Writing to Learn Science

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English and social studies teachers expect writing to play a major role in their classes. They regularly assign and evaluate essays and research papers. Most science teachers I know do not think of writing as an important part of their classes. To be sure, they assign lab reports and occasionally ask students to answer questions at the end of a chapter, but writing is not really important in their class work. Moving and caring for delicate and expensive equipment takes a great deal of time. Then there is the demanding problem of preparing for laboratory sessions and the subsequent clean-up, repair, and replacement of equipment. "With all these other concerns," they say, "who has time for writing?"

I used to share this view with my colleagues, but in recent years I have come to value writing in my classes, not just writing to show that a lab task has been accomplished, but writing to learn. What I have discovered is that writing helps my students understand science more fully than any other teaching strategy can. The learning fostered by written reports more than compensates for the time they require. Written reports that must be scientifically accurate, interpretive, creative, analytical, and evaluative demonstrate those highly prized goals of abstract thinking which all teachers hope to foster.

Arnold Arons and Robert Karplus, science professors who have studied levels of intellectual development, state:

> If it is indeed true that one-third of the school population is formal operational by the age about 14 while one-third is still concrete and that these proportions do not change substantially from then on in spite of schooling, then we face the implication that our educational system is not contributing significantly to intellectual development (abstract, logical thinking) (*American Journal of Physics* 1976, 44).

These researchers also state that helping students to make progress in becoming formally operational should be a major objective of education.

One of the first ways I use writing in my classes is to help students learn the vocabulary of the discipline. I do this by having students write poems which they call *biocrostics,* an adaptation of the **biopoem.** Some serve as unit summary; some are just a welcome break from lectures, labs, and tests.

Students are asked to produce a poem by using the letters in the name of one of the plants or animals we are studying. Biology students believe that the "bio" stems from biology and no one tells them differently. The only other rule for these poems is that each line must include some fact about the organism which is being immortalized and, if questioned, the student must provide supporting evidence for a given line. The following examples are from a life science class which students take as a last resort for fulfilling science graduation requirements.

Points are given for correctly using vocabulary words from the study unit. Each statement (line) must begin with the first letter of sequence in the spelled animal name. These exercises require conceptual understandings of the basic "lifestyle" of the animal as well as creativity within the constraints of the letters in the name. Notice that the life science class uses the common name.

Pedra Santos

Mollusks (CLAM)

C alcium PROTECTS the average BIVALVE
L ike a HATCHET a foot gives the movement they have
A ll people think the SIPHON'S the neck
M uscles close the shell quick to save them by heck!

Todd Bennett

Phylum Mollusca
SQUIDS

S hells are VESTICLE and we call them a "pen"
Q uick is the movement that caves them again
U nder their suckers is a toothed horny nail
I nk sacs protect them by making "smoke screen"
D eep sea kinds are LUMINOUSLY seen
S trong vicious jaws make them not like a snail.

The next examples are from a vertebrate zoology class for which biology and chemistry are prerequisites. The class requires much reading and writing as well as laboratory projects. Only binomial nomenclature is allowed in these biocrostics. The other rules are the same, but the complexity and application of higher cognitive levels are immediately apparent.

Shannon Joplin and Carolyn Gross

STRONGYLOCENTROTUS FRANCISCANUS

S ea
T ube feet

R adiating spines
O rganisms
N ot human
G onads good with French bread
Y ummy
L ow tide line
O ceanic
C rawling
E ggs fertilized outside body
N ot a land animal
T able delicacy
R ich in taste
O mnivorous non est
T hree jaws in pedicellariae
U rchin
S even inches across

F rench bread good with gonads
R ed or purple
A ppendages
N ot a dinosaur
C oiled intestine
I talians like to eat 'em
S tarfish relation
C ommensal and parasitic worms
A ristotle's Lantern
N ot caviar—but close
U nplentiful
S low locomotion

Because I feel that biological terms are as difficult for students to master as any foreign language, I use other forms of writing to help students learn them. Crossword puzzles provide a challenging way to test mastery of vocabulary. I have a computer which will generate a crossword puzzle when I type in definitions or "fill-in-the-blank" answers with a list of vocabulary words. Crossword puzzles only match words. After using a couple of examples of computer-generated puzzles, I ask students to generate their own (without computers). The crossword puzzles are a good warm-up for learning to write biology.

The next step is a one-period exercise which has proved stimulating for the students and enlightening to teachers. It has been dubbed: "Use as Many as You Can Correctly," and it begins with a list of words dealing in a relatively broad field recently studied. The amount of material covered is roughly equivalent to a chapter on which students would be tested.

Students are encouraged to be imaginative, which will reveal whether or not they are comfortable enough with the vocabulary to express themselves freely and intelligently. The exercises build a sense of awareness and mastery of the principles of biology as well as a knowledge of acceptable usage and mechanics. No matter how well a student grasps a scientific concept or how beautifully an experiment has succeeded, unless the student can explain that concept or experiment clearly to someone else, he or she does not, in fact, understand the concept or the research project very well. As E. Fred Carlisle says, "A young scientist must be able to represent and communicate well" ("Teaching Scientific Writing Humanistically: From Theory to Action." *English Journal* 67 [April 1978]: 35–39.).

Fifty to sixty words seem to fit a fifty- to fifty-five–minute period. I tell my students that they may write fact or fiction, but what they say must be biologically correct. A good score for the average student is correct use of about thirty words. The example shows imagination as well as an innovative approach to include more words.

Grading is based not only on correct usage of biological terminology, but also on cohesiveness and organization. This exercise could be used in almost any unit in secondary science.

Here is the list used by the student whose example is included:

arthropods
chiton
exoskeleton
jointed appendages
analogous
thorax
abdomen
head
compound eye
simple eye
fused
crustacean
antenna
legs
coelom
air tubes
pupa
chrysalis
metamorphosis
transformation

differentiation
nymph
molt
social colony
cephalothorax
carapace
telson
wings
internal segmentation
beeswax
green gland
barnacle
arachnids
mites
scabies
centipede
millipede
cheliceras
mandibles
nectar
adaptive radiation
gills
air tubes
tactile hairs
pollen
proboscis
caste
naiad
wing

Bellacia, Juan

Arthropods

We went to the beach during spring vacation. My mom said that it looked like everything at the beach was some kind of clam, snail, or worm. I said that couldn't be right because I learned in biology that there were more ARTHROPODS in the world than anything else. I started looking around and sure enough there were little crabs running all around. They don't look much like the grasshopper or crayfish in our biology book because they walk sidewise and their ABDOMENS are tucked under. But they have EXOSKELETONS made of CHITON. Their HEADS and THORAXES are FUSED. They sure have JOINTED APPENDAGES and they can really move fast on their LEGS. I think that the crabs are CRUSTACEANS and breathe by GILLS (into CEPHALOTHORAX). At the dock they were selling big crabs for one dollar each alive! My mom didn't want to, so my dad cooked two! Then I knew what a CARAPACE was. Some people pulled it off while the crab was still alive. Ugh!! After the crabs were cooked I looked at the way they eat. They had big pinchers and I think pinchers should be on your list! They sure didn't have WINGS but those mosquitoes that came to our camp that night had WINGS and long PROBOSCIS. I think that what the crabs ate with were MANDIBLES!

The next morning my mom yelled because a spider had built a web across the flap of our tent. I told her that it was just an ARACHNID that ate bugs and that it might have at least six SIMPLE EYES. She didn't care.

When we went down to the beach to go swimming I cut my feet on all the BARNACLES. No one believed that barnacles were any relation to the crabs. So why take biology if nobody believes you? Huh! I suppose I could get more points if I talked about bees and NECTAR and POLLEN and BEESWAX but I really don't fool around with them. But I know they live in SOCIAL COLONIES.

I think I get 25.

Once students are comfortable with the vocabulary of what we are studying, I move them toward more extended writing tasks. One of these is a form of **role-playing.** My assignment follows:

> Become an animal and write authentically about that animal's existence for a day, an hour or whatever length of his lifetime is appropriate depending on how much detail about your animal is available in our library. Do not anthropomorphize your entity. If you choose to be a reptile, use a *reptilian* brain. Some of you will choose mammals to be on the "safe side." Your grade depends on accuracy regarding the animal's habitat, diet, movement, (in other words, all the ways it satisfies necessary life processes). You will have one period in the library for research . . . An extinct animal is acceptable. Try to choose a creature about which you can find sufficient data.

We write a paper because we have a story to tell: an introduction, a narrative, and a conclusion. If the message that the paper is to present cannot be precisely or concisely defined, how can the paper be written? A review of brain evolution is appropriate as a reminder that the reptilian brain can have limited responses which relate only to survival, that all three brain layers may exist in a mammal, but that the surface area of a cerebral cortex determines thought processes. In this paper all levels of learning—facts, concepts, values—must be woven into the paper. Grading is based on focus, coherence, clarity, emphasis, and organization.

This role-playing prepares students for the written reports I require later in the term. For example, a vertebrate zoology class was given a semester project which included the articulation of a vertebrate skeleton (which each student obtained from a local veterinarian, the zoo, or a road kill). A report included with the completed skeleton required a detailed life history of the species as well as a comparison of the analogous and homologous parts with that of some other vertebrate class. A detailed bibliography was also required. I ask students to use the same form as that required by the English and social studies departments in our school district.

Occasionally these projects go awry. One meticulous student overtreated her cat skeleton in a sodium hydroxide solution and completely dissolved it. With no time to prepare another, she collected bones from several specimens, and produced an extremely unusual project. The articulation of the bones of these unrelated species provided impetus for her paper.

> HOMO DERANGEO: A New Theory in Human Development
>
> Many evolutionists believe that the stages of man's recent development include the Ancestral hominid, Australopithecine, HOMO ERECTUS, primitive HOMO SAPIENS, and finally, modern man; in short, human beings have descended from the ape. We, however, cannot accept this absurd, erroneous idea. Based on our own archaeological discoveries, we are proposing a new theory of evolution: man evolved from the HOMO SEPULAR CAROLIFIC GROMIFULUS RUTHENOSIS AMMONEOZOIC DERANGEO, a degenerate bird form. We believe the HOMO DERANGEO first appeared on October 9, 1732 B.C., and evolved to modern human form in less than twelve days. Additional evidence has shown that the HOMO SAPIENS' evolution was completed in the seventeenth hour of this twelfth day.
>
> We can begin to support our assumptions with this original skeleton of the HOMO DERANGEO, discovered on December 30, 1981. As we were making our annual ascent of Mount Bonaparte, Washington, we uncovered a small, indistinct animal skeleton encased in glacial ice. Being unable to arouse the 951 residents of Tonasket, a nearby town, we transported the fragile specimen to our laboratory in Seattle. After carefully melting the ice and revealing the skeleton, we discovered many interesting details. The decomposed, putrified remains of a small flag, of unknown nationality, were found tightly clutched in the specimen's right palm. Naturally, we must assume that this primitive creature, the HOMO DERANGEO, was engaging in an obviously human activity while climbing Mount Bonaparte's 7,280 feet: it was simply claiming this

territory for its own native homeland. Logical evidence such as this is only a minute portion of the overwhelming factors which point to the HOMO DERANGEO as man's predecessor.

The theory of man's descent from the ape is flawed by the inability to draw accurate family trees and several "missing links." There are many aspects of the HOMO DERANGEO's development which we believe connect this degenerate bird to human evolution. Modern men, like modern birds, inhabit nearly the entire earth; however, apes are limited to more specific living regions. Also, apes have a continuous brow ridge, the torus supraorbitalis, which both modern men and birds lack, as did the HOMO DERANGEO. These dissimilarities between man and ape, coupled with the likeness of man and bird, can only exemplify man's obvious descent from the HOMO DERANGEO.

Another evident factor which links man with the HOMO DERANGEO is the placement of the teeth. Human beings are distinguished not only by their basically identical molar patterns, but also by the shape of the shape of their canines. The beginnings of these canines can be observed in our HOMO DERANGEO as enlarged, flesh-tearing devices. After the fossilized teeth had been exposed, we found distinctive remains of tissue fragmentation; we believe that this represents a primitive gum disease, providing a clear link with man's modern periodontal disease.

The derivation of the HOMO SAPIEN's ear can also be detected in the HOMO DERANGEO. Rudimentary ear canals appear in our specimen as two horn-like protuberances emerging laterally from the top of the cranium. It is apparent to us that during the twelve day evolution period, these horns collapsed down the sides of the head, imbedding themselves in tender flesh to become the first human ears.

The inverted rib cage of our degenerate bird obviously provides an evolutionary link with modern man's ominous abdominous: the pot belly. Through the amazing development of the HOMO DERANGEO, the flabby tissue surrounding the abdominal cavity remained intact while the upper ribcage expanded. Another intriguing element of the human evolutionary process involves the transformation of the HOMO DERANGEO's wing. On the seventh day of the HOMO DERANGEO's evolution, the muscles collapsed, lowering the wings into another position. They became adapted to this new location, and served as primitive scapulae. This development of the bird wing into the pristine human scapulae, along with the customary abdominous, provides yet another convincing indication of man's evolution from the bird.

The progression of the HOMO DERANGEO was also marked by changes in its arms, legs, claws, tail length, and posture. The placement of these items on our HOMO DERANGEO show that our specimen must have expired within the first or second days of this evolution period. The size of the HOMO DERANGEO increased eightfold during the twelve day interval, therefore accounting for the disproportionate limb growth. As the evolution process continued, the HOMO DERANGEO began to develop clawlike fingernails, and we have deduced that our specimen was unquestionably of the female gender; indeed, fingernails of any great length are truly distinct feminine characteristics. The tail, unlike the fingernails, was swiftly degenerating, and we have estimated that the caudal vertebrae were completely detached by the sixth day of evolution. Finally, we can see the rapid development of upright body position as a clear link with modern human posture.

Thus, we have introduced our new theory of human evolution, and have supported our contentions with legitimate scientific data. Now, we can only hope that our enlightening discovery will become the accepted theory of evolution, and that our intensive research and analyses will help convince future generations of their true ancestor, the HOMO DERANGEO.

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Although the student shows some lack of knowledge regarding binomial nomenclature and putrefaction, the paper could be considered a success. Even the bibliography of this paper is creative. This student would not have been able to turn her lab disaster into such a successful comedy if she had not had plenty of experience with writing to learn. Specifically, I think the role-playing we did in writing made it possible for her to write a fine satire on the abstracts all students were required to read for this assignment.

Students in natural science courses are not the only ones to profit from written techniques. Chemistry and physics students quickly learn what they understand and what they do not when they are asked to "explain" their laboratory findings.

Chemistry laboratory reports usually follow a standard format: title, purpose, procedure, data table, computations, and answers to questions or problems. The individual preparing the report has little opportunity to demonstrate conceptual understanding or abstract reasoning. A different approach can be used in most laboratory reports. Students may be asked to write an interpretation of the laboratory exercise and include the data table as an addendum. To eliminate verbosity and to expedite evaluation, the interpretation should be limited to one page. In traditional reports, there are few clues as to whether or not the students understand the real purpose of the lab. This student, however, goes beyond the recipe stage to draw conclusions, raise questions, and propose new theories.

John Okimoto
Int. Chemistry
11/1/83
Labtime!

Stoichiometry Stuff

It's that time again, when chemicals react and balances balance, yes, it's lab time! In this most recent lab, we reacted Potassium Chromate and Lead (II) nitrate and got Potassium nitrate and lead (II) chromate. And here is that equation, in living black, white, and incidental blue:

$$K_2CrO_4 + Pb(NO_3)_2 \longrightarrow 2\,KNO_3 + PbCrO_4$$

Each of the reagents was measured semi-carefully so that there was .005 moles of each, .97 g of K_2CrO_4 and 1.66 g of $Pb(NO_3)_2$. After reacting this stuff in water and separating the products, we were left with Lead Chromate ($PbCrO_4$) and Potassium nitrate (KNO_3). We had .0052 moles and .0084 moles each, respectively, and the mass difference between reagents and products was −0.09g (2.63g before and 2.54g after). Apparently something got lost somewhere.

As for our results versus theoretical results, we came sort-of close. Since mole relationships are given by the coefficients in a chemical equation, we should have gotten .005 moles of $Pb(CrO_4)$ (1:1 ratio) and .010 moles of $KBNO_3$ (1:2 ratio). Checking the results on the data table shows we came pretty close on the $Pb(CrO_4)$, off by +.0002 moles, but we were off by −.0016 moles for the KNO_3. Since we had too much $PbCrO_4$ and too little KNO_3, I guess we didn't decant right.

Since moles are derived from mass, our mass measurements worked the same way. We should have ended up with 1.615g of $PbCrO_4$, but got 1.69g − .075g too much. We also got .85g of KNO_3 instead of 1.01g, a difference of .16g. Oh, well.

Finally, we will address that all important question, "Why are some filtrates yellow and some not?" An informed source has told me that chromate is yellow, so it seems to follow that any substance containing chromate will be at least a little bit yellow. Or so it seems.

DATA TABLE

Mass of beaker A	101.12g
Mass of K_2CrO_4	.97g
....	
Mass of $PbCrO_4$	?

Lab analysis.

We added 20 ml of distilled water into 0.97g of yellow K_2CrO_4 = .005 mole. It turned out as a yellow solution. We also added 30 ml. of distilled water into 1.65g of $Pb(NO_3)_2$ = .005 mole. Then we added the clear $Pb(NO_3)_2$ solution to the K_2CrO_4 solution, a few milliliters at a time. At first white precipitate was formed, but then later the whole mixture was turned into yellow. The mixture was heated to the boiling point, then we let the precipitate settle. We decanted the liquid into the funnel again. When the filtering was complete, we removed the filter paper from the funnel and placed it in the beaker with the precipitate. We then let the beaker #1 and beaker #2 dry overnight in the oven. When both beakers were dry, we measured the masses carefully.

The precipitate that was formed was PbCr so the equation for the reaction is . . . .

$$K_2CrO_4\,(aq) + Pb(NO_3)_2\,(aq) \longrightarrow 2KNO_3 + PbCrO_4\,(o)$$

From our data, the determined mass of the product is 2.82g. There are two moles for KNO_3 and 1 mole for $PbCrO_4$. The calculated theoretical masses of reactants and products from our experimental results are 2.625g for reactants and 2.82g for products. Their difference might be caused by our mistake in measuring and in filtering. Some filtrates were yellow and others were not, because some people used a little too much of K_2CrO_4.

Questions for Problems:

1. $2HCl + Mg \longrightarrow H_2 + MgCl_2$
2. 25.41
3. 4.51

Not only do students demonstrate greater understanding of concepts in their interpretative lab reports, they show greater mastery of material as a result of their writing to learn. In the classes which have used writing to learn, students have higher test scores than students in other classes. Putting the material down on paper seems to improve retention. In addition to higher unit tests, I find that students do better on semester or year-end multiple choice tests when they have written to learn science. Students understand more and remember it longer because of writing.

Many college-bound students take advanced placement examinations. A score of three through five on these tests earns them college credit in the subject. The examinations given in biology and chemistry consist of a battery of multiple choice questions and a list of four or five subcategories from which two areas must be chosen as subjects for essays. The evaluation of these essays constitutes 50 percent of the total score. Since students have been writing to learn science, they have gained self-confidence in taking these AP tests, and their scores in the essay section have improved steadily since 1981, the first year we began the writing-to-learn program. An added bonus is the measurable improvement of scores in the multiple choice portion of the test. It appears that writing helps students with all types of learning.