Teaching Effective Communication in a Writing-Intensive Analytical Chemistry Course

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Each department at Stanford University offers undergraduates a writing-intensive course. This course is intended to teach students how to communicate in the language of their chosen field and is required for all majors in the department. In chemistry, the Writing in the Major course is a laboratory and lecture course in analytical chemistry called Theory and Practice of Quantitative Chemistry. To address the challenges of teaching writing while at the same time delivering analytical chemistry content and providing an enriching hands-on laboratory experience, we have developed a variety of activities, assignments, and mentoring structures. Several ideas are emphasized by the writing aspect of the course: clear writing and clear thinking are inextricably linked, feedback from peers and mentors is not something to fear, revision is vital, and (in the world of professional science) collaborative efforts extend beyond the planning and execution of an investigation to include the analysis of data and the communication of results.

Structure of the Course

Theory and Practice of Quantitative Chemistry is usually taken by chemistry majors and minors in their second or third year. It is the first course that is required for majors exclusively—it is not required for pre-medical and engineering students—so class enrollment tends to be 20 or fewer students. With a group of this size, it is possible to give each student a significant amount of individual attention in the form of written feedback and face-to-face meetings.

The laboratory experience is the focus of this course. Students spend two afternoons for a total of seven hours in the lab each week. During the 10-week course, the students complete four laboratory projects: the classic gravimetric determination of chloride, the spectrophotometric determination of aspirin, a microscale acid–base titration, and the application of ion chromatography to an analyte system that each student selects. The class meets for ninety-minute lectures two mornings each week. The lecture material is selected to relate directly to the laboratory experience, providing theoretical background to the experiments and offering glimpses of new and exciting developments in the field of analytical chemistry.

Laboratory Report Requirements

For each of the four experiments, the students are required to complete an extensive laboratory report. These reports are the primary writing assignments in the course, and constitute up to 80% of the final grade. To give students a sense of writing as it is done by professional chemists, we require that the reports follow the organization of a scholarly journal article. Before they begin to write, the students are given some suggestions of what material to include and what questions to address in their reports. For example, the students are told that the introduction section of their second laboratory report should be 1–2 typed pages and should meet the following five requirements. The writing in the introduction must: (1) compare and contrast absorbance and fluorescence spectroscopies and their limitations, (2) show the quantitative relationships between concentration and absorption/fluorescence, (3) describe the limitations of these quantitative relationships, (4) show equations and define terms used in the two spectroscopies, and (5) provide specific information about applying absorbance and fluorescence spectroscopy to the analysis of aspirin. These instructions are very explicit for the first experiment and become more general as the term progresses.

For the first three experiments, the students write the lab reports individually, even though they have worked in pairs or groups in the laboratory. This procedure ensures that each student gets sufficient practice with writing and revising. The fourth experiment—the application of ion chromatography to some real-world analyte system—is the lengthiest and most involved in the course. For this experiment, the students work in groups to decide on the analyte system, develop the experimental procedure, gather the data, analyze the results, and write the lab report. It is hoped that the students decide on an equitable division of the labor; this division is entirely up to them. Of course in any group there is the potential for dissension, but in our experience the group dynamics have been unproblematic. One possible reason is that students select their own groups, so they tend to form units that can work smoothly together. The experience of writing in groups is intended to help the students develop an appreciation for the challenges of working collaboratively on a piece of writing, which is the normal means of preparing research manuscripts.

Sample Laboratory Report and Critique

During one of the first lecture periods, the organization of a typical journal article is described, emphasizing the purpose and structure of each major section. Examples from the literature are shown and discussed. At this time, the students get a handout in which a laboratory report for an experiment done in the course is critiqued, section by section, and revised. Although reading the sample lab report and critique does not offer an active experience of writing, critiquing, and revising (the students will get extensive practice with each of these activities in the course), it serves two important functions. First, it explicitly points out pitfalls frequently encountered in the writing of a laboratory report of this type. For example, in writing their own reports many students place material in the wrong section, discussing data in the results section, giving too much procedural information in the abstract or introduction, or placing too much introductory

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material in the discussion. Second, this sample document and its critique emphasizes the process of rereading and revising and shows explicitly one way in which such revisions might be done. As an example, the report draft contains a particularly disorganized introduction. The critique suggests that one way to improve the section is by writing an outline of the most important points and using the outline as a writing guide. Such an outline, containing all the information of the first draft but with a clear organizing principle (general ideas are followed by specifics), is provided, and the revised introduction follows clearly from the outline.

Library Activity: Search and Critique

To deepen their understanding of how journal articles are organized, the students are asked to read an article from an analytical chemistry journal and critique its organization and clarity, using three specific prompts to guide their analysis. The exercise is optional, yet because successful completion is rewarded with bonus points, almost all students participate. Given a list of journals that can be found in the chemistry library, the students are told to pick up a recent issue and select an article whose title or abstract looks interesting. They are told to scan the article and advised not to worry if they don't understand the details of the science being presented.

Students then write a 1–2-page response paper based on the following instructions.

- Read the title and abstract, picking out words or phrases that seem important, then read the introduction and notice which words are defined or explained. Assuming that the most crucial words and phrases are defined in the introduction, did the abstract effectively alert you to the most important ideas and topics of the paper? How do the authors emphasize their main concepts?
- Look at the figures, tables, and captions. Using the information they contain, write a one-paragraph summary of what system was investigated, what method was used, and one or two of the major findings. If you cannot create a summary, what additional information would you need?
- Consider how logical transitions are made in the paper. Things to look for include transition words, words that are introduced in one sentence and elaborated on in later sentences, and "old" ideas used to introduce "new" ones.

The feedback from the students regarding this assignment has been overwhelmingly positive. Other approaches to using journal articles as teaching tools have been recently described *(1, 2)*. These approaches also involve detailed prompts to stimulate the students' critical evaluation of the organization and writing style of papers from the literature.

Undergraduate Writing Teaching Assistant

A major factor in the course's success has been the involvement of an undergraduate writing teaching assistant (TA). This TA is a chemistry major who has taken the course in a previous year and excelled in the writing component. Using a detailed rubric, he or she grades the lab reports for their organization, clarity, grammar, and style (graduate TAs provide a more chemistry-specific evaluation). The writing TA holds individual conferences with the students to discuss the graded reports and to address areas in which the students' writing needs improvement.

On the basis of these conferences, the students rewrite one of the first three lab reports, and revision almost always improves the quality of the report dramatically. The writing TA is trained by the teaching staff of the course (professor and head graduate TA) as well as the university's pedagogy consultant for the Writing in the Major program (someone with extensive experience with writing and rhetoric). This training enables the writing TA to evaluate and advise with confidence. The presence of the undergraduate TA in the course benefits the course's students by allowing for individualized discussions with someone who is simultaneously a peer and a voice of experience. The TAs also benefit from their involvement because they gain experience reading and critiquing writing about science, developing a critical eye that will serve them well in their own writing.

The use of peer feedback to improve writing has been described for courses in organic chemistry *(3)* and chemical engineering *(4)*, as has the use of campus writing centers *(5)* and graduate students from English or related disciplines as reviewers *(6)*. The use of an undergraduate writing TA who has recently completed the course may offer a unique compromise between these extremes. The writing TA is a peer who is both familiar with the chemistry content of the course and experienced with the writing tasks required. He or she can speak from experience, drawing on lessons learned from prior work in the course.

Oral Communication

In the last year, a speaking component has been added to the course. Most professional scientists receive little training in public speaking, and only when faced with the task of giving a job talk or a conference presentation will they practice organizing their thoughts, preparing effective visual aids, and delivering material in clear and engaging speech. Oral communication is vital, however, in any career path a chemistry undergraduate might pursue, from presenting new ideas and findings at professional meetings, to sharing information and building consensus in the workplace, to succeeding in professional interviews.

To give them speaking experience, the students prepare a presentation about a research paper of their choosing. They are required to use visual aids, and many students create theirs using PowerPoint presentation software. Because each presentation is only ten minutes long, the students must distill out and present only the most important information. A list of pointed questions is provided to help the students in structuring their talks. These presentations by the students—followed by a question-and-answer period—are one of the highlights of the lectures.

In the oral communication component of the course, as in the writing component, the relationship between communication and comprehension is emphasized. In the process of writing or speaking, the students will often discover gaps in their knowledge or understanding. The task of communi-

cation forces a critical examination of content mastery. In this way, the student's understanding of the material and ability to communicate the material develop and improve in synchrony.

Assessment

One drawback of a writing-intensive course of this type is that grading and assessment are fairly involved. Because we are interested in evaluating both how well the students did the laboratory experiment and how well they write about what they did, a simple grading scheme giving points for high-quality data will not suffice. To simplify the task as much as possible, the teaching staff is given a rubric that very closely follows the guidelines the students receive before writing their reports. This rubric is used during grading and is returned to the students with the report so they can see exactly how the evaluation was performed. Points are distributed such that roughly 30% of the grade is determined by the quality of the writing and the rest is determined by the quality of the data and how well understanding of the relevant scientific concepts is demonstrated. It must be acknowledged, however, that dividing the evaluation between "writing" and "content" in this way employs an artificial distinction, and that ideally, the two factors should be evaluated simultaneously. In the speaking component, the graduate TAs evaluate the presentation based on organization and clarity of the material, as well as the students' presentation skills and ability to respond to questions from the audience.

Summary

One indication of the course's success is that several of its students have won university-wide writing prizes. Another is that in comparing the first reports the students write to the last ones, substantial improvement can be seen in practically every case. Several students each year express interest in serving as the writing TA. Although the course is characterized as work-intensive (both for the teaching staff and the students), it serves the important function of strengthening the students' ability to think and write clearly about science they have done. Practice with speaking, writing, and reading as professional chemists do will certainly give the students confidence and proficiency in communication that will benefit them in whatever career path they choose.

Literature Cited

1. Paulson, D. R. *J. Chem. Educ.* 2001, *78*, 1047–1049.
2. Tilstra, L. *J. Chem. Educ.* 2001, *78*, 762–764.
3. Shibley, I. A., Jr.; Milakofsky, L. M.; Nicotera, C. L. *J. Chem. Educ.* 2001, *78*, 50–53.
4. Newell, J. A. *Chem. Eng. Ed.* 1998, *32*, 194–196.
5. Sunderwirth, S. G. *J. Chem. Educ.* 1993, *70*, 474–475.
6. Bailey, R. A.; Geisler, C. *J. Chem. Educ.* 1991, 68, 150–152.