"It's a Shame to Put Such Wonderful Thoughts in Such Poor Language": A Chemist's Perspective on Writing in the Discipline[1]

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Abstract: Starting from the premise that good writing requires sound thinking, this paper presents a workable process for developing and using writing assignments as thinking and learning tools within a historical and philosophical context. Though presented from the perspective of a chemist, this process is actually general in nature and links writing assignments with specific learning objectives and evaluation methods. Writing assignment examples, used for a variety of purposes, draw from freshman through graduate courses in chemistry.

Introduction

As an undergraduate chemistry major, I took an honors English course entitled "The Novel" my junior year. We read and discussed nine novels and wrote at least that many papers. Mine were returned filled with red ink indicating the many flaws in my writing. On a paper late in the semester, there was nary a red mark until I found a notation in the margin, several pages into the paper: "It is a shame to put such wonderful thoughts in such poor language." I was a sloppy writer as an undergraduate. Good writing was neither required nor expected in my major, and I simply didn't learn how to write well. I should point out that this was in part characteristic of the times. The Department of Chemistry Web site at this university now lists this department objective for the students in the chemistry program: "Communicate effectively in both written and oral forms typical of the chemical literature and professional conferences." Times and expectations have changed.

When I entered graduate school in physical chemistry, we were expected to write quarterly progress reports. Mine were submitted to a faculty member who happened to be a journal editor. He expected professional writing even of graduate students. Reports that were poorly written or that contained grammar, punctuation, or spelling errors were returned with none of the problems marked, but bearing a note indicating that I should fix and resubmit the reports. As became obvious at that university, everyone, chemists included, was expected to be able to communicate well in both writing and speaking.

When I began teaching, I vowed to not let my students continue with poor communication skills and to impress upon them that professionals in any field need to communicate clearly and succinctly. But how would I, a trained chemist, be able to teach writing or speaking skills? How could I effectively use writing to teach chemistry?

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I am not alone in asking these questions. There remains in chemistry, and I suspect other fields well outside the traditional writing-intensive disciplines, a general reluctance to embrace writing as a teaching and learning tool. This is not to say that inroads haven't been made. Searching the keyword "writing" in the electronic index to the *Journal of Chemical Education*[2] retrieved nearly 500 references. Removing those about chemical reactions rather than writing text leaves well over 400 papers using writing in different ways for a variety of purposes. Klein and Aller (1998) and Shires (1991) have published bibliographies of sources involving writing in the chemistry curriculum. Oliver-Hoyo (2003), VanOrden (1987), and Stout (1997) all use writing to promote thinking in chemistry. Kovac and Sherwood (1999) and Deese, Ramsey, Walczyk and Eddy (2000) use writing to improve learning and Whelan and Zare (2003) use a writing intensive course to teach effective communication skills.

Books published about writing in chemistry tend to focus on writing for scientific audiences or writing lab reports, for example Coghill and Garson (2006) or Robinson, et al. (2008), or the laboratory notebook (Kanare, 1985). Very recently Davis, Tyson and Perchenik (2010) have published a book intended to be bundled with chemistry textbooks about writing in chemistry. However, this book deals more with the writing process than with using writing as a thinking and learning tool.

There are also detractors. Labianca and Reeves (1985) argue against teaching writing in a chemistry class. Stanislawski (1990) writes of a student complaint many of us have heard: "Writing assignment? But this is a chemistry class not English!" Whimbey and Jenkins (1987) argue that merely having students write does not appreciably improve their learning. Moore (1993) appears to agree, asking "Does writing about science improve learning about science?"

Klein and Aller (1998) cite four reasons for the general reluctance among chemists for including writing activities among their teaching tools. All of these remain true to varying degrees today.

1. Many chemists do not see how writing can be an effective teaching and learning tool in chemistry
2. Teaching writing will detract from the teaching of chemistry
3. Grading writing is too time-consuming
4. Chemistry teachers lack adequate training to teach writing.

A fifth point, not discussed by Klein and Aller, is that

5. Many chemists, comfortable with quantitative evaluation tools; find writing, a qualitative tool, more difficult to evaluate.

Moore (1993) actually refutes the first two of Klein and Aller's (1998) points. Moore answers his own rhetorical, title question arguing persuasively that writing does not improve science learning *unless students learn to write well* (my emphasis). Moore's paper shows that teaching biology students how to write effectively, as opposed to correctly, does in fact lead to improved learning about biology. Others have observed the same including Kirkpatrick and Pittendrigh (1984) in physics and Meislich (1987) and Stout (1997) in chemistry. Carroll and Seeman (2001) and Stout (2010) have gone even farther by using autobiographies as the basis of forging deep and lasting connections between students and the discipline of chemistry. Hulleman and Harackiewicz (2009) have recently shown, as has been long felt to be true, that assignments specifically targeted to make science relevant to students increase their motivation and learning. These works show that writing can be a useful teaching tool in chemistry and, when used well, need not detract from the subject matter as will be discussed in more detail below.

Point 3 about the time-consuming nature of grading writing is true. It does take more time to evaluate written responses than to look for a proper answer of a calculation or a multiple choice question. However, if we truly believe, as I do, that writing can lead to both mastery and deep understanding, then grading written answers is worth the time. There are ways to make grading easier and faster, addressing both points 3 and 5. A few are presented below.

It is not actually necessary to teach writing to be able to use writing assignments as teaching tools. You can expect students to use their best, college level, writing skills. If you can then recognize good writing or writing flaws that hinder students from fully expressing their understanding, you can effectively use writing assignments as effective teaching and learning tools. The teacher in me rebels at this approach even though I used it in the early years. This brings point 4 above back into play; how can I, not being trained as a writing teacher, teach writing?

Writing workshops designed to provide basic skills in teaching writing are fairly common, particularly on campuses with a formal, campus wide writing program. I have found them quite helpful. Many college and university campuses have some form of writing help available for students, and I make use of the writing center on our campus to supply more substantial help with writing skills than I am able to provide.

A Workable Technique

Over the years, I have developed a practical, workable technique for incorporating writing in to my chemistry courses as a teaching and learning tool. My philosophy is based on three principles. The first is that good writing and good thinking go hand in hand. This principle is persuasively presented in influential books by Emig (1988) and Zinsser (1988), and placed in a practical context by Moore (1993). It is the basis of my earlier publications (Stout, 1997; Stout, 2001) of writing assignments designed to elicit deep thinking.

The second principle is that if good communication skills are expected of our graduates then we should teach our students to write and expect them to write often and well (Stark, Malcom, Lowher & Hagerty, 1986). Labianca and Reeves (1985) and Klein and Aller (1988) raise concerns about the time needed to teach and then evaluate writing detracting from the teaching of chemistry. To overcome these concerns, we must both acknowledge that writing is important and a valuable tool for teaching and learning. Then we will need to learn how to effectively use it in our courses.

These two principles are firmly supported by the literature. The third principle is more personal: While I may not be able to teach writing effectively, I believe I can recognize the traits of both good and poor writing. Recognizing these traits is sufficient to evaluate writing and gives me a starting place to help students become better writers. Also, as I mentioned earlier, when students need more help than I can provide, I refer them to our campus writing center which provides more substantial help. I generally refer about 4% of my students to the writing center.

My use of writing assignments has revealed an unexpected benefit. Some students in chemistry have difficulty with the mathematics associated with explaining chemical principles and solving chemical problems. Writing assignments give students a different avenue to express their understanding of chemistry. Students will occasionally exhibit a conceptual understanding in a writing assignment that appears to be missing in mathematical assignments. Without the writing assignments, it would likely be assumed that these students did not understand the concepts.

Evaluative Tools

Just as I had to learn to write well, I had to learn how to evaluate written material effectively. One answer is to use well-constructed rubrics, tools well known in some disciplines but infrequently used in chemistry and physics and, I suspect, other quantitative fields. A carefully constructed rubric assigns numeric values for different levels of understanding, writing quality, or skill mastery; putting quantitative values on qualitative information. There are a number of good references available for designing evaluative tools including rubrics (Peirce, 2006, and references therein; McMahon et al., 2006; NPEC, 2000).

Multidimensional Rubrics

My rubrics are often multi-dimensional. I begin with dimensions that deal with the specific content of the activity, based on the learning objectives of that assignment. Many assignments also have a writing quality dimension. For example, I often assign an elemental autobiography in general chemistry courses (Stout, 2010). Students are to assume the identity of an element and write their story (NOT a report). Evaluation of these autobiographies is accomplished using a 3-dimensional rubric consisting of writing quality, story quality (story rather than report) and science content. The three dimensions can be considered merely three different rubrics. This version is shown in Table 1 below. I choose to think of them as a three-dimensional space showing relations among the three dimensions. Three-dimensional graphing software is available. I have used RasMol (2010) molecular visualization software. Using sophisticated graphing software is a bit tedious; I generally visualize these dimensions mentally and seldom make an actual graph.

Table 1: Elemental Autobiography - Scoring Rubric

Points		
earned	**possible**	**Story Quality (20 points)**
	18-20	Engaging narrative, chemistry skillfully woven into the story
	16-17	Good narrative, adequate engagement, facts woven into story
	14-15	Adequate narrative, listing of facts distracting from narrative
	12-13	Marginal narrative and engagement, listing of facts, too long or too short
	10-11	More a listing of facts than narrative, too long or too short
	< 10	Very weak narrative, too long or short to be effective
	Points for section	
earned	**possible**	**Writing Quality (15 points)**
	13-15	EXCELLENT: Precise, controlled language, good word choice, sentence structure and transition
	10-12	Occasional lapses in any of the qualities of EXCELLENT

	6-9	Frequent lapses in any of the qualities of EXCELLENT obscuring meaning
	3-5	Erratic use of language significantly obscures meaning
	< 3	Meaning masked by poor or sloppy language
	Points for section	
earned	**possible**	**Science Content (15 points)**
	12-15	Numerous (15-20) chemical facts Or: narrative driven by a fact or set of facts about the element
	7-11	Few (~ 10) chemical facts
	2-6	Very little chemistry (but still may be a good story)
	Points for section	
	TOTAL POINTS EARNED	

It is reasonable to assume that good stories are written by good writers. A two-dimensional graph of my grades for an assignment from several years ago, showing a projection of data onto the writing and story quality axes is given in Figure 1. It is readily apparent that the story quality is only weakly related to the writing quality. The real issue was that some of my students really didn't believe that I wanted a story. When I introduced the activity by reading excerpts from the chapter on Lead from the "Periodic Table" by Levi (1984), the story of a fictitious lead miner from the Middle Ages, my students that term wrote much better stories, as shown in Figure 2, and the best writers generally wrote the best stories though there is still a considerable range of writing quality. Analysis of these two-dimensional representations of a multi-dimensional rubric can reveal patterns that can help assess why students have difficulties with an assignment and suggest how the assignment might be improved.

Figure 1. Elemental autobiography story quality vs. writing quality before reading an example story

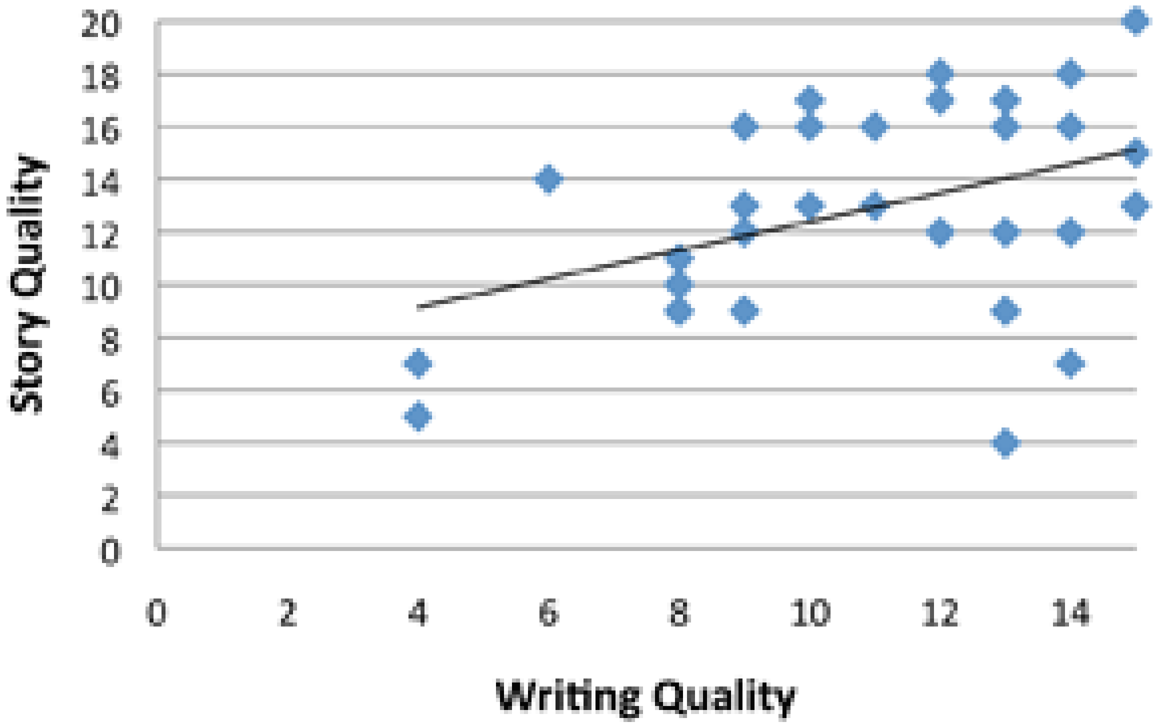
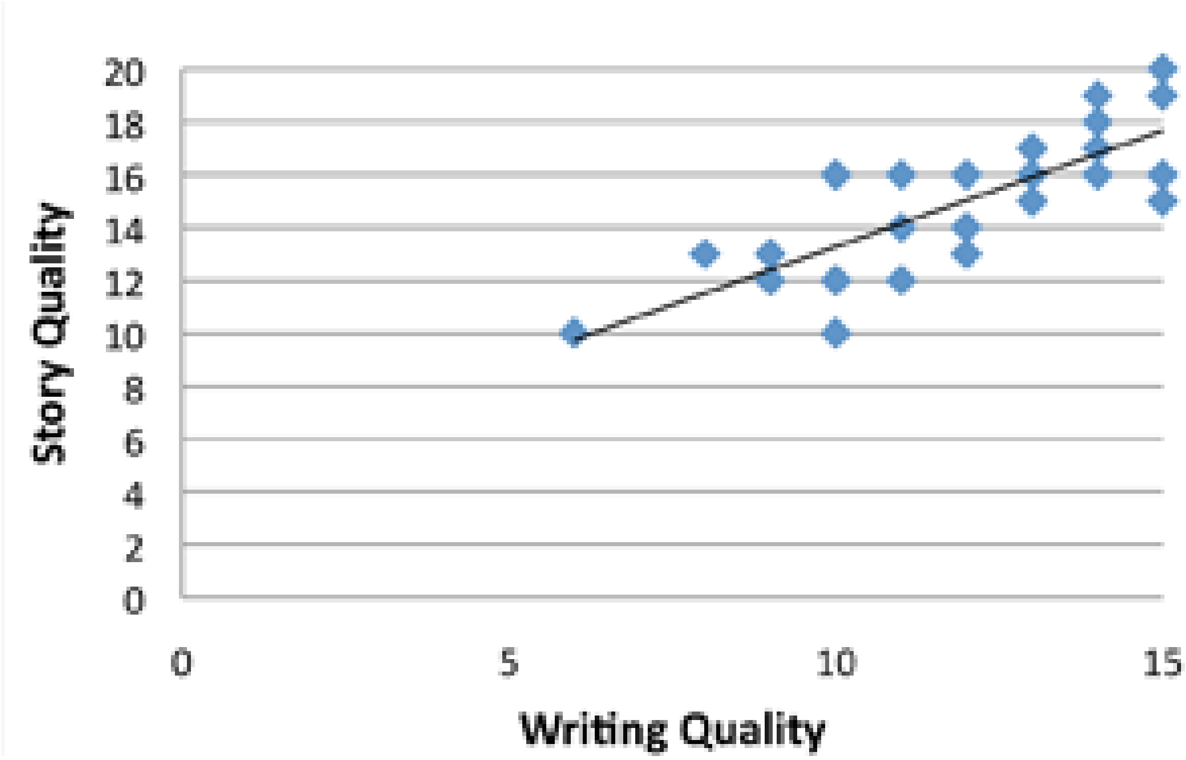


Figure 2. Elemental autobiography story quality vs. writing quality after reading an example story



In evaluating the writing quality of this and other assignments, I look for some specific, illustrative details, some of which directly relate to the connection of thinking and writing. In major writing assignments, those that have the potential for another draft, I evaluate the writing quality using the guidelines given by Moore (1992), giving feedback designed to elicit better writing. In some semesters, peer review, discussed below, has also been used. A poor writing score (typically < 8) on the first draft will result in a referral to our campus writing center. Run through the Department of English, our writing center is open to any student on campus for help with the process and mechanics of writing. When referring students, I include a description of the flaws I have noted along with an indication of how badly the imprecision of writing is limiting my view of the depth of their thinking. The center will notify me that a referred student has visited, a notification I require before accepting a revised assignment.

Assigning Grading Axes

In my physical chemistry laboratories, writing is primarily focused on the calculated results of an experiment and an explanation of their meaning. Two grading axes involve the quality of data and calculations, and of the explanation of their meaning. I always expect a quality abstract, which provides a third axis. Most of the experiments require only a brief report; two require a full (as for a journal) report. Those experiments have an additional grading axis. Quality writing is expected in any report and is most apparent in the abstract, the discussion and the conclusion sections. In these sections, my understanding of the quality of the students' thinking can be the limited by the quality of their writing. I always advise my students of this and have been known to return reports ungraded, stating that I suspect they know more than they are effectively communicating to me and that they need to improve their writing to convince me that they do in fact understand the experiment. My sense is that most poorly written reports are more a matter of poor thinking and understanding rather than poor writing. Only about 10% of the laboratory students I refer to the writing center eventually turn in reports demonstrating a significant understanding of the experiment.

The take home message is that I would have missed this 10% of students, not recognizing their understanding of the experiment, without the rewriting. I generally cannot know if a poor laboratory report truly reflects poor thinking (the default assumption) or is merely limited by poor writing. Recognizing writing problems and allowing students to fix them gives me a way to make this discernment when grading.

Peer Review

For writing assignments with multiple drafts, such as term papers, I find peer review to be a useful evaluation tool. Not only is peer review evaluative; it can also be instructive. To review a work substantively requires careful reading and critical thinking. If we can properly structure the peer review process, it will provide reviews which benefit the writers and can elicit critical thinking from the reviewers (Towns et al., 2000/2001). Trautmann et al. (2003) note that students giving guided reviews "perceived that they gained more by writing [reviews] than by receiving them" (p. 445). The key words here may be "guided review." Both to provide useful reviews and to promote critical thinking, students need to be led through the review process with some kind of a guide or rubric. I generally base rubrics for peer review on my own rubric for the assignment, reworded if necessary to elicit a substantive response from peer evaluators.

The wording of guide or rubric is critical (Trautmann, 2009). Consider a writing assignment from general chemistry asking students to provide written directions for a general stoichiometric calculation. An evaluation rubric which asks "Does the writer discuss the conversion of the units of the measured substance into moles?" or "Does the writer describe the use of the mole ratio?" leads to little thinking and potentially yes or no answers. On the other hand, a rubric which prompts students with "Describe to what extent the writer does or does not give you sufficient information to construct the necessary equation" requires both understanding of the process and critical thinking to answer.

A useful tool for peer reviews is Calibrated Peer Review (CPR) (Regents of the University of California, 2001). CPR is an on-line program through which teachers can make writing assignments and students can submit their work which is then peer reviewed. Reynolds and Moskovitz (2008) provide a good description of how CPR works and discuss its strengths and limitations.

Whether you use the CPR process or a "home grown" process, well-organized peer review can help with the evaluation of written material and can also strengthen writing and critical thinking skills. The key to making it work is a well constructed rubric which asks questions requiring understanding and thought to answer (Trautmann, 2009).

Designing Writing Assignments (with Evaluation in Mind)

When first considering an assignment, I initially consider what I want my students to think about or to understand. This helps to generate the primary objectives of the assignment and suggests how they might be evaluated. Identifying the objectives leads to the defining of grading axes, including how to recognize quality along each axis. I next decide upon the relative importance and interrelationships of these axes. Only after the content axes are developed do I add a writing quality axis. In other words, all of my writing assignments are content driven not writing driven.

This may seem an unusual way to start. It seems more intuitive to create the assignment first and worry about grading it later. However, I consistently find that by thinking carefully about what I want my students to think about, what I hope they will recognize through this thinking, and then how to grade for these specific concepts, I can create far better assignments eliciting the kinds of thinking and answers I want from my students.

Content Objectives - A Worked Out Example

Table 2 presents a summary of general content objectives for many of my writing assignments. An actual assignment has a much more specific set of objectives. For example, there are two objectives for the stoichiometry assignment described above. The first is to promote a deeper understanding of the general process of solving this type of problem. The second is to assess this understanding.

Table 2 - Content Objectives for Writing Assignments

To promote critical thinking
To promote deep understanding
To assess the level and quality of thinking
To assess the ability to present and discuss laboratory results
To assess understanding of fundamental concepts
To assess the ability to apply knowledge
To assess the ability to evaluate information
To assess the ability to combine information in a new way

Stoichiometry deals with the amounts of substances involved in chemical reactions. There are many different ways to approach such a calculation and even more chemical reactions that could be considered. The many such calculations have the common unifying concept of a mole ratio. Recognizing this unifying concept, understanding where it comes from, and then writing a generalized set of instructions applicable across the board requires a deep understanding of stopichiometry. My assessment of deep understanding looks for three key things:

- The mole ratio as a unifying factor,
- The source of a mole ratio in a chemical problem, and
- Generality

My grading axis is described in Table 3. It places these three key points within the context of a full stoichiometry problem. Each item is worth a specific fraction of the total points an assignment can earn. The point distribution is from a recent exam.

Table 3 - Stoichiometry Assignment Grading Axis

__/03 pts	Recognition of the centrality of mole ratios
__/03 pts	Indicating the source of mole ratios
__/02 pts	Discussion of how to enter a stoichiometric calculation
__/02 pts	Discussion of gooing from the mole ratio to the desired units
__/03 pts	Generality - Citing 3+ specific examples in lieu of generality
__/02 pts	Construction of a general mathematical solution

When the objectives and grading axes are set, I can write an explicit assignment, allowing me to precisely state what I expect my students to think and then write about. Broadly worded questions generally do not work well. Students with less well developed understanding often answer with a listing of facts they remember about the topic without exploring the relationships among these ideas. I tend to write tightly focused, fairly leading questions, especially in lower division courses. One example of this approach is an assignment that asks students to provide written instructions to solve a general stoichiometry problem:

> Precisely describe in words the step by step procedure for building an equation to solve any stoichiometric problem.

After the question above was used in my recent General Chemistry I course, the average score on stoichiometry related questions on the American Chemical Society Gen Chem I exam were higher than those of a past class where this writing assignment was not used. Unfortunately given our intentionally small class sizes (20-30 students typically) and the spread of answers, this difference has only a 70% statistical certainty. In my opinion, this writing assignment led some students to understand stoichiometry who otherwise might not, and led others to understand it better, but there were still some who failed to understand the concept.

A number of other writing-based assignments serving a variety of purposes have been published elsewhere (Stout, 1997; Stout, 2001; Stout, 2010).

Examples

Small Scale Assignments

Too many of our laboratory students glibly follow printed experimental directions with little understanding of the process or why a specific step might be important. In other words, they are failing to understand the chemistry of the experiment. In many laboratories, I use a pre-laboratory quiz at the very beginning of a lab period. Questions focus on specific steps in a procedure and/or the chemistry being studied through that experiment. Knowing these quizzes are coming prompts many students to study the lab in more depth before the lab period. They are beginning to understand the experiment rather than merely do it. Alas, some students simply don't care, don't study the lab, fail the quizzes, and learn little from the laboratory.

In lower level courses, I use writing assignments asking students to summarize a topic or explain the importance of a specific step in a process often within a specific context. Summary requires students to think carefully to recognize and rank the important aspects of a topic. Explaining the importance of a specific step within a sequential procedure requires consideration of the how this step logically follows those before it and how subsequent steps logically follow in turn. Asking students to discuss a key step requires them to first understand much if not all of the procedure. In both cases, students begin to recognize the connections among ideas or steps of a procedure, deepening their understanding.

These kinds of lecture and laboratory assignments ask students to go beyond reading (and thinking they understand) to examine concepts more deeply and begin to see the logic in the concepts or procedures; the expectation is that students will thereby achieve intellectual ownership of the concepts. An example of such an assignment comes from environmental chemistry:

> Explain how it is that ozone is considered both harmful and helpful. Under what circumstances is it harmful and helpful? What chemical or physical properties make it each?

Another comes from physical chemistry:

> Explain how the van der Waals a and virial[3] B constants predict the existence of a liquid phase.

Responses to this type of writing assignment need not be long, generally a single paragraph, sometimes a single sentence. Evaluation of these assignments usually involves one axis dealing with the quality of understanding demonstrated. I consistently find that using this kind of assignment leads students to expect them and to begin thinking more deeply on their own, which is the primary objective.

Abstracts

An abstract of a scientific experiment is a summary describing what was done, how it was done, what the important results were and, most importantly, what these results mean. To write a quality abstract, students must have a basic understanding of the entire experiment. Requiring students to write abstracts of their experimental reports assesses how well they have understood the experiment. Unfortunately merely requiring abstracts seldom works. I typically see three general problems with student written abstracts:

1. "Abstracts" read more like introductions than summaries.
2. "Abstracts" often report data as results.
3. The significance of the experiment is seldom recognized, and the important conclusions are not drawn.

It is clear that my students need to be taught how to write a proper abstract which in turn requires teaching them how to stand back and look at the experiment as a whole, putting it into perspective.

In my Physical Chemistry laboratory, the first assignment asks students to write an abstract. I begin the assignment with an interactive discussion of a short paper specifically designed to identify the main results or concepts presented. I give students citations to several sources about abstracts from both books (Coghill & Garson (2006) and Robinson et al. (2008)) and journals' "Authors" sections (for example JCE (2011)). The assignment is to read a paper missing its abstract and then write an abstract for it. I find that after this assignment my students generally write better abstracts and certainly demonstrate a better understanding of the experiments they have done.

Essay Questions

Chemistry is generally considered a quantitative subject and most commonly evaluated quantitatively. Even so, there is room for qualitative responses to questions that ask students to explain, defend, compare etc. I use qualitative essay questions occasionally in most courses and frequently in some. For example, I recently taught a graduate course in our Master of Science Teaching program on the History of Chemistry. A week prior to the midterm examination, I gave my class a very broad question with the promise that several questions on the midterm exam would come from this broad one. The initial broad question was in part "Consider the similarities and differences in how science is practiced in eastern and western cultures." The exam contained the following question:

> Over the history of the Nobel Prizes in science, the Nobel Prize Committee has recognized mostly western-trained scientists. Only very recently have a few Japanese-trained scientists been awarded Nobel prizes and to date no Nobel prize has gone to a Chinese-trained scientist. Today, Chinese leaders admit that their education system does not adequately prepare future scientists to make fundamental breakthroughs.
>
> Discuss, in about a page, how science developed in different cultures and the relationship between the kind of education typical of a culture and the kinds of science a person with this education is likely capable of doing.

I view this technique as "priming the pump," causing students to begin thinking broadly about a topic. The exam questions then see how far they can push their thinking down a specific path within the broader topic. The responses to the question above (and the other one based on my priming question) were more substantial, showed deeper insight and connections between ideas than the questions not based on the priming question.

Essay questions that change perspective on a topic provide a useful evaluation of subject matter (Stout, 1997). Many physical chemistry students find entropy to be one of the most conceptually challenging and difficult topics in the course. In the class, we define entropy, discuss it in some detail, and use it in problems, all from a rigorous scientific perspective. On a take home exam question, I may turn the tables, asking my students to explain this concept to a curious niece or nephew in middle school. This forces students to look at the concept in a different way than we have in class and gives me a good picture of how well they understand entropy at a fundamental level. Students who have only memorized a definition or some facts will find it difficult to answer this question and typically give answers similar to our classroom discussion. Those who have truly understood the concept will find it much easier to put the concept into a new context, appropriate for a different audience.

A similar example on a different level, coming from the final exam for my History of Chemistry course, demonstrates other aspects of this kind of question. On several occasions in the course, we discussed the pressures that societies put on science. We discussed formal ethics and students wrote an essay about the ethics violated by Jan Hendirk Schön who was proven to have faked the data behind at least 17 publications (Service, 2002). A question on the final exam asked students to consider how society's pressures for quick results and applied research may have influenced Dr. Schön. This question asked students to combine class discussion and their essay in a new and different way, fundamentally testing my students' abilities to think.

In a physical science course (a freshmen-level, general education course), we studied both current energy sources and several potential alternative sources of energy. An essay question on the final exam mentioned the recent opening of the Atlantic coastal plain to oil exploration and the rethinking of this opening after the major oil leak from a deep well in the Gulf of Mexico. It went on to cite a proposal to place wind powered generators along the Outer Banks of North Carolina, strongly opposed by the tourism industry along the coast. Students were charged to advise the Department of Energy in choosing between these two possibilities. They were to state and defend their recommendations and were told their grade would be based solely on the quality of their defense. This question asked students to use what they learned through a number of class discussions and several small research assignments to synthesize a coherent defense of a position on the issue. This tested both students' understanding of the issues and the quality of their thinking.

Evaluation of essay questions typically involves a multi-dimensional rubric. One or more dimensions are specific to the question's academic objectives. The last assesses the depth of thought demonstrated in the essay. I remind my students to use college level writing in essays, but I do not directly evaluate the writing for essays in time limited exams.

Deep Thinking

Essay assignments can also prompt students to think deeply. On their own, students seldom think as deeply as we might want. To promote deep thinking, instructors must lead students along the thinking pathway. This can be done in several ways, including asking one or more leading questions or asking students to explore the relationships between concepts. The more subtle or complex the relationship, the deeper the thinking must be to examine it.

In a recent environmental chemistry class, students constructed a spreadsheet using a sophisticated carbon cycle (EECE 449, 2009) to forecast atmospheric carbon dioxide (CO_2) levels going into the future. Students were then asked to investigate several scenarios, for example, doubling fuel mileage standards for cars and trucks. They were asked to write about how they programmed each scenario, how a specific scenario changed the CO_2 levels extrapolated into the future, and what that might mean for global temperatures. Based on this information and our classroom discussions of the many and varied issues involved in reducing CO_2 emissions, my students were asked to recommend and defend an effective, detailed plan for reducing CO_2 emissions.

This series of assignments was designed both to explore the environmental issues involved and to elicit deep thinking about them. I specifically chose a problem with both complex and subtle interrelationships among the many issues involved. The midterm exam from a past offering of the class asked students to explain the environmental, economic and political issues and the connections among them for a different environmental problem. The students in this class answered a similar question, particularly the connections part, with deeper insight and in greater detail than their predecessors. This suggests that they were prompted to think deeply in the suite of CO_2 assignments and that this deep thinking persisted at least through the midterm exam.

Conclusion

Why do I use writing in my courses? The reasons are many and varied. Chief among them is that writing, at least good writing, gives me a window into my students' minds. It helps me understand how much of the material they understand and the depth of their understanding. Writing also gives me a glimpse into how well my students can make the connections among concepts that mark them as mature thinkers. As much as writing offers me these evaluative tools, it also focuses thinking; to write well, students must first think well. For this reason, writing is a profoundly useful teaching and thinking tool. It actually helps my students develop into the mature thinkers I encourage them to become.

Other reasons for using writing center around my hope and goal for my students to recognize that good communication skills are expected of the professionals they will soon become in the field of chemistry - something I did not fully recognize until I was well into graduate school.

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[2] The Journal of Chemical Education site was recently moved to the American Chemical Society (ACS) Publications web site. The ACS site does not support keyword searches. Keywords can be searched through the Chemical Abstracts, which is a more complex undertaking in a subscription database.

[3] The van der Waals and virial relationships describe the gas phase. It is not obvious to most students that these equations of state for a gas predict the liquid phase.

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