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Writing is Thinking: Using Writing to Teach Science

George Greenstein
Amherst College, Amherst, Massachusetts 01002
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Abstract

I discuss a pedagogical strategy in which we ask students to write about science. Such writing is to be done regularly and often, in class and out of class, in the format of brief "letters to a friend" and longer essays. The goal of this technique is not to teach students how to write; it is to use their writing to help them learn the science. Such exercises can be helpful even if the instructor never reads the students' compositions.

1. INTRODUCTION

In this essay, I want to describe a pedagogical strategy that I have been using regularly in recent years. It is not very widely adopted, but I have found it helpful in my teaching. Perhaps you will find it helpful too.

The strategy is to ask my students to write: regularly and often; in class and out of class; in the format of letters to an imaginary friend, brief diary entries, and more extensive essays; some carefully composed and others not so carefully composed; some that I read and grade and others that I never even glance at. I make such exercises an integral component of my teaching, and I have found them to be a valuable addition to my pedagogical toolkit.

I do this because I believe that <u>writing is thinking</u>. In order to write about a subject, a student must think about it—and thinking is what we want our students to do. The clearer the thinking the better: the more often it takes place the better. In this essay, I will describe ways in which we can encourage such thinking by asking our students to write.

I want to make clear that I am not proposing that we use our science courses to teach writing. Writing is indeed an essential skill, and it is one that our students need to learn—but that is not what I am talking about here. My point is just the opposite: I am proposing to keep right on teaching science, but that we enlist writing as one of the ways to do this.

We might think that students, particularly beginning ones, just do not know enough about science to be able to write intelligently about it. After all, in order to write, you need to have some ideas of your own that you want to express. We have a tendency to believe that beginning students have not yet progressed far enough to develop their own ideas about a scientific field. We might suppose that the most helpful thing we can do is teach them the science: only after they have gotten some of it under their belts will they be able to do some independent thinking and writing.

But I believe this attitude is false. In this article, I present exercises designed to help students move beyond a "listen and then solve problems" format and think for themselves—not just in advanced courses, but at the beginning level as well.

2. SOME EXERCISES

2.1 An Example

Here is an example of what I mean. Ten minutes before the end of class, ask each student to *write a brief letter to an imaginary friend explaining what happened in class today*.

In giving such an assignment you are asking each student to express the subject matter under discussion in her own terms. You have asked the student to replace your words about the subject with hers, to "translate" your view into hers. You are giving your student an opportunity to take possession of the subject. Now the issue is no longer what you said in class: it is what she makes of what you said.

Such an exercise can be helpful in other ways. On the one hand, listening to a lecture can be a purely passive experience for a student: writing about it adds an active element to the classroom experience—it "wakes 'em up." Secondly, to the extent that you make this a regular component of your teaching, students will quickly get the point, be induced to pay closer attention during class, and work to ensure that they understand everything. Finally, such an exercise fixes in the student's mind the subject matter of the day. Once the student shuts her notebook and walks out the door, other things take up her attention, and she may simply forget some of what happened. By asking the student to write about the day's work, we give it an opportunity to lodge in her mind.

2.2 No Jargon

Here is a useful addition to the above assignment. *In writing your letter, remember that your recipient has never been to college. So you cannot use any technical jargon and you will need to explain everything in plain English.*

The goal here is to force the student away from a reliance on an intellectual crutch. Often the use of jargon can be for the purpose of hiding one's lack of understanding. A glib and facile student can throw around all sorts of technical terms without having much of an idea of what they mean. Asking a student to avoid jargon is asking him to explain clearly what he is talking about—and, in order to explain something, he needs to understand it himself. How common it is for we professors to say that we never really understood a topic until we taught it! What is true for us is also true for the student: we are asking him to teach an imaginary other person.

2.3 Intuition

Sometimes, we find that a perfectly intelligent student has become strangely limited when studying science. All his natural intuition seems to have deserted him. He seems to be unable to think clearly. It can be frustrating to us, as teachers: our students seem so dense.

I would argue that we are misjudging our students. They are not dense: they are floundering. We have taken them to an utterly alien world. Nothing about the world of science is familiar to them. Nothing connects with their personal lives. They have never experienced asteroids, the principles of stellar structure, or the expanding universe. And more than that: what we have to tell them can be directly contrary to their personal experience. So simple a matter as the Earth and Sun are an example. In everyday life, the Earth is the ground beneath our feet, and the Sun is a brilliant disk in the sky overhead. What is the connection between this and the mental image we are seeking to convey of two spheres, one solid and the other gaseous, the two of them orbiting about one another through the vacuum of space? Of course students find their previous experiences to be of no use in such a new situation. Of course they do not see how their natural intuition can be brought to bear upon it.

Non-scientific disciplines do not have this problem. They involve material that is perfectly familiar to our students. The student taking a course in a discipline such as literature will be reading books whose subject matter reaches her on a gut level: two characters fall in love, or a character commits a crime and feels guilty. In an economics course, the student encounters scarcity and plenty, in a history course conflict and competing agendas. All these are issues that the student has encountered in her own experience.

Faced with such a difficulty, it is our responsibility to develop instructional exercises which reinforce students' intuition. Asking our students to use plain English is asking them to use their old, familiar language—to use the way of thinking that serves them so well in daily life. It takes them back to familiar, comfortable territory, a territory that they intuitively understand, and one in which they can function well. It is giving them the opportunity to replace your words—words filled with jargon and with alien concepts—with theirs. It is asking them to make your understanding their own.

2.4 Analogies

To this end, another sort of writing exercise might be helpful:

- *Write a brief essay in which you present an analogy to the material presented in class today.*
- *Explain why it is a good analogy.*
- *Is the analogy perfect? If not, in what ways might it lead you astray?*

Analogies are yet another way to take a new and unfamiliar subject and give it an everyday flavor. It gives our students a means of deploying their intuition and intelligence in this alien territory. People involved in Physics Education Research have a saying: you can only learn what you already almost know.

Perhaps a personal anecdote is in order. Once I was getting ready to teach the physics of sending a spacecraft to Mars. I was planning to discuss minimum-energy orbits, launch windows and the like. But it struck me that, before beginning such a complex topic, it would be a good idea to introduce an analogy.

I knew I had a good one. It occurred to me, however, that, rather than presenting my wonderful analogy, it might be prudent to ask my students to invent their own. Mine had struck me as being so obvious, so clearly correct, that I figured all my students would come up with the same one—and if so, what a wonderful lesson that would be. How wrong I was! Every student turned out to have an analogy different than mine.

Furthermore, each was different from all the others. I was frankly astonished at the wide range of analogies my students came up with.

I had learned that my mental image of a subject, so clear and obviously correct to me, differed radically from that of my students. Nor, it turned out, was my analogy superior to the others. Many of my students' analogies were just as good as mine. This was a form of feedback to me, and it was a salutary lesson.

2.5 Writing About Problem-Solving

Beginning students often act as if science were nothing more than the manipulation of meaningless, abstract symbols. Sometimes they seem to think that if you push the x's and y's around the page for long enough, the right answer just might show up. And perhaps it is not surprising that they think this, since manipulating formulas and plugging in numbers may be the only thing we have ever asked them to do. Maybe they think that this is the only thing we ever do.

As teachers we are trying to help our students develop not just a knowledge of how to solve problems, not just a knowledge of the facts of science, but also a "seat-of-the-pants" approach to it. A strategy that can be helpful here is to pose a problem, and to ask our students to *describe in plain English, using no mathematical symbols whatsoever, the train of logic they intend to use in solving the problem.* (For example, if you have asked your students to calculate the brightness of sunlight on Mars, the logic of the calculation would be to (a) understand that what we are looking for is the flux, (b) recall the inverse square law, (c) look up the luminosity of the Sun and its distance from Mars, and (d) plug these into the formula.)

The goal here is to help the student realize that in solving a problem he is not pushing meaningless symbols around randomly: he is using those symbols as the shorthand representations of a train of thought.

There is another advantage to this strategy. Once the student sits down to calculate something, she is focusing on the details of the calculation itself: making sure the input numbers are correct, that she pushed the right buttons on the calculator, and so forth. It is like focusing merely on the spelling in an essay—yes you have to do it, but it is not the main point. Asking the student to focus on the logic of her calculation is giving her the opportunity to separate out this component of the task before her. Calculating things requires care: care that can get in the way of the sort of thinking we want our students to do before they sit down to calculate.

Yet another strategy is to ask the student to write about *what she needs to know about a problem in order to solve it*. For example:

- You want to measure the mass of Jupiter by observing its moons. What do you need to know about these moons in order to do this?
- You are an engineer charged with the task of designing a solar-powered rover, which will explore the surface of Mars. You are trying to figure out how big its solar panels need be. What do you need to know about Mars, and about solar panels, in order to do this?

Notice that here we are not (yet) asking the student to solve the problem: indeed, so far we have not given her enough information to do so. Rather, we are asking her, before she sits down to calculate, to do some thinking! Again, the reason is to replace pushing around meaningless symbols with clear thought.

2.6 Longer Assignments

The above writing exercises can be completed in a matter of minutes, and they can be used in-class. We can also give longer exercises, designed to be done as homework. For example –

- *Write a segment of a textbook in which you teach the principles underlying rocket propulsion.*
  To repeat: how often do we find that we never really understood a subject until we taught it!
- *Before you turn it in, test it out on a friend and revise it if necessary.*

Many students see no need to revise anything they have written: the first draft can be the only draft. The second component of this assignment can be a useful corrective.

Another assignment –

You are a program officer in the NSF, and you have put out a request for proposals for research on solving the mystery of dark matter. A huge pile of proposals has landed on your desk. Unfortunately, you have sufficient funds to support only one of them. Write a report in which you discuss

- *The research envisioned in three of these proposals*
- *The one you have decided to support*
- *The reasons for your decision*

Your report should be capable of withstanding the scrutiny of a hostile congressional subcommittee.

There are several benefits of such an assignment. On the one hand, it asks the student to review everything she knows about the subject, and to synthesize it into a coherent whole. It asks her to make a clear and unambiguous choice. And most important of all, it asks her to give good reasons for that choice.

One can also give assignments concerning what we might call “meta-science:”

The Hubble Space Telescope cost about $2.2 billion. Was it worth it?

If we wish, we can ask our students to approach the question in a quantitative manner. How many taxpayers contributed to that $2.2 billion, and what was each taxpayer’s portion of the sum? Over what time span was the money spent? How does the Hubble’s cost compare with what we annually spend on movies, or on your home town’s public school system? The student might also address the matter of spinoff. Has the technology that went into the Hubble led to any tangible benefits to society?

But I would not want to leave it at that. Such a writing assignment asks students to address the intangible aspects of science as well. Research does not take place in a vacuum: we depend on the wider society to support our work, and we need to honestly engage with that society and its concerns. Furthermore, it is worth noting that most of our students are not going to become professional scientists. This is obviously true for those in our “science for the non-scientist” courses. But it is also true for those of our science majors who will move into industry or government, or start up their own businesses. For all our students, then, the wider social- and policy-aspects of science should be an integral aspect of what we teach.

Another writing assignment: *Do you find that your study of science is threating your own religious beliefs?*

Here we directly confront a divisive social issue. Many people today find themselves personally threatened by science. This certainly underlies the persistent opposition we find in America to the teaching of evolution in our schools. On the astronomical side, many religious groups have argued against the great age of the universe revealed by research. I would argue that it is far better to directly confront these issues in the classroom than to skirt about them.

But the confrontation need not be confrontational! If you have established a good ambience during the semester, you can have a helpful and clarifying—and healing—conversation with your students on what might be a painful subject.

(Incidentally, it might be worth mentioning that, in confronting such deeply personal topics, you need to keep your own beliefs under strict control. You may find yourself reacting strongly to your students' arguments. You might find yourself feeling attacked, and you may react defensively. You need to keep these reactions in check. It does not matter whether you agree with your students' arguments: it only matters whether the students made their points well.)

3. READING THE ASSIGNMENTS: THE "TIME PROBLEM"

There is a problem with this pedagogical strategy: there can be an awful lot of stuff to be read! Particularly if your class has many students, there is the danger that reading their essays will take far too much of your time.

3.1 You Don't Necessarily Have To Read Them

In some circumstances, there is an easy solution to the problem: you may not need to read what the students wrote.

Notice that none of the benefits to writing that I listed above involve your having read anything the students have written. This is an obvious advantage if your class is large. Such a strategy will also make it possible for you to give such writing assignments often – as I hope you do. But I want here to focus on several other positive benefits of adopting such a strategy.

If students know you will be reading their compositions, they will devote a good deal of effort to making them well-written. Paradoxically, I would argue that in some situations this can be a bad thing! Writing well is hard, and it requires concentration. But in the present context this diverts students from what you want them to be thinking about. You do not want your students to be concentrating on grammar or on English prose style: you want them to be concentrating on science. Again I return to my basic rubric: writing is thinking. What do you want them to be thinking about? I would say that in the present context it is science that you want them to be thinking about, not writing.

There is an issue of what we might call "intellectual constipation." Many students —and many professors!—find the task of writing very hard, and they simply freeze up when asked to do it. The person who can talk all day nonstop suddenly becomes tongue-tied when asked to put her thoughts down on paper. We want to design a strategy that evades such "constipation." To do this, it can be helpful to ask the student to write, and to make clear from the start that the instructor is not going to read what the student wrote and that it will not be graded. This can free up the flow of words—and again, of thoughts.

I want to emphasize that in the long run we do indeed want our students to write well. We do indeed need to teach them to write. But that is not what I am talking about here. I am talking about using writing to teach science.

3.2 But Maybe You Should Read Them

It must be admitted, however, that if students know you are not reading their essays, they will be tempted to take the assignments lightly. Why should they put effort into work that has no effect on their grades?

There is a second reason why it makes sense to read the students' work. Earlier I argued that in asking a student to write we are asking her to replace your understanding with her own. This raises a new issue. If a student has replaced your understanding with her own, maybe her own understanding is faulty.

But your students' writing can provide you with feedback. If you read a student's writing and find that she has made a mistake, you can intervene to correct her error. Furthermore, there are other sorts of feedback. Suppose you find that many students have made a mistake—and that, indeed, they all made the same mistake. Then it is not really the students who have made an error: it is you. You thought you had explained something clearly, but in fact you were not so clear. Or maybe you were admirably clear, but your clarity did little good, because the students' understanding has been influenced by misconceptions. In any event, reading your students' letters can give you valuable feedback.

Here is a different kind of feedback. Throughout the semester you have been asking your students to keep a diary. After each class meeting, they note in their diaries:

- *What they liked the least about this class*
- *What they liked the most*
- *What they did not understand that they wish they did*
- *What they once did not understand that now they do*

Every so often you collect the diaries and read them. The point is

- to enable the student to set his own thoughts in order
- to give you feedback—both about how the student is doing, and how you are.

So the "time problem" is real, and it makes sense that the students' writings be at least sometimes read and graded. Furthermore, it is best that students be asked to write often: if not, they will quickly realize that their writings have little effect on their grades, and they will behave accordingly. What to do?

There are a number of strategies you can employ to cut down on the time required to read the students' essays:

1. If you are not reading for the purpose of correcting the students' English prose style, you can skim over each piece of writing quickly.
2. Teaching Assistants can do the reading. Furthermore, these TAs need not be highly versed in Astronomy: advanced undergraduates are perfectly capable of judging the work of non-science majors. The TAs can be Physics majors as well. Such a technique requires only that you meet with the TAs after each assignment, discussing with them what distinguishes a good piece of writing from the bad.
3. Massive Open Online Courses sometimes employ the technique of peer grading. Each student's work is graded, not by the instructor, but by a group of other students, and the grade you give is the average of the peers' grades. Some instructors of MOOCs have calibrated this method by themselves grading a representative sample of student essays: they have found that the grades they would have assigned do not differ wildly from those assigned via this method.
4. Your grading can be random: some assignments are graded, others not. Since on any given occasion the students do not know whether their work will be graded, they must take them all seriously.

All these can dramatically cut down on the time required of you.

3.3 Maybe the Process of Reading is Educational In Itself

Here is another exercise involving writing. Begin by asking for a brief, in-class piece of writing. Then –

- *Pair up with the person sitting next to you. Exchange what you wrote: each of you should read the other's essay*
- *After doing so, discuss them for a few minutes*

In their conversation, each student can offer a critique of what the other student has written.

The following are some of the things that might emerge in such a conversation:

- "I like your way of thinking about this—but my way is different. Here is how I think about it."
- "We both seem to be right. How can this be?"
- "I disagree with what you said. Here's why."
- "I didn't understand the subject till I read what you had to say about it."

These conversations can help both students as they work to understand the material. And the conversations need not take a lot of time.

4. GETTING STARTED

If you find the pedagogical techniques I am advocating here interesting, there is the matter of how you will go about adopting them. Unfortunately, there is going to be something of a "potential barrier" you will need to overcome. Changing how one teaches can be a difficult task, and it is sure to take some time. For this reason, I would advise that you start slow, giving only a few writing assignments during your first iteration.

In the long run, however, I would argue that you will want to reach a final state in which you give writing assignments often. If you don't, students will soon decide that you don't regard them as being very important, and they will not take them seriously. But once such techniques become part and parcel of your methodology, they can be a useful addition to your instructional toolkit.

5. FURTHER READING

Following are a few articles you might find helpful.

- A brief bibliography, containing articles both on learning how to write and on using writing as an aid in learning science is contained in:
  Romberger, J. "Teaching Scientific Writing Conventions: Learning to Write is an Integral Part of Writing to Learn in the Sciences," https://owl.english.purdue.edu/owl/resource/671/05/
- Three studies of the effectiveness of writing assignments, all containing bibliographies:
  – A study seeking to identify under what circumstances writing about science enhances student comprehension:
  Moore, R. 1991, "Does Writing About Science Improve Learning About Science?," *Journal of College Science Teaching*, pp. 212–217.
  – A study involving high school lab reports:
  Barry, J. "Using Writing In The Science Classroom To Develop Critical Thinking Skills," www.sas.upenn.edu/~justinpb/Files/appliedresearchpaper.pdf
  – And a study of whether having female students write about their most important values in a science course helped them overcome gender stereotypes:
  Miyake, A., Kost-Smith, L., Finkelstein, N., Pollock, S., Cohen, G., and Ito, T. 1981, "Reducing the Gender Achievement Gap in College Science: A Classroom Study of Values Affirmation," *Science,* pp. 669–671.
- Two articles on how writing is used in actual practice:
  Chabot, C. and Tomkiewicz, W. 1998, "Writing in the Natural Science Department," *Writing Across the Curriculum,* pp. 52–59.
  Len Reitsma, L. 1999, "Innovative Writing Assignments in the Natural Sciences," *Writing Across the Curriculum,* pp. 57–63.
- Advice on how to generate good writing assignments:

"Resources for Teachers: Creative Writing Assignments,"

http://writing.mit.edu/wcc/resources/teachers/createwritingassignments

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