It's About the Science: Students Writing and Thinking About Data In a Scientific Writing Course

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Introduction

Unquestionably, college writing courses ought to foster critical thinking. A quick glance through the pages of any issue of the major journals reveals writing teachers' assumptions that (given the correct pedagogical efforts) writing courses should enable students to come to a critical awareness of their positions as writers through learning to read critically. That is, students must learn to analyze texts in order to consider the roles writers might take to resolve issues of importance to themselves and their audiences. In so doing, students become more mature language users and better, more careful thinkers.

The problem for the teaching of discipline-specific writing is that disciplinary standards of style and form often trump writing teachers' concerns for fostering critical thinking; as a result, teachers overemphasize correctness and format. A cursory examination of several popular textbooks on scientific writing confirms that critical thinking is important to many teachers' ideas about scientific writing. Audience analysis and rhetorical purpose are frequent topics in these texts. Yet, in these same texts the discussions about critical thinking are often outnumbered by the details about correct form or appropriate style. For example, one popular textbook on writing in biology states, "bad scientific writing often reflects fuzzy thinking" and "questioning the writing, guides students toward a clearer understanding of the biology being written about" (Pechenik 1997 p. xiii). However, this same text later lists "keys to success" including "remember the word data is plural" (p. 11), "say exactly what you mean" (p. 6), "always underline or italicize species names" (p. 10), and "don't plagiarize" (p. 9). Another (one with "critical thinking" in its title) makes a connection between clear thinking and effective scientific writing, yet spends a greater amount of time describing correctness of terminology, "true and correct language," and syllogistic form (Moriarty 1997, p.30). The problem with these and other texts that take the same approach is that they provide information about critical thinking only in the abstract and at a time when students are struggling with the meaning and interpretation of scientific data and concepts. When confronted with a morass of abstract information and an assignment due date, students understandably pay more attention to explicit instructions regarding form and style. Any idea that scientific writing is a means to participate in the intellectual life of science is buried.

For students, participation in the intellectual lives of their disciplines means moving past learning disciplinary content, although writing has been shown to help them in this regard—as evidence, consider the many studies of writing across the curriculum (WAC) programs. However, if students are to learn the rhetorical tools needed to become active participants in their fields (Bazerman 1992), WAC needs its counterpart, writing in the disciplines (WID). WID extends WAC in that both WID and WAC help students to think critically about disciplinary content; but WID also helps students to develop their writing skills as they articulate their understanding of content in genres appropriate to professional audiences. Understanding WID in this context has shaped our goals in the upper-division scientific writing course that we discuss below. Our goals for this course have been 1) to create a context in which students focus on learning about science and scientific data, 2) to demonstrate how scientific writers use genre to respond to rhetorical situations, and 3) to provide students with a set of rhetorical tools that they can apply as they articulate their own ideas. In reaching these goals, students are able to overcome the duality of academic expertise (Geisler 1994)—they are simultaneously able to learn disciplinary content and the rhetorical skills necessary to articulate that content to a professional audience. Such an approach can help to demistify the relationship between scientific language and the structure of scientific knowledge (Stockton 1994).

OUR APPROACH

Our approach is based on the belief that a generative view of genre can be the basis for students learning how to think critically about science. The generative view of genre is advanced by Coe (1994), who argues for recognition that writers' creative processes are influenced and socialized by their awareness of forms appropriate to the rhetorical situation in which they are writing. In this view, form is both constraining and generative; it effectively eliminates certain options from consideration, yet it provides opportunities for writers to engage in purposeful communication with their audiences in ways those audiences recognize as legitimate (Cooper 1999). A genre-based approach to teaching writing, then, goes beyond formalism. In moving past formalism, teachers of rhetorical genre enable students to see the larger social purposes behind language structure (Cope & Kalantzis 1993). By critically considering these purposes as well as their own for writing, students come to see their writing in the context of their roles as professionals.

This idea of genre as generative leads us to define *scientific* writing in the following way: specific types of documents that scientists typically write and read in their professional work. The definitive feature of these documents is not, as formalism would suggest, an abstract collection of conventions. Rather, for us, what defines scientific writing is that rhetorical situations, audiences and goals are directly related to scientific practices. Thus, the class emphasizes critical thinking tasks that scientists must perform in order to successfully participate in scientific fields; these tasks include working with data and interpreting the meaning of data, and framing scientific issues and understanding the complexity of those issues. In this way, the class fits into a larger process of learning what it means to think and act like a professional scientist.

In fact, a number of scholars have noted that learning professional genres is part of a larger developmental process in which students learn to understand and critically analyze data and issues as professionals. As Driskill, Lewis, Stearns, and Volz (1998) said, rhetorical knowledge influences students' abilities to reason critically and think about science. Writing teachers can facilitate this process by helping students think about data in legitimately scientific ways—that is, in ways that will be useful to other scientists. As Haas (1990) pointed out and as Winsor (1996) confirmed, learning to write well for one's disciplinary colleagues comes from an understanding of the conditions under which one may participate in the discipline. In our course, we facilitate that understanding by exposing students to scientific literature and discussing with them the rhetorical options illustrated in that literature—in other words, about the possible means by which they may use genres to participate in their fields. In fact, Bazerman (1994) states that genres enable writers "to advance their own interests and shape... meanings in relation" to their fields, as well as to "grant value and consequence to the statements of others" (p. 79). With this in mind, our course provides students with the opportunity to see their writing as a means to agency (that is, to legitimate participation in science) and as a way of learning to assess the written contributions of others. In this way, we underscore the concept that genres are generative, for each genre provides scientific writers with a range of possibilities for agency, and scientific readers with a range of possibilities for response.

As generative, genres are seen not as restrictive collections of arbitrary "standards" but, as Miller (1984) has explained, "the rhetorical means for mediating private intentions and social exigency" (p. 163). This view leads us into conversations with students about scientific writing, in which we emphasize that "acceptable" scientific writing is always undergoing incremental change—since individual writers must deal with the fact that rhetorical situations resemble each other only superficially (Freedman & Adam 1996). In other words, we present genres to students as possibilities from which they must learn to generate texts that accommodate their individual goals while at the same time serve the needs of their field. As such, we help them to see "available patterns through which [they] might act" (Berkenkotter & Huckin 1996, p. 24) in their efforts to communicate science through writing.

Our Tools

Building on our generative approach to genre, we operate under three principles. First, like many writing teachers, we teach writing as a process of drafting and revision. Second, also like many others, we recognize that when students work with ideas in multiple contexts, they come to understand them in more comprehensive ways. Finally, we acknowledge that writing assignments are most effective when they build on students' own interests, and follow a progressive course structure. In our course, we sequence assignments that 1) allow for multiple revisions throughout the semester; 2) are typical genres of scientific writing appropriate to different contexts (a literature review, a deliberative essay, an article critique, and a research proposal); and 3) are not rigidly formulaic, in that they leave room for individual variation in developing arguments.

While the success of the course does not necessarily depend upon the use of this sequence or these genres, our experience is that students show marked improvement in their understanding of scientific data when they follow this progression.

To facilitate this progression, we offer students multiple opportunities for feedback, both from their peers and their teachers. While our motivation for implementing these activities is mostly pragmatic—scientists often work in groups, and receive feedback from peers and superiors—it also allows students to read and respond to others' work from fields similar to their own. We feel this provides them additional insight into the academic work of science, for it exposes them to the review/response process that is a hallmark of scientific publishing. Furthermore, collaboration in document development contributes to students' engagement in their learning (Burnett, White & Duin 2000) and can help them to see additional perspectives on the content of their papers (Trimbur 1989). These activities are used throughout the sequence of assignments.

The sequence of assignments, we feel, maximizes students' abilities to see scientific data in multiple ways. Beginning with a literature review of a very specific issue within a scientific field gives them an opportunity to gather information, explore the complexity of an issue and encounter the chaos of initial research. It also allows them to identify relevant concepts, disagreements, and patterns within a body of research. We next move into a deliberative essay, in which the students use the literature from the review as a basis for understanding the data and their applications to different contexts. In their essays, the students must articulate ways of working with data to solve complex issues. After the deliberative essay, students critique a chosen article from the literature they have worked with in order to assess this particular article's contribution to the debate articulated in the deliberative essay. This assignment also requires them to use additional sources from their previous assignments to support or reject the line of thinking reflected in the article. Finally, the students write a research proposal that advocates new work within their field. The proposals come about in a number of ways: from identifying areas in need of research in the literature review; from recognizing the implications of certain lines of research through writing the deliberative essay; and/or from assessing in the critique the strengths and weaknesses of previous research.

This sequence provides students with opportunities to read and address issues raised in the literature, and to use data in various contexts. In so doing, they begin to clarify for themselves the possible interpretations of the data and how those interpretations can be applied to various arguments. Although the data drive students' understanding of a topic, the particular genres generate a range of rhetorical possibilities for articulating that understanding. As students acquire knowledge of the genres and use them in the sequence, they develop their abilities to identify rhetorical possibilities embedded in each genre. This process helps them to engage data in meaningful ways.

By helping them to engage data meaningfully, our sequence of assignments makes our scientific writing course as much about *thinking* as it is about *writing* (see Stout 1997). As students draft and revise their assignments, we see their thinking and writing about the issues and the evidence developing along four different lines. These developments, or shifts in thinking, come about due to the multiple opportunities students have to critically evaluate and apply data from the literature in the sequenced assignments. First, students learn ways that scientists work with data to address questions of significance to their fields. Second, as they come to see how scientists interpret data, they also develop their own ways of thinking about scientific research and evidence. Third, they learn that multiple frames exist for scientific debate, and that data may be framed and reframed according to the requirements of various rhetorical situations. Finally, students are better able to articulate in writing the richness of scientific data and the complexity of scientific issues. Because we see a close connection between learning genres and understanding data, we believe that in order to acquire competence in writing the genres, students must shift their thinking about data in the above four ways. By making these shifts, students develop critical thinking skills needed by professional scientists as they participate in their fields.

CASE STUDIES

To illustrate how students may accomplish these four developments, we now present four case studies. In each of the case studies can be seen at least one of the above shifts. While we are not naïve enough to believe that all our students accomplish all of the shifts, we do contend that the assignments in sequence help students move through all four to some degree. As such, we present the case studies as illustrative, yet not perfect, examples. But while imperfect, the case studies do illustrate how four students came to think and write more critically about how available data influence scientific argumentation.

Sarah: Learning to work with data

Sarah, a third-year biology major, described herself as a "bad writer"; indeed, her writing showed many mechanical errors at the beginning of the semester. While Sarah's mechanics did improve—substantially—by semester's end, she learned a more significant lesson about the nature of validity and generalizability of scientific evidence.

Sarah chose to investigate the relationship between aspartame consumption and adverse reactions in phenylketonurics, that is, in people whose metabolisms cannot process phenylalanine. Phenylalinine is present in varying quantities in products sweetened with aspartame—and those who cannot process it typically suffer brain damage as a result of ingesting those products.

In her literature review, Sarah found a scientific issue within this topic—the lack of definitive studies—but she did not provide a valid criticism of those studies for her readers:

Most laboratory studies are examining the possibility that aspartame consumption provokes adverse neurological reactions in phenylketonurics. . . the problem with the current research is a lack of studies utilizing many human subjects...

Her argument for her literature review was that the small sample size prevents the data from being authoritative, and thus the studies could be discounted or invalidated; she contended that they were not generalizable.

Through written comments, the instructor pointed out that sample size alone is not a determinant of validity nor of generalizability and asked her to consider if there was something about the sample that would indicate it was not representative of the overall population.

Sarah had no answer; since her experience in science was limited, she couldn't find reason to discount the samples on anything but their small size. As she continued to comb the primary literature, Sarah found *no* study that satisfied her requirement of "adequate" sample size. Because of this perceived stumbling block and her own frustration, she chose to change her entire topic for her deliberative essay. However, as evident in her mid-semester conference, she continued to search the literature for studies on phenylketonurics. She told her instructor that one article mentioned the difficulty of finding large numbers of phenylketonurics—evidently, it's a rare disorder—and that she was changing her mind about the studies: perhaps they were valid.

Still, she continued to struggle, on paper, with generalizability and validity. As she began drafting her article critique, Sarah returned to her original topic and found a way to shape her criticism to a scientific audience. She aimed to make a methodological critique of a published study, but she knew she could not criticize the piece strictly for its sample size without risking having her arguments appear invalid. Her arguments in the draft were 1) the failure of the study to account for long-term effects; and 2) "only thirteen PKU [phenylketonuric] heterozygotes were examined."

Again, the instructor pointed out the problems with a critique based on number alone: "The study *is* valid—there is no reason to discount the methodological logic and design, which is what determines validity." The instructor further questioned if she was really talking about *generalizability* by referring to one sentence in the draft of her critique that appeared to make the distinction clear:

> It may prove helpful to use the results of this study as a base for further research of PKU heterozygotes.

This one sentence indicated that Sara was beginning to shift her thinking about the evidence—she was no longer looking exclusively for this article to provide the definitive (that is, a clearly generalizable) study. In her revised critique, she made this point the focus of her paper, still mentioning sample size but now viewing the study as a *beginning* or as a contribution to a conversation. Her thesis statement from her critique indicated a significant change in her thinking about what can be useful (that is, valid) about a study whose results are not necessarily generalizable:

> Because the explanatory power of the results is lessened by the small sample size and short duration of the study, it may be useful to construct new protocols in future work.

Notice that she immediately referred to future work, taking her idea of the "base" to its logical end and serving her field in a way that is quite scientific: encouraging more research when it appears necessary to do so. In her proposal, written soon after her article critique, Sarah responded to both of her earlier criticisms by designing a longitudinal study of phenylketonurics identified from previous studies—the meta-analysis needed, in her view, to solve the problem of generalizability. The proposal genre allowed Sarah to address the problem of nongeneralizable data because the proposal genre requires a response to past studies that problematizes, but does not reject, the data in those studies. Because of what she learned about how scientists work with data, Sarah came to see how scientists critically evaluate past data to identify opportunities for future research.

Elissa: Learning to interpret data

Elissa, a third year biology major whose father is a cancer specialist, was determined to address some medical issue in the course. Throughout her life, many family discussions focused on diagnosis of and treatments for various types of cancers. Even though she had heard that ovarian cancer was more rare than breast cancer, she wanted to research why the mortality rate for ovarian cancer was so high and why the medical community was not doing more to prevent deaths. Her perspective was that if the medical community simply screened women (like they do for breast and cervical cancer), women would not die from this disease at such a rate. Her understanding of scientific evidence was simplicity: it either provided treatments and cures for everyone or it didn't. The idea that multiple interpretations and applications of data exist was not apparent to her.

From her initial understanding of the literature for her literature review, she concluded that "the prognosis of ovarian cancer is low because of the limited use of the diagnostic tools and the insensitivity of current treatments." Although she cited data that demonstrated that one blood test (the CA125) provided an 80% accuracy and that the ultrasonogram showed estimated sizes and shapes of tumors, she could provide no analysis of when or for whom the data were applicable.

Her instructor suggested that she read the primary studies more closely and try to determine under what circumstances and for what population the test provided the results she cited. Her initial response was that she should change her topic because the data she read was too confusing. However, with some encouragement from the instructor to persevere by reading more studies and discussing those studies with others, she attempted in her deliberative essay to use those studies to support her argument that the general female population should be screened for ovarian cancer. Yet, when she tried to argue that perspective, her research left her increasingly frustrated.

In her mid-semester conference with the instructor, she noted that the research as well as subsequent discussions with two cancer specialists (one being her own Father) all contended that implementing diagnostic tools for the general public was only seen as appropriate if the diagnostic tool decreased the mortality rate. Because neither the blood test nor the ultrasonagram were found to decrease mortality (they only increased the survival by 3-6 months), these screening devices were not considered sensitive enough to use for the general population. Her frustration with her deliberative essay as well as her dissatisfying search for an article to critique for the next assignment motivated her to continue searching the literature.

With continued prompting, she began to investigate under what circumstances and for which populations a CA 125 might be accurate and an ultrasonogram might provide supporting evidence. She then began to focus more closely on the population most at risk for ovarian cancer and the population for whom diagnostic tools might be most accurate. By researching forward in the literature via the Web of Science (a science citation index) she found a number of articles, one that she chose to critique for her third essay, which focused on ovarian cancer rates in postmenopausal women. She found the incidence of ovarian cancer increases rapidly after 50 with the peak incidence around 70-74 and that preliminary trials are using the CA 125 and ultrasonograms to set baselines for *postmenopausal* women. This critique was a turning point in her understanding of this issue, for when she realized the women most at risk were postmenopausal, she was able to reinterpret the data she had written about in the literature review and deliberative essay.

In light of her additional research, Elissa revised her literature review to provide insight regarding what researchers know and don't yet know about diagnostic tools, and she began to rethink her thesis for her deliberative essay. Finally, her proposal gave her the opportunity to consider the research to date and her new interpretation of it. Because preliminary trials were using the CA 125 and ultrasonograms to set baselines for postmenopausal women, she proposed studies be designed to track those women for 10-20 years, using this baseline (much like what is done with mammograms). By working through the full sequence of genres, Elissa was finally able to let go of her belief that "just better screening" would save lives.

She stated her final conclusions in the following way: A much more effective screening would result if only postmenopausal women were screened because 1) they are at highest risk 2) the diagnostic tools are more accurate for these women 3) if these tools detect the cancer early, the 5 year survival rate jumps to 80% (vs. 25%).

Elissa came to realize that diagnostic tools or treatments for diseases cannot always provide simple answers to illnesses: She learned that interpreting data is often very difficult; in order to do so correctly, she had to understand the precise ways which medical practitioners can and cannot apply specific research.

Zach: Learning to reframe issues

Zach, a fourth-year biology major, selected "medical marijuana" as his topic of interest. Not surprisingly, the first draft of Zach's literature review confirmed what his instructor had feared—he had absorbed a lot of the popular literature on the topic but did not seem to be familiar with the science surrounding the topic:

> Marijuana, pot, weed, cannabis; these are all different terms for the (partially) socially acceptable drug that fuels a great controversy… despite the pros and cons the evidence on both sides are compelling enough to warrant a reanalysis of the legality of the drug…
>
> Upon review of the research, the data on the effects of marijuana paint both a positive and negative picture of the drug. There is an inordinate amount of conflicting data and a serious prejudice that hinders the ability for proper research.

As these excerpts suggest, Zach saw medical marijuana as a neat "controversy," with good and bad sides, and a clear right and wrong, in order to justify his evident feelings that marijuana should be legal for medical usage. Of course, the legal/political issues about marijuana use are very different than the scientific ones. However, Zach didn't know enough about science, or the limitations of the genre, to know that he shouldn't address a legal question in a review of the scientific literature designed to be read by scientists. Furthermore, although he claimed an "inordinate amount" of conflicting studies had been done, he cited only three primary articles—indicating he did not yet see the need to base the review on certified, peer-reviewed science. He still saw the research as fueling a legal, not scientific, disagreement, and he wanted his writing to bring it to a close—an inappropriate (if not impossible) goal for a scientific literature review.

During the class workshop, Zach received comments from his peers which discouraged him. Some of the comments written on his draft seemed to show their confusion about his topic and motivation: "Are you sure you want to get into this question?" and "Is this a paper about medical uses or effects?" These comments reflected some confusion, obviously, and they pointed Zach to larger rhetorical questions: What *was* his purpose for writing a scientific literature review? What was the issue at stake? How would he address the conventions of the genre, yet still use it to serve his rhetorical goals?

Zach's instructor attempted to prod him to clarification. In response to one of Zach's drafts, the instructor offered:

> It's hard to see what the technical/medical significance is here. You spend 1 1/2 pages relating marijuana's therapeutic uses but there's no indication of why your audience should have that information. It's hard to see because the sources from which you draw are not scientific—they are journalism—

> and so, it's difficult for you to define what the *scientific* issue is here. Is it that scientists don't understand the effects? Is it being underutilized as therapy? Or what? Go to the primary literature and see what the research shows; then draw some meaningful conclusions to guide research (not law).

Zach's initial drafts of his literature review did not improve substantially; however, through writing the deliberative essay he learned how to define an issue of relevance (the need for marijuana policy reform) to his targeted audience (in his case, the Food and Drug Administration). By writing his deliberative essay, Zach was forced to separate political from scientific issues because he had to focus on policy in order to address the FDA. After assessing additional primary literature, largely in preparation for his article critique, Zach realized that scientists researching marijuana and its medical uses were not concerned so much with policy as they were with determining biochemical pathways.

Through preparing for his critique, he found a way to define an issue of interest to science: a lack of reliable information about marijuana's biochemistry on which to base policy decisions regarding medical marijuana use. Finally, in drafting his proposal, Zach was able to reframe the issue of medical marijuana in a way that showed his understanding of the differences between scientific and political questions. From the proposal's abstract, it's clear that Zach successfully reframed his topic without abandoning his original interest:

Marijuana (cannabis sativa) has been found to have a countereffect on the reward system of rats. This reveals that cannabinoids do not cause dependence in organisms ingesting tetrahydracannabinol-9 (THC-9). However, this evidence does not positively identify the effects on the human reward system. Thus, this experiment aims to identify how these endogenous chemicals affect human reward systems... If research could substantiate that the humans' counter-reward system is congruent with the rats', then the issue of dependence could be resolved. This issue is one of the most often heard in arguments that group cannabis with recreational narcotics.

Zach was finally able to reframe his thinking because he better understood the nature of a scientific issue. The proposal genre offered a chance to apply what he had learned about issues through writing the previous assignments. In

Zach's proposal, he was able to distinguish between the metabolism of cannabinoids in rats and humans, and to understand the problem the unanswered scientific question regarding metabolism in humans presented. In so doing, he made the point that lack of definitive evidence is the *scientific* issue in this case. What is more, by keeping his interest in politics intact, he defined for his readers the role of his research in resolving the larger legal question he originally wanted to answer.

Clarissa: Learning to appreciate the richness and complexity of data

Clarissa, a junior biology major, worked part-time for a consulting firm which worked on a number of asbestos related cases. She explained that what she was learning on the job fueled her interest to research asbestos removal and asbestos related diseases. Throughout the semester, her papers reflect a gradually more sophisticated understanding of the complexity of the data she uncovered and a better understanding of how to apply those data in the appropriate context.

As she drafted her literature review, her initial conclusion about asbestos was that it is still a health hazard. Some sources provided data that stated that "80% of malignant mesothelioma occurs in men exposed to high levels of asbestos"; other sources stated that the EPA claimed that "younger people are more likely to get mesothelioma." Because Clarissa generalized these context specific data to multiple and interchangeable contexts, one of the summary conclusions she reached on an initial draft of the literature review was that "we need to get this hazardous material out of schools."

Through written comments on her draft, her instructor prompted her to provide a more thorough understanding of the relationship among the data. Clarissa was asked, for instance, to make sense of the literature that discussed the effects of high levels of exposure on children as well as the literature that discussed asbestos related illness (mesothelioma) in men. Her interpretation of the data from these various sources was that just because young people are "more likely to get mesothelioma" they must be exposed to high levels. Her instructor questioned this assumption and commented:

> Just because children are at higher risk does not necessarily mean that they are exposed to levels that can

> lead to illness. Where and at what levels are children exposed to asbestos?

Clarissa continued to search for confirmation of her conclusion regarding children and asbestos to support her deliberative essay; however, she uncovered many conflicting opinions about the data and began to notice "other" pieces of information in the articles. The data continually referred to specialized workers, the general public and children, as well as low levels and high levels of exposure. In inventing the argument for her deliberative essay, she had to work through these complex data to determine their significance. In particular, if she was to argue successfully, she knew she had to distinguish between when and for whom different levels of exposure were problematic.

As she continued to search for clarification, she encountered data on management strategies and asbestos and found that the risk of disease was very small when asbestos management strategies were in place. As a result of her continued research and developing awareness of the data, she focused her deliberative essay on management strategies vs. removal. Her working thesis became:

> Maintaining rather than removing intact asbestos is preferable because the general public is not exposed to high-levels and rarely exposed to even low levels (and if so, for only short periods).

Although her deliberative essay helped her to better understand the effects of high and low exposure levels, she still could not distinguish between the effects of short and long term exposure. However, through writing her article critique, she realized this distinction. She critiqued an article that clarified the relationship between high levels and deadly diseases (the positive correlation) and long-term low levels and deadly diseases (an unknown correlation). She also realized at this point that school children are not exposed to high levels and are rarely exposed to low levels, and even then, only periodically. This article critique helped her see that she had to interpret and apply the evidence she was finding in terms of four factors: the level of exposure, the length of time of exposure, the type of exposure (specialized worker vs. general public), and the management strategy in place (maintaining vs. removing the asbestos). When she realized the complexity of the issue and that she had to consider data that touched on all of these factors before she could present a convincing argument, she was finally ready to revise her earlier papers and present a proposal. For her proposal, Clarissa was able to use her newly acquired understanding of the relationship among these four factors to devise an appropriately complex study. She suggested a study that tracked, over long time periods (10-15-20 years), one set of specialized workers (school custodians), who are exposed to low levels of maintained asbestos in the schools.

Overall, as Clarissa began to appreciate the complexity and intricacies of the research, she also began to use data more appropriately and not to generalize context specific data to multiple contexts.

Comments on the Case Studies

As stated above, we do not wish to suggest that all students in our classes experience the shifts in thinking that Zach, Sarah, Elissa and Clarissa did—no teacher and no course can insure 100 percent success. However, we do argue that our course provides students with more and better opportunities to make those shifts than formalist instruction in scientific writing can. In addition, although the examples above focus on the development of specific areas, we also realize that these areas cannot be easily separated. That is, as students learn to use and interpret data, they reframe the issue; as they reframe the issue they come to more fully appreciate the complexity of their topics. Their learning is recursive and interconnected.

Finally, the four students whose work is described above were able to succeed by taking advantage of the opportunities presented by the structure of the course, but they also were enabled to act by certain contextual factors. Were these contextual factors not present, we contend that students would not be as able to complete the assignments; they also would not be as likely to see the relevance of the course's work to their major studies and to their field. Hence, courses such as ours cannot be a panacea for all problems that face writing in the disciplines. However, the course does illustrate how, if other factors are present, students can make significant shifts in their thinking about science and scientific data.

CONCLUSION

Of course, we also contend that these "other factors" cannot be ignored. At the curricular level, these factors include strong commitments to undergraduate education and research, including funding and mentoring programs. Our students enjoy an environment in which many faculty members share the responsibility for instruction in scientific writing (cf. Gottschalk 1997); biologists in our department accept and support the presence of writing as integral to the curriculum. What is more, our university supports undergraduate science majors through small research grants, which must be applied for through a proposal-review process. Many of our students use the course to develop proposals for those grants, offering them an immediate sense of rhetorical purpose. Because these research opportunities are present, students are legitimized as participants in the scientific work of the university—a kind of peripheral participation that allows them to see themselves as scientists. The net effect is to raise the students' expectations of themselves, which stimulates their efforts to think as scientists instead of students. Our students are affirmed in these efforts by the biology faculty, whose research projects often provide opportunities for undergraduate researchers.

Additionally, the writing courses are offered within the biology curriculum; as such, they create a context for writing for the students: Students see themselves as scientists learning how to write rather than students in a writing class in which they are permitted to write about science. Also, at the departmental level, our course is supported by the presence of other writing-intensive courses for biology majors. These courses—which are entitled "critical thinking" courses—are seminars in which scientific literature is read and reviewed collaboratively by faculty and students. The students write critical responses to what they read. In so doing, they come to learn how scientific readers understand and analyze the literature, just as they do in our classes. What is more, in the critical thinking courses, they have the opportunity to see their professors as scientific readers and writers—which may help to clarify the ways in which scientific writing is read, interpreted, and used. The courses create within the biology curriculum a strong position for writing and, accordingly, support for writing instruction among the biology faculty.

We hope the point of the above discussion is clear: In addition to moving beyond formalism, it is also important for a course in scientific writing to be located within an appropriate curriculum, and to have institutional and faculty support for students as scientists-in-training to realize its potential. If these factors are lacking, students will receive from other vectors messages contrary to what the best scientific writing course would emphasize. When no clear role is understood for writing in a science curriculum, more often than not the result is a formalistic emphasis on correctness. If no opportunities exist for students to make writing instruction relevant, they (understandably) will treat that instruction as an exercise with no application outside the completion of assignments. While writing in the disciplines can effect changes in students' thinking and can move them to a more professional relationship with technical language, it cannot overcome institutional factors that encourage a narrow formalism. If these factors and formalism are finally to be overcome, it is first necessary to cement a place for writing in science curricula.

REFERENCES

Bazerman, C. (1992). From cultural criticism to disciplinary participation: Living with powerful words. In Herrington, A. & Moran, C. (Eds.), *Writing, teaching, and learning in the disciplines*. (pp. 61-68). New York: Modern Language Association.

Bazerman, C. (1994). Systems of genres and the enactment of social intentions. In Freedman, A. & Medway, P. (Eds.), *Genre and the New Rhetoric*. (pp. 79-101). London, UK: Taylor & Francis.

Berkenkotter C. & Huckin, T. N. (1996). *Genre knowledge in disciplinary communication: Cognition/culture/power*. Mahwah, NJ: Lawrence Erlbaum Associates.

Burnett, R. E., White, C. I., & Duin, A. H. (2000). Locating collaboration: Reflections, features, and influences. In Staples, K. & Ornatowski, C. (Eds.), *Foundations for teaching technical communication: Theory, practice and program design*. Greenwich, CT: Ablex Publishing Corp.

Coe, R. M. (1994). 'An arousing and fulfillment of desires': The rhetoric of genre in the process era—and beyond. In Freedman, A. & Medway, P. (Eds.), *Genre and the New Rhetoric.* (pp. 181-190). London, UK: Taylor & Francis.

Cooper, C. R. (1999). What we know about genres, and how it can help us assign and evaluate writing. In Cooper, C. R. & Odell, L. (Eds.), *Evaluating writing: The role of teachers' knowledge about text, learning, and culture.* (pp. 23-52). Urbana, IL: National Council of Teachers of English.

Cope, B. & Kalantzis, M. (1993). Introduction: How a genre approach to literacy can transform the way writing is taught. In Cope, B. & Kalantzis, M. (Eds.), *The powers of literacy: A genre approach to teaching writing.* (pp. 1-21). Pittsburgh, PA: University of Pittsburgh Press.

Driskill, L., Lewis, K., Stearns, J., & Volz, T. (1998). Students' reasoning and rhetorical knowledge in first-year chemistry. *Language and Learning Across the Disciplines 2*(3), 3-24.

Freedman, A. & Adam, C. (1996). Learning to write professionally: 'Situated learning' and the transition from university to professional discourse. *Journal of Business and Technical Communication 10,* 395-427.

Geisler, C. (1994). Literacy and expertise in the academy. *Language and Learning Across the Disciplines 1*(1), 35-57.

Gottschalk, K. (1997). Putting—and keeping—the Cornell writing program in its place: Writing in the disciplines. *Language and Learning Across the Disciplines 2*(1), 22-45.

Haas, C. (1990). *Writing technology: Studies in the materiality of literacy*. Mahwah, NJ: Lawrence Erlbaum Associates.

Miller, C. R. (1984). Genre as social action. *Quarterly Journal of Speech 70,* 151-167.

Moriarty, M. F. (1997). *Writing science through critical thinking*. Sudbury, MA: Jones & Bartlett Publishers.

Pechenik, J. A. (1997). *A short guide to writing about biology*. 3rd ed. New York: Longman.

Stockton, S. (1994). Students and professionals writing biology: Disciplinary work and apprentice storytellers. *Language and Learning Across the Disciplines 1*(2), 79-104.

Stout, R. (1997). Good writing assignments = good thinking: A proven WID philosophy. *Language and Learning Across the Disciplines 2*(2), 9-17.

Trimbur, J. (1989). Consensus and difference in collaborative learning. *College English 51,* 602-616.

Winsor, D. (1996). Writing well as a form of social knowledge. In Duin, A. H. & Hansen, C. W. (Eds.), *Nonacademic writing: Social theory and technology*. (pp. 157-172). Mahwah, NJ: Lawrence Erlbaum Associates.

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