper understanding beyond mere formatting: "I came to learn that it can be more important to focus on the principles of your methods and the most important principles of your design, rather than creating a lab report that this is exactly the order in which I did everything." He also felt this learning, as opposed to what the other participants reported, was not confined to writing in biology or, more specifically, to what was required for the SciComm paper. Instead, Jake saw the larger lessons he learned in SciComm as applicable to a wide range of writing: "I think that in my papers I've greatly improved on the logic, and the organization. This whole semester, not just in SciComm but in all of my writing, in my literature writing, in my history writing, but I think a large part of that has come out of the thinking in SciComm.''

In terms of his SciComm research paper introduction, Jake offered a comprehensive reading of the field, the importance of the laboratory techniques using the normal activity of DNA polymerases, and the potential payoffs of the line of research he was pursuing in Experimental Biology. As he reconstructed in an interview his thinking process for his introduction, he showed his comfort with the work and with taking on the identity and using the language of a molecular biologist in pursuing this line of research: ''I tied it all together into this continual search for improved DNA polymerases. Well, we're then going to use site-directed mutagenesis to study the DNA polymerases that are needed for PCR for better improved study of genetic, I guess to tie it back to my motivation in the introduction of how we're trying to mutate and explore protein function and structures.''

Jake also brought in far more literature to his introduction than other students, and in Ogren's comments on his draft, she wonders if he has read these sources or had found them cited in secondary sources, which almost all other students tended to do. In his start-of-term interview and in response to her comments, Jake noted that ''I always go to the source. And I do not take it for granted. . . . I do not like citing secondary sources. I'll go and find in the literature the original papers and quote from those and reference them.'' Overall, Jake scored highly on this preliminary draft, needed to make few changes to his final draft, and ended with one of the top SciComm grades in his section (see box 1.4).

Jake's success in SciComm and Experimental Biology and his academic achievements offer a contrast to the other research participants in his sophisticated view of the processes of and stakes for the communication of scientists. As Jake described the primacy of the research article format, he showed how he viewed the writing of science as a social act rather than merely a faithful rendering of the natural world. He understood format as a ''mold'' of sorts, then commented: ''There definitely has to be a mold when you're writing some of these papers because that's how . . . it's like a guild system. Journals, you go into the guild system, and you have to do it their way for you to get to the top of the guild. But once you're the master of the guild, then you can define the practice.''

It would not be a stretch to imagine Jake as ''master of the guild'' someday as an editor of a scientific journal and a key shaper of what scientific writing might look like or what constitutes authentic texts. But those activities would likely be in the interest of the advancement of science and its impact in the wider world. Jake described

Box 1.4
Jake's SciComm introduction, first and revised drafts

Introduction first draft with instructor's comments

The genomes of increasingly sophisticated organisms, including humans, have been sequenced, leading to examination of implications of genomics on proteomic expression, cellular development, and the inheritance and *patho*physiology of human diseases. Genes have been characterized by expression in isolation, and their protein function elucidated by various techniques, including mutation. This characterization and cataloguing of genetic information~~,~~ *and* protein structures ~~and~~ across species is allowing molecular biologists and geneticists to probe patterns of conservation in evolution [*among other things*], ~~understand~~ recombinant DNA methods [*seems misplaced*]. In addition, developments such as recombinant DNA techniques and gene 'knock-out' during homologous recombination and other methods permit ~~engineering of~~ protein expression *engineering* and proffer future medical treatments, such as gene therapy [*The methods are important for showing targets for drug therapy.*]. ~~Simultaneously,~~ ~~t~~*T*hese developments have required the ability to create large quantities of synthetic DNA from samples as small as single molecules, with efficiency, low cost, and high fidelity.

A primary method of *in vitro* DNA synthesis, the polymerase chain reaction (PCR). PCR controls the duplicative machinery of Nature [*?*], DNA polymerases, to replicate DNA. The reaction first melts double-stranded DNA to single strands

Introduction final draft

The genomes of increasingly sophisticated organisms—including humans—have been sequenced, leading to examination of implications of genomics on proteomic expression, cellular development, and the inheritance and pathophysiology of human diseases. Genes have been characterized by expression in isolation, and their protein function elucidated by various techniques (including mutation). This cataloguing of genetic information and protein structures across species is allowing molecular biologists and geneticists to probe patterns in evolutionary conservation, match homologous genes with function, and associate mutations with disorders. In addition, developments such as recombinant DNA techniques and gene 'knock-out' during homologous recombination may enable both protein expression engineering to identify genetic targets of disease and gene therapy to correct them. These developments have required the artificial synthesis of large quantities of DNA from samples as small as single molecules, with efficiency, low cost, and high fidelity.

A primary method of *in vitro* DNA synthesis, the polymerase chain reaction (PCR), manipulates nature's duplicative machinery (DNA polymerases) to replicate DNA. The reaction first melts double-stranded DNA to single strands (95 deg C), anneals 3′-5′ reverse and 5′-3′ forward primers to the ss DNA (56 deg C) by complementary binding, then extends the primers as *in vivo* by the 5′-3′ endonu-

Box 1.4
(continued)

(95 deg C), anneals 3′-5′ reverse and 5′-3′ forward primers to the ss DNA (56 deg C) by complementary binding, then extends the primers as *in vivo* by the 5′-3′ endonuclease activity of DNA polymerases in a solution of dNTPs (at 72 deg C) (Saiki, R., Mullis, K., et al., 1988 [*Did you read the original article?*]; see also Nobel Lecture of Kary Mullis, 1993). A single cycle duplicates the DNA, while n cycles amplif*y*~~ies~~ the native DNA sample (X0) exponentially, by $X(n) = X02^{n}$. The 95 degress Celsius condition to thermodynamically dissociate DNA base-pair hydrogen bonds denatures normal proteins, and necessitates either regular input of DNA polymerases or thermostable alternatives. *Hyperthermophiles* of the kingdom Archaea, such as *Thermus aquaticus* found in deep water hydrothermal vents or geysers, have thermostable polymerases (e.g., [*e.g., requires a comma*] *Taq*) with optimal function at up to 80 degrees Celsius. The continued selection and development of such highly-processive and thermostable polymerases for commerical PCR is of great interest (Cline et al., 1996). In addition, identification of small genomic variations, such as mutations characterizing disease or single-nucleotide polymorphisms (SNPs) associated with parasite drug resistance, requires high fidelity DNA amplification.

One particular technique expanding our understanding of genomics is site-directed mutagenesis (Smith, 1985 *[Did you read the original article?*]; see also Nobel Lecture in Chemistry 1993). This process manipulates the PCR amplification clease activity of DNA polymerases in a solution of dNTPs (at 72 deg C) (Saiki, R., Mullis, K., et al., 1988; see also Nobel Lecture of Kary Mullis, 1993). A single cycle duplicates the DNA, while n cycles amplify the native DNA sample (X0) exponentially, by $X(n) = X02^{n}$. The high temperature (95 deg C) needed to thermodynamically dissociate DNA base-pair hydrogen bonds denatures normal proteins, and necessitates either regular input of DNA polymerases or thermostable alternatives. *Hyperthermophiles* of the kingdom Archaea, such as *Thermus aquaticus* found in deep water hydrothermal vents or geysers, have thermostable polymerases (e.g., *Taq*) with optimal function at up to 80 degrees Celsius. The continued selection and development of such highly-processive and thermostable polymerases for commerical PCR is an imperative for efficiency in biotechnology (Cline et al., 1996). In addition, identification of small genomic variations, such as mutations characterizing disease or single-nucleotide polymorphisms (SNPs) associated with parasite drug resistance, requires high fidelity DNA amplification.

One particular technique expanding our understanding of genomics is site-directed mutagenesis (Smith, 1985; see also Nobel Lecture in Chemistry 1993). This process manipulates the PCR amplification of DNA by use of synthetic forward and reverse primers with customized central mutations surrounded by site-complementary pairs. The mutated primer anneals to the template ssDNA of interest, is elongated by polymerases, then subse-

Box 1.4
(continued)

of DNA by use of synthetic forward and reverse primers with customized central mutations surrounded by site-complementary pairs. The mutated primer anneals to the template ssDNA of interest, is elongated by polymerases, then subsequent cycles linearly amplify the mutant DNA; the mutant protein of interest can then be studied following cloning and expression (e.g.) by microorganisms. This permits study of the direct relationship of genetic sequence to protein structure to protein function.

Specifically, structure characterization by X-ray crystallography or NMR spectroscopy combined with study of site-directed mutants has allowed elucidated and improvement of 5′-3′ endonuclease and 3′-5′ exonuclease mechanisms for PCR polymerases. Hashimoto et al. (2001) crystallized the family B DNA polymerase of the archaeon *Thermococcus kodakaraensis* KOD1, identifying an exonuclease active cleft (E-cleft), a Palm domain, and two Thumb (endonuclease) sub-domains. It was in the unique loop of the E-cleft that Kuroita et al. (2005) found a mutant (H147K) in KOD1 that resulted in a 2.8 fold increase in 3′-5′ exonuclease activity over the wild-type enzyme. This modification of a key residue by site-directed mutagenesis improved fidelity from a mutation frequency of 0.47% to 0.12%, as opposed to 7.9% in Taq and 1.3% in *Pfu*, while maintaining superior elongation rates (130 bp/s compared to 20 bp/s for *Pfu*). Specifically, Kuroita's success emphasizes the criticality of this residue in the catalytic exonuclease mechanism. Generquent cycles linearly amplify the mutant DNA; the mutant protein of interest can then be studied following cloning and expression by microorganisms. The biologist becomes an experimentalist with active control of the genetic sequence-protein structure-protein function relationship.

Recently, detailed structural characterization (by X-ray crystallography or NMR spectroscopy) combined with study of site-directed mutants has elucidated and improved PCR polymerase 5′-3′ endonuclease and 3′-5′ exonuclease mechanisms. Hashimoto et al. (2001) crystallized the family B DNA polymerase of the archaeon *Thermococcus kodakaraensis* KOD1, identifying an exonuclease active cleft (E-cleft), a Palm domain, and two Thumb (endonuclease) sub-domains. It was in the unique loop of the E-cleft that Kuroita et al. (2005) found a mutant (H147K) in KOD1 that resulted in a 2.8 fold increase in 3′-5′ exonuclease activity over the wild-type enzyme. This modification of a key residue by site-directed mutagenesis improved fidelity from a mutation frequency of 0.47% to 0.12%, as opposed to 7.9% in Taq and 1.3% in *Pfu*, while maintaining superior elongation rates (130 bp/s compared to 20 bp/s for *Pfu*). Specifically, Kuroita's success emphasizes the criticality of this residue in the exonuclease mechanism. This work demonstrates the promise of site-directed mutagenesis to engineer native protein (or enzyme) forms for improved performance in biotechnological and industrial applications, such as high-fidelity PCR.

Box 1.4
(continued)

ally, it demonstrates the promise of site-directed mutagenesis to engineer native protein (or enzyme) forms for improved performance in biotechnological and industrial applications, such as high-fidelity PCR.

Pfu, a DNA polymerase from the archaeon *Pyroccocus furiosis* widely used in the PCR amplification of DNA samples, is a homolog of KOD with an E-cleft domain of hypothesized homologous exonuclease function. Like KOD, modification of histidine 147 in the unique loop of *Pfu* is predicted to alter exonuclease activity, revealing similarities with the KOD exonuclease mechanism, and has similar potential for mutagenic polymerase improvements. We present data assessing the role of H147 in the 3′-5′ exonuclease and 5′-3′ endonuclease activity and mechanisms of *Pfu*, as determined by comparative assays of wild-type *Pfu* with mutant *Pfu* proteins prepared by site-directed mutagenesis of the AA147 residue. Moreover, we discuss the relevance of homology comparisons for prediction of the functional outcomes of mutants of similar proteins.

Great job, [Jake]. See comments within.

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We present data assessing the role of H147 in the 3′-5′ exonuclease and 5′-3′ endonuclease activity and mechanisms of *Pfu*, as determined by fidelity and processivity assays of wild-type *Pfu* compared with a cohort of mutant *Pfu* proteins prepared by site-directed mutagenesis of the AA147 residue. Moreover, we discuss the relevance of homology comparisons for prediction of the functional outcomes of mutants of similar proteins.

the responsibilities of the scientist in relation to his or her writing: ''That responsibility is not just simply to communicate your thoughts but you're also responsible to whoever reads it.''

It is important to recall that Jake was the lone senior among study participants. His sophistication and ease with his identity as a scientific writer are perhaps the result of his advanced class standing in comparison to the other case-study students. Thus, all four cases raise questions about the relationship between overall sociocognitive development and writing success, a factor that comes into play in the next chapter as students further along their undergraduate careers and more committed to the discipline with which they identify seem to have much more success as scientific writers.

Summary of Introduction to Experimental Biology and Communication

The goal of SciComm—to develop students' discursive identities as scientists, including knowledge of the scientific article's components, the rhetorical role of those components, and the processes by which a scientist produces an article—was achieved in varying measures for the case study participants. All four students reported high levels of satisfaction with their SciComm experiences, and all believed they had created a foundation on which future writing could stand. Implications of these results include the role of the relationship between students' views of knowledge creation in scientific writing, the ways that shifting student and career identities affect a developing scientific identity, and the strong role that school as a context (students' identities *as* students) played in their learning:

Students' view of scientific writing—whether as knowledge transfer or as rhetorical act—played a strong role in their success as scientific writers and in the class itself. SciComm students who saw scientific writing as mostly a matter of information transfer (albeit in concise and highly structured forms) tended to struggle more with the relatively authentic classroom tasks they faced. Students who could imagine the audience's needs for their writing and connect that writing to past texts and future texts tended to have more success. Jake, the lone senior, had success at taking on new roles and shifting his career goals, and this shift did not present uncertainty for him as a scientific writer. Instead, his confidence that he could take on new identities and learn new rhetorical situations (and, perhaps most important, recognize them as rhetorical situations) resulted in a strong performance. The other three case study participants had a view of scientific communication as largely information transfer and were unsure of the ways that the context of SciComm might extend to other contexts. The developmental continuum that this result indicates speaks to the need to assess students' views of knowledge production in science and to be explicit about the applicability of skills learned in a particular context to additional contexts.

Students' shifting identities and uncertain futures played a strong role in their success in SciComm. Carla's uncertainty about her major and April's lack of definite vision for her future raised questions about students' developmental readiness to benefit from authentic tasks. The need to develop rhetorical flexibility and apply lessons learned in SciComm to future scientific writing was in competition with their larger concerns about majors and careers. Jake's clear vision of his future—and the kinds of writing, speaking, and thinking that he would need to do—allowed him to optimize his SciComm experience. Certainly students who are learning to write in college often have shifting identities as students and for their postcollege careers. In fact, the writing tasks themselves can play a role in helping students develop these identities, particularly their discursive identities as scientists and engineers.

The context of schooling—students' time available, dedication to writing and revising, the presence of a grade or/evaluator, and the realization that these tasks were not quite "real"—played a strong role. For several participants, career decisions based on previous academic success and writing behaviors based on high grades in previous classes did not necessarily serve them well in SciComm. The ongoing dilemma is to separate the contribution of writing tasks to students' development of discursive identity from the assessment of those tasks as more than one teacher's individual values. However, schooling is also a laboratory for students—a place to try out new discursive roles and to receive instruction in how to write, speak, think, and act. For most students, SciComm is a preliminary step in that development, one that they will build on by subsequent course work and communication tasks (as shown in subsequent chapters of this book). Students' identities are in flux, in other words, and this state is the norm, presenting opportunities for growth and development.