Writing Across the Curriculum in College Chemistry: A Practical Bibliography

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Writing Across the Curriculum (WAC) has been a force in education for more than 25 years. Yet WAC in chemistry might seem still something of a mystery, especially for the chemist new to teaching or to the language studies teacher unfamiliar with conventions of thinking and writing in chemistry. Fortunately, teachers in higher education who wish to explore the uses of writing in chemistry have a wealth of material to draw from in the literature. Our review of that material is intended to address the needs of those teachers who want to get started using writing in their chemistry classrooms. Thus, the focus will be primarily on practical matters. We begin by pointing to studies that suggest why WAC can be useful, then turn to reports of successful approaches to using writing at all levels of the chemistry curriculum. Additional resources are listed at the end of this article.

Why Writing Is Useful in the Classroom

Writing Across the Curriculum, as a pedagogical strategy, has attracted teachers because it offers a way of teaching subject-area knowledge at the same time it facilitates the development of thinking and writing skills (Britton, et al. 1975). Writing in subject areas also encourages students to learn communication and other social interaction skills, which educators and industry professionals believe are critical to succeeding in the workplace (Stark, et al. 1986). However, to take full advantage of WAC theory and practices, faculty and administrators must look to writing as more than an end product, a curricular goal in itself. Instead, they must also see writing as the *means* to the end, as a way students can learn by exploring ideas and making connections between them (Madigan, Writing 1987). Some faculty, intent on incorporating writing into their classroom, focus so heavily on the end products of writing that their effort might be

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better described as "grammar across the curriculum." While grammar and basic writing mechanics are crucial to a chemist's education, focusing solely on these superficial matters ignores the greater benefits that WAC can bring to the classroom.

For help in understanding the relationship between writing and learning and the relevance of WAC methods to subject-area teaching, many turn to Emig's (1977) "Writing as a Mode of Learning," which connects research from philosophy, psychology, education, and other fields, to writing and the field of composition. Emig contends that writing is a uniquely different means of composing ideas and expressing oneself, and this uniqueness makes it especially useful to the learning process. Writing actually forces students to analyze and synthesize information in ways that are meaningful to them. Moreover, it helps them become active learners: when they use writing to express the concepts they acquire from their textbooks, classrooms, and labs, they become involved in an active process of sense-making. Teachers who would like to explore the theoretical underpinnings of WAC further could turn to two early works, Britton (1972) and Freisinger and Petersen (1981), among many others. Rosenthal (1987) and Beall and Trimbur (1993) provide practical insights that focus WAC theory on the particular interests of chemistry and chemical education.

Rigorous, methodological research on writing-to-learn is available. An early study, Britton, et al. (1975), examined over 2000 student writings from different subject areas and found that students learn when they write about subjects in a range of different ways, such as through private expressions (personal journals) and more public transactions (informational notes to the teacher). This finding has encouraged some WAC teachers to look to a genre approach to writing-to-learn. The use of personal journals as described in *The Journal Book* (Fulwiler 1987) and the use of poetic writing in psychology described by Gorman, Gorman, and Young (1986) are two such examples.

Writing-to-learn pedagogy has had broad support in chemistry over the years. The American Chemical Society endorsed the importance of writing and its connection to learning by stressing writing-to-learn methods at its Sixth Annual Conference on Chemical Education in March, 1992. That conference determined that chemistry teachers could use writing to track student thinking patterns, to improve student understanding of chemical concepts, to increase communication between students and professors and thereby improve opportunities for learning, and to use writing as a way to emphasize experiential learning and deemphasize didactic lecturing (Beall and Trimbur 1993). And using writing throughout the chemistry curriculum provides students much-needed opportunities to practice writing with a variety of purposes, audiences, and formats. These goals can be accomplished in a variety of ways.

Ways to Implement WAC

Many accounts of chemistry teachers using WAC methods in their classrooms, for a variety of purposes, can be found in the literature. Their experiences offer insights that demonstrate a strong sense of practicality and the field's deep commitment to learning. The following strategies were selected on the basis of their ease of use and/or effectiveness in teaching chemical concepts; some strategies require more time and effort than others.

General and First Year Chemistry

The American Chemical Society Division of Chemical Education formed a task force in 1992 to study ways to reform the general chemistry curriculum. The Task Force defined five major issues (Rickard 1992):

- rekindling and sustaining student learning;
- teaching science as it is practiced;
- avoiding an impression that chemistry is too abstract and theoretical;
- developing more cooperative, interactive modes of learning; and
- linking chemical concepts to current events and social issues.

The literature suggests that WAC methods can help achieve many of these goals.

The University of South Florida, for instance, added to its general chemistry course a weekly one-hour participation section in which students were engaged in hands-on activities that involved problem-solving, writing, and critical thinking. Worrell (1992) describes one of these activities that improves students' ability to understand mass-to-mole and mole-to-mass calculations. In the activity, students in small groups perform an experiment and write up their observations; then after making their calculations, they describe in writing an experiment that confirms their calculations. According to Worrell, the strategy increased student enthusiasm and improved their personal satisfaction and sense of accomplishment.

In another instance, Stanislawski (1990) asked students in the first term of his first year chemistry course to write about components in the analytical process, such as data collection, recognizing relationships, and drawing inferences. In the second term, students used the analytical process to write critical evaluations of selections from the chemical literature. In the third term, students used the same methods to examine an issue of their own choosing. Stanislawski found that most students willingly accepted the writing assignments, and that most students found the writing to be a useful way to develop and demonstrate critical thinking skills.

Beall (1994) used short, ungraded in-class writing to help him identify students' preconceptions about chemistry and track their understanding of the concepts taught. During lectures, students took five minutes to respond in writing to questions related to material covered by the lecture. These responses were not graded, although several papers were selected and shown to class at the next class meeting. Beall found this to be a powerful way to identify students' misconceptions about lecture materials so he could remedy them quickly. Showing the papers during the next class helped him identify troublesome areas in the material, and highlight good writing as well.

Upper Division Chemistry

Writing-to-learn methods are particularly useful in upper division chemistry courses where students are often asked to synthesize and integrate more specialized information. Rosenthal (1987), for instance, used lab reports in her physical chemistry class to help students develop such medium-level cognitive skills as classification, summary, and comparison and contrast, which are necessary to performing the higher-level thinking involved in analysis and argument. She points out that students need practice at the medium cognitive level if they are to be competent at drawing conclusions from data by the time they graduate. And because lab reports are already part of the upper division laboratory course, teachers can provide practice in both medium- and higher-level cognitive skills without adding new components to the curriculum.

In his organic chemistry survey course, Wilson (1994) promoted problem-solving skills and critical thinking by requiring students to explain in writing the problems they solved during their labs. These one-page papers, which accounted for 20% of students' final grades, not only helped students learn the material, they also provided a clear indication of student misconceptions and weaknesses. Although initially concerned about the extra workload in grading papers, Wilson found he could move through them quickly by evaluating them primarily for the accuracy of their chemistry answers, commenting only if necessary on writing mechanics.

In his organic chemistry class, Powell (1986) asked his students to write often. Several times a semester they wrote abstracts of journal articles that expanded on lecture topics and placed them in the context of real-world issues. These one-page papers required outside reading, planning, and writing, and promoted skills in analysis and synthesis, as well as reading and writing skills. Papers were ungraded, but students exchanged papers and commented on each other's work. This helped them develop critical sensitivities to differences in style, choice of language, and choice of content.

In addition, Powell asked students to keep a lecture notebook — a journal of lecture notes — where students learned to summarize and synthesize technical information in their own words. Students then revised and rewrote these notes at home with materials taken from the text and outside readings. Powell reviewed the notebooks periodically for content and to determine if students were acquiring the discourse conventions appropriate for their educational level. The notebooks enabled Powell to emphasize the importance of keeping regularly written records of scientific thoughts and ideas. It also enabled students to process the material through a personal, expressive mode of discourse.

Students in Powell's class also kept lab notebooks to record the experimental methods and materials, the proceedings, and their observations, of their lab experiments. The lab notebooks enabled Powell to teach professional discourse conventions of chemistry. Moreover, they gave him a chance to introduce the requirements for and procedures of recording technical information and data and of generating laboratory reports from a database.

All of these writing activities might seem overly ambitious, but Powell feels that the effort is justified because making written records are "an essential activity of the chemical sciences" (p. 415). Still, he was able to minimize some of the work by having students review each other's writing and by making periodic notebook reviews optional.

To be successful, Olmstead (1984) points out, students must be able to explain scientific material clearly to a variety of audiences, for a variety of purposes. Helping students learn to communicate well, then, should be a goal for all chemistry teachers. In his advanced laboratory course at California State, Fullerton, Olmstead used students' experiments as the subjects of various writing assignments, such as detailed procedure and discussion reports, abstracts, research proposals, journal articles, popular science reports, and more, to help students gain experience using different discourse conventions in the chemical fields.

Writing can be used to address other learning difficulties. Lavoie and Backus (1990) define these as "impedances to learning" and categorize them as either (1) content related, (2) process related, related to either (3) individual personal and cultural differences, or to (4) individual developmental differences. Lavoie and Backus explain these impedances within the context of learning styles. They present a chart connecting learning difficulties and writing assignments aimed at reducing these difficulties. Chemistry teachers who are unsure of what kinds of writing to use in their class might find help here.

The literature explains other strategies in detail. Strauss and Fulwiler (1987) encouraged students to put their questions and concerns in writing, and then drop them in a question box before they left class. The strategy did not detract from class time or involve much instructor time or effort, but the suggestions provided useful data for shaping future class meetings, and enabled closer contact between students and instructor. McHale (1994) encouraged students to grasp the relevance of chemistry at the same time they learned chemical concepts and improved writing skills by assigning 4-5 page, graded term papers about current events that involved basic chemical principles. VanOrden (1985) describes how the ungraded short writings she assigned encouraged critical thinking and taught chemical concepts, and Malachowski (1988) explains how ungraded journal writing improved the depth of student involvement and understanding of chemical concepts.

Two curricular experiments that have proved successful deserve special mention here. Swan (1995) describes an environmental chemistry course at Princeton team-taught by writing and chemistry instructors that enables science and non-science majors to fulfill their general education requirements in writing or science, respectively, through a writing-intensive option or a science lab option. The results of this cross-curricular experiment suggest that the difficulties in teaching and learning science derive from scientific rhetoric and pedagogy, and not from any intrinsic characteristic of science. Swan found that the traditional presentational structure of chemistry in classroom instruction and in science writing, which moves from general principles to specific details and focuses on the chemistry, the object of study, actually hampered student learning and communication for both science and non-science majors. The general principle, which was new information for both sets of students, did not provide a context for making meaning of the details that followed.

The problem of helping students learn to make and express meaning was one that Coppola and Daniels (1996), and others at the University of Michigan, attempted to address in their restructuring of the undergraduate chemistry curriculum. They realized that the traditional curriculum minimized the historical, philosophical, sociological, linguistic, and moral considerations of chemistry and did not help students develop effective communication or collaboration skills that would help them express themselves to construct meanings and solve problems. In revising the curriculum, written and oral communication and collaborative learning became central to lab courses that were recast to capture the essence of the research experience — the design, implementation, and evaluation of an experiment with an uncertain outcome. Critical to the success of their approach was the assumption that understanding is constructed socially, not in isolation, through language. The courses situated lab problems within contexts students could easily understand, and then encouraged practice with techniques and group collaboration to help students develop both technical and social skills. In one iteration of this approach, the "collaborative identification of substances" assignment, students were given an unknown substance, were instructed on identification techniques, and then were asked to find the two other students in class who had the same substance. Within the context of this task, students easily understood the processes and techniques of learning and implementing procedures to identify the substances and recording their results on paper. In addition, to complete the task, students had to talk to each other, express what they had learned, and compare their findings to locate the other students with identical substances.

Overcoming Constraints of Writing in the Chemistry Classroom

One of the major objections to using writing in the chemistry classroom is that it takes time and attention away from covering content (Labianca and Reeves 1985). But if we acknowledge the importance of writing in the curriculum, we can begin seeing writing as integral to the process of doing and learning chemistry, rather than as a tangential activity. Further, as the literature supports, writing enhances the learning of content rather than distracting from it.

Writing needn't be overwhelmingly time-consuming. Ungraded assignments, peer reviews, and short notes to the teacher and to other students, all reduce the time and effort required by the teacher to evaluate writing. And all can be used to emphasize content and provide practice in writing. The key is to make every writing assignment serve the purpose of teaching and learning content.

Another common objection is that chemistry teachers lack adequate training required to teach and evaluate writing. Although it might be true that chemistry teachers cannot teach writing as an English teacher might, chemistry teachers are in fact the experts and the best judges of what constitutes good writing in chemistry, and there is no reason why chemistry teachers need to accept poor writing from their students. Additional expertise can be found in English, Rhetoric, or Composition departments, and in Writing Centers, among other places. Collaborating with faculty both in chemistry and across campus is helpful in discovering strategies for teaching and grading writing.

Resources for Students (and Faculty) Writing in Chemistry

A number of resources are available to help both students and teachers learn more about the conventions of communicating scientific material. Perhaps one of the best resources on formal discourse conventions in chemistry is *The ACS Style Guide,* published by the American Chemical Society (Dodd 1986). Students find the *Guide* useful in learning about the science paper, the citation system endorsed by the ACS, and the methods for handling a range of details from tables and charts to punctuation. Other sources focus specifically on particular kinds of writing, such as writing lab notebooks (Kanare 1985), abstracts (Foos 1987), and proposals (Weissmann 1990).

Two fine resources for grammar and composition conventions are Day's *Scientific English: a Guide for Scientists and Other Professionals* (1992) and *How to Write and Publish a Scientific Paper* (1988). As a former journal editor, and former president of the Society for Scholarly Publishing, Day has a great deal of insight into scientific writing conventions. *Scientific English* covers the mechanics of grammar and principles of style most important to science writing. *How to Write and Publish a Scientific Paper* describes the science paper and abstract in commonsense detail. A number of other helpful resources are included at the end of this article.

Final Thoughts

Although substantial literature exists that links writing to successful learning in chemistry, more research is needed. Careful descriptions of the characteristics of the discourse conventions used by chemists, especially as they are practiced in industry, are lacking. These descriptions could be used to inform more relevant teaching as well as lead to further developments of Writing Across the Curriculum's body of knowledge. In addition, experiences with writing in team situations in chemistry, especially in capstone courses, would further enhance our knowledge of WAC in chemistry.

The literature reviewed here provides extensive evidence of the success with which chemistry teachers can bring writing into their classes. Because WAC methods offer such fertile opportunities for creative teaching and learning, each individual classroom can be a site for new successes and developments.

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