Thinking Through Writing

by Joel Castellanos

Thought experiments in physics.

Far too often, students, when assigned essays in science classes, simply rearrange information into a selective summary. Facts are an essential foundation, but there is a need to go further; the essence of science is not a collection of facts, but a process by which facts are realized and can be used. Logic, reason, critical analysis, and critical questioning are all a part of this process. To help my students develop the necessary skills, I give them a series of writing assignments tailored to encourage thinking.

My method of introduction is to distribute a packet containing the assignments and say nothing about it to the students until the following day in order to pique their interest. The next day, I spend a full period discussing it. In particular, I make sure that students understand what is going on in each of the examples as well as the meaning of words like "assumption," "contradiction," "analogy," and "focused research." I usually cover two or three chapters before starting this assignment so that the students have a variety of topics to choose from.

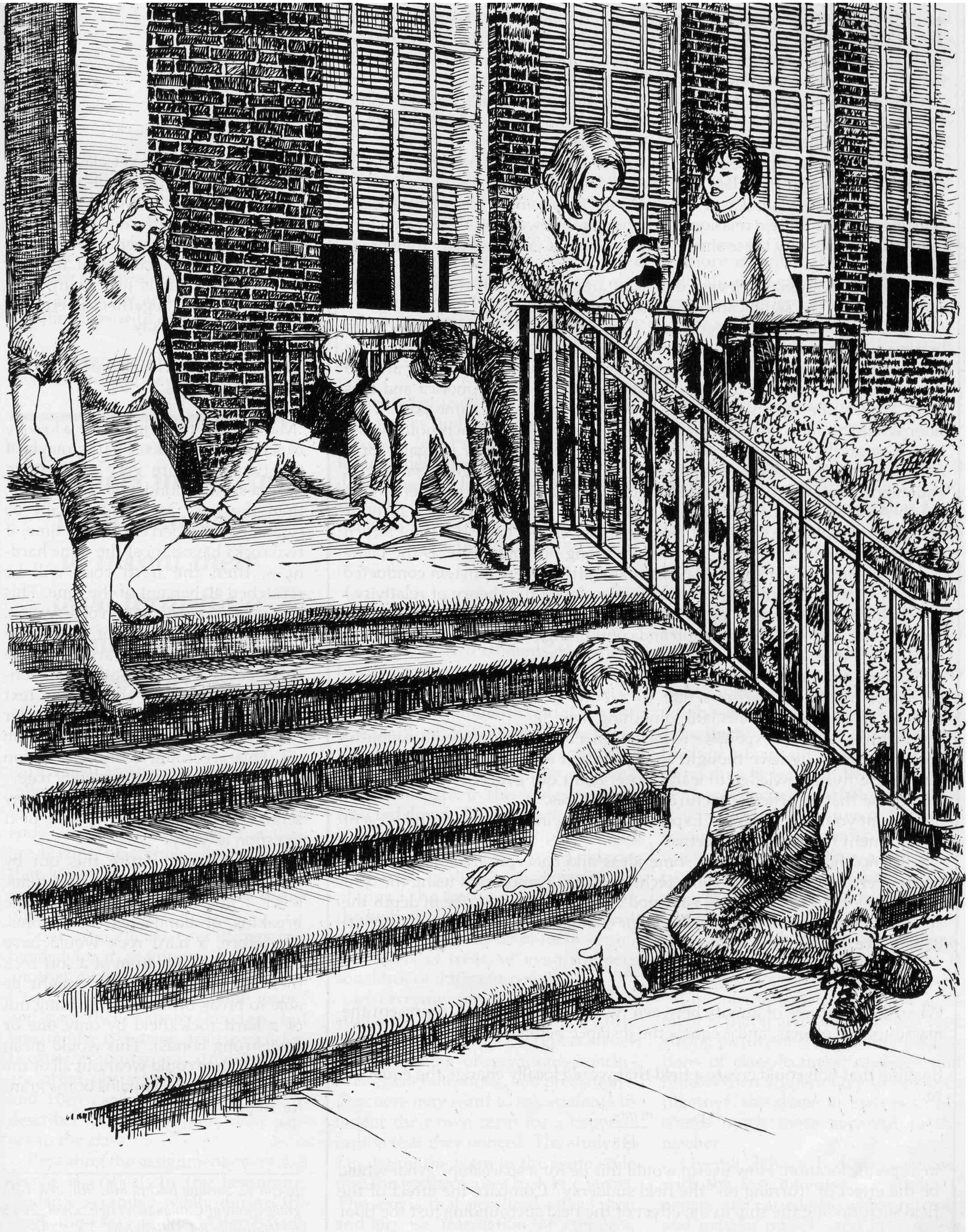
I help students choose a topic by distributing a list. (See "Typical Topics" on p. 72.) If a student chooses to examine an apparent contradiction in a concept, he or she will often successfully point out a contradiction and then proceed to check assumptions. A perfect example of this is what Doug Poluck, a 9th grade student at Gill/St. Bernards High School, did with the concept of Moh's hardness scale:

"I know that hardness is a characteristic property of minerals. The text explains that a given rock will scratch all rocks that are softer than it and it will not scratch any rocks that are harder than it. However, this does not make sense. I have noticed granite steps in very old buildings that are worn down in the centers where people most often step, yet shoe soles are softer than granite. Therefore, Moh is all messed up."

When this student connected something he studied in class with something that he observed in life, he used original thought. The statement above is excellent, but it is not complete; either his assumptions or the original statement must be incorrect. The student's checks and guesses need not be "correct," just logical, since often an "incorrect" guess turns out to be an interesting insight. Here is the way that the student critically examined the idea above:

Assumption 1: Granite steps being *worn out* by shoes can be compared to a hard rock being *scratched* by a soft rock.

"I know that glass has a hardness



—*Art by Lisa Mathias*

Typical topics

Focus on one concept in the textbook that a) has already been covered in class, and b) you have some original thoughts on. But what if you do not have any original thoughts? Here is a good place to start. Any *one* of the following suggestions would be sufficient for a complete paper.

- Choose a concept that you feel is confusing or contradictory (or both), and analyze it. A concept that you don't understand at all will not work, but one that you understand partly is a good choice.
- Does part of a topic you have chosen remind you of any other concept you have studied in this class or in other classes? Tie the two together. In what ways are they similar or parallel? Are these similarities or parallels a coincidence or is there a relationship between the two topics? Research into and speculate on why these similarities or parallels exist and why they break down.
- Present additional, relevant details of an example that the text already uses. Point out the significance of those details.
- Conduct a thought experiment. For example, if you were trying to better understand the Earth's rotation, then you could use the following thought experiment. Imagine an airplane that takes 24 hours to fly around the world. Imagine that it takes off at sunset in South America and flies west, around the equator, returning one day later to the same port. Consider what the time (local time and day) would be during each hour of the trip. Repeat the conjecture for an eastbound trip. Repeat it again for a north-south trip crossing both poles. As an aid to your thought experiment, you might set up a light to represent the Sun and a globe in a manner so that South America is initially at sunset. Work your model through a 24-hour period by turning the globe and moving toy plane. At each 1/24th of a turn (each hour), look at the way the Sun is shining on your plane. Is the plane closest to sunset, sunrise, midday, or midnight? (Albert Einstein conducted this type of experiment very often as he developed the theory of relativity.)
- Examine in detail an analogy or metaphor that the textbook uses with a chosen topic. Explore the common and contrasting properties of each side of the analogy or metaphor.
- Create and explain your own analogy or metaphor. If well thought out, even well worn comparisons (life to a bowl of cherries) can cause the explorer to think of or articulate something new.
- Pictures are very expensive to include in a book. Therefore, the publishers have given extensive thought to the content and layout of each picture. Try to use this knowledge to learn more. Point out everything relevant to the course that a particular picture communicates.
- Invent your own diagram. Explain everything in the diagram and present an argument for why it is effective.
- Science fiction. Start with some ideas and concepts that have already been covered, and postulate some technological advancement using the concept(s). Use both research and educated speculation to describe in depth the applications of your new technology. For example, Newton's law of gravitational force states that

$$F \approx \frac{m_1 m_2}{d^2}$$

Where F is the force of gravity between two objects, m_1 and m_2 represent the masses of the objects, and d equals the distance between them.

Imagine that you could create a field that would locally change the equation to

$$F \approx -\frac{m_1 m_2}{d^2}$$

in a specific location. How useful would this be for a spaceship? What would be the effect of "turning on" the field suddenly? Compare the effect of the field surrounding the ship to the effect of the field surrounding just the floor

greater than copper, yet glass is more easily broken. Brittleness is obviously different from hardness. Maybe 'wear-outness' is also different from hardness. However, it seems to me that wear-outness' is not different. It seems that wearing out is just many little scratches all put together. Therefore, Assumption 1 is okay."

Assumption 2: Hard rocks *always* scratch soft rocks.

"Maybe hard rocks just have a *tendency* to scratch soft rocks. That is, maybe if the two rocks are very different in hardness (diamond and soapstone), then the hard rock will actually be scratched 0.01 percent of the time; if two rocks have almost the same hardness, then the hard rock will be scratched 40 percent of the time. This idea seems consistent with observation. When I rub two rocks of almost the same hardness, it appears that both rocks get scratched. (Both rocks definitely get marks on them.) The text says that the 'marks' on the harder rock that are not scratches will rub off. This, according to my observation in lab, is not always completely true.

"If it is true that a soft rock may scratch a hard rock, then the next question is 'Why?'

"Maybe I can figure this out by thinking of a scratch on an atomic level. I guess that a scratch is the breaking of bonds between atoms. Therefore, a hard rock would have strong bonds. An atom of a soft rock (held by six weak bonds) might be able to break off an atom sticking out of a hard rock (held by only one or two strong bonds). This would mean that my shoe could wear out all of the submicroscopic mountains of the granite steps . . . . Dead end."

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of the ship. Consider possible discontinuities in nature that might be a logical result of your new technology. How would the ship surrounded by the field behave as it moved out from Earth's gravitational field? How would the ship be affected as it approached Jupiter? Our solar system is within the Sun's gravitational field; what effect would this have? Would the Sun's effect be constant or would it critically vary during an Earth-Jupiter voyage? Not only is Jupiter farther than the Earth from the Sun, but also, as both planets revolve, the angles between the three bodies change. Would this spacecraft be most useful for domestic flights or for interstellar excursions? Why? How would this ship turn? Would it be necessary to have this gravity-field drive coupled with a more conventional drive?

—J.C.

"The formulation of a problem is often more essential than its solution, which may be merely a matter of mathematical or experimental skill. To raise new questions, new possibilities, to regard old problems from a new angle, requires creative imagination and marks real advances in science."

—Albert Einstein

Assumption 3: The wearing out of granite steps is directly caused by shoes.

"If there were diamond particles in the dust on the steps, then when people walk they would really be scratching the steps with diamond dust . . ."

In the example above, you can see that the student never really came up with a final answer; he just very critically examined the question. I tell my students that it is good to include "dead ends" in these essays and that they are blazing new trails. A logical idea that leads one person to a dead end will often spark a fresh idea in someone else's mind.

Teachers may want to ask students to invent their own term for a generalization they noticed.

Soon after the first set of papers is handed in, it is important to spend another 60 minutes going over them. I usually copy parts of some essays and pass them out to the class, but you might try using transparencies. Because grammar and attention span are often obstacles in a class of 9th and 10th graders, I ask students to describe, rather than read, their papers to the class.

Repeating the assignment every 4–8 weeks is critical. In the beginning, students scramble wildly during the week the essay is due. After having written three or four, however, most students get used to the kind of topic that works and the kind of thinking involved. Most actually begin looking for and developing topics while they do each night's homework or listen in class. Ideally, this will develop into a habit so that the students apply active reading and active listening to life in general.

Directly observable phenomena

For one or two students, the scientific terms that are used in class daily may seem to be a random collection of words. These students find it impossible to think logically and creatively about something that seems completely random. However, these students can participate if the assignment is watered down. The students could be led away from atoms and planets and to phenomena that are directly observable, such as the flight of paper airplanes, the movement of water through mud, the creation of different angles and patterns by branches from two kinds of trees, or even the personalities of different people.

In carrying out the assignments, students should use the scientific method and a formal lab report structure, including observations, conclusions, generalizations, and predictions. Teachers may want to ask students to invent their own term for a generalization that they noticed. The students can define the term in the same style that the textbook uses to define terms. The aim is that practiced articulation and precise translation of complex, direct experiences into words will help students to visualize the application of an abstract idea after reading a definition.

Although the papers are organized like formal lab reports, I make sure that the bulk of a paper comes from the student's own mind. There may be times when a student needs to research a specific piece of information, such as, the mass of Jupiter or the name of a mineral that has the same hardness as quartz but is less dense. However, extensive use of data and facts results in an encyclopedia-style paper, which is not acceptable. I emphasize that the purpose of the assignment is to teach students how to think about the science that they have already learned. When the students are successful, their papers will rely heavily on deductive or inductive reasoning. The students can check their papers by asking a friend or parent to read the finished product *aloud.* If the reader becomes confused and needs to stop and go back, then the essay probably is not finished. Relevant and creative comic relief is welcome but should be discreet.

One of the benefits of this assignment is that it gives the teacher a very strong picture of the students' perceptions of class lectures, readings, and films. When students try to fit pieces together, the shape of each piece becomes much more apparent to the teacher.

Overall, I have had great success with the assignments. The students' papers are varied, enjoyable to read, and usually reflect—and provoke—a lot of thought. ■